ABSTRACT

Title of Dissertation: **USING CITIZEN SCIENCE TO COLLABORATIVELY RESEARCH AND MANAGE CHESAPEAKE BAY**

Suzanne E. Webster, Doctor of Philosophy, 2021

Dissertation directed by: Dr. William C. Dennison, University of Maryland Center for Environmental Science

Chesapeake Bay is a complex socio-ecological system with an equally complex adaptive management program. The environmental management community has expressed a need for more local-scale environmental data and increased stakeholder engagement in Bay restoration efforts. Although citizen science has the capacity to meet both of these needs, participatory research is currently underused and undervalued. Additional research is needed to help Chesapeake Bay environmental stakeholders develop and leverage citizen science partnerships to accomplish diverse research and management goals. This dissertation explored various challenges that limit the use and potential impact of citizen science in Chesapeake Bay. Three distinct studies were conducted to gain a more complete understanding of stakeholders' perceptions and experiences concerning public engagement in scientific research. These studies employed several qualitative and quantitative approaches, including interviews, participant observation, surveys, and cultural consensus analysis. This research provided evidence of widespread agreement that diverse stakeholder concerns should be more prominent in management decisions. Research also found shared feelings of disempowerment across the Chesapeake environmental community. Environmental stakeholders appreciated that science plays a central role in informing environmental policy, but they had mixed perspectives on the utility of citizen science. This research found an underlying cultural understanding of environmental monitoring that provides a foundation for collaboration among stakeholders with different priorities. These findings indicate that citizen science programs can a) serve as boundary spanning organizations that help stakeholders foster a more cooperative mentality, b) allow diverse groups to strategically work together to accomplish goals, and c) increase the impact of volunteer-collected data on Chesapeake science and management. This research also showed that using a transdisciplinary approach to citizen science can increase stakeholders' feelings of engagement, improve perceptions of a program's overall credibility, and increase the program's overall likelihood for impact. The results of this place-based study in the Chesapeake region are also broadly applicable to other socio-environmental systems. This dissertation provides evidence-based support for continued and expanded stakeholder engagement in environmental science and management and offers specific recommendations to support more collaborative, productive, and empowering citizen science partnerships that inform holistic and innovative environmental management decisions.

USING CITIZEN SCIENCE TO COLLABORATIVELY RESEARCH AND MANAGE CHESAPEAKE BAY

by

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Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
2021

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Acknowledgements

My time as a doctoral student has been an incredibly challenging but rewarding experience. Like many of life's adventures, the process of writing a dissertation and earning a PhD is deeply collaborative and I feel very fortunate to have had so many people support me throughout my journey. It is my pleasure to thank those who made this dissertation possible.

First, I want to express my heartfelt gratitude to my advisor, Bill Dennison. Thank you for giving me the space and trust to explore, think creatively, and be a trailblazer. I truly appreciate your continuous mentorship and your friendship. I am also deeply grateful to the members of my dissertation committee for their support and guidance over the course of my graduate career. Michael, thank you for encouraging me to ask thoughtful questions, write freely, and live fully. Judy, I am so grateful for all of your thoughtful advice, and I appreciate that I can always count on you to make me smile. Andrea, thank you for asking challenging questions, providing insightful feedback, and for being such a wonderful all-around role model. Astrid, your energy and passion for your work are truly a source of inspiration for me and I am so grateful to have had your support on this journey. Additionally, I want to thank Dr. Isabella Alcañiz and Dr. Jeremy Testa for so generously serving on my dissertation committee during my final defense and comprehensive examinations, respectively.

I also want to express my appreciation for the University of Maryland Center for Environmental Science, the Chesapeake Bay Program, and the University of

Maryland Graduate School for providing funding that supported various phases of my graduate work. I also want to thank all of the Chesapeake Bay environmental stakeholders who shared their perspectives with me for this research. Thank you also to the MEES program staff for your guidance and patience, and to my fellow classmates for your communion. I am particularly grateful to all of my former colleagues at the Integration & Application Network, and to several other collaborators within the Chesapeake Bay environmental research community. I have valued the opportunity to learn from you all, grow together, and enjoy authentic friendships. I especially want to acknowledge the people who directly contributed to my research as co-authors, including Caroline, Liz, Christy, Brooke, Katie May, and Sky. Furthermore, I want to thank the whole team at Maryland Sea Grant for helping me to pursue a unique professional opportunity while I finished my studies. Also, thank you to my coworkers at NOAA, especially Derek and Kelly, for everything you have done to make my fellowship year such an uplifting and educational experience.

Finally, I am grateful to my family and friends who have shown enduring interest in my work and offered endless encouragement. Thank you especially to my parents, Rhonda and Mark, as well as my siblings, Natalie and Luke, for supporting me through the low points and celebrating with me during the high points of this journey. I also want to thank Betsy, Mitch, my grandparents, Jessica, Rose, and other family members and close friends who have cared deeply and cheered me on from the sidelines. Also, thank you to Fiammetta for being my dependable late-night study buddy during the final sprint. Finally, from the bottom of my heart, I want to thank my husband. Drew, you ground me while also lifting me up. You challenge me and energize me. You always know how to engage me with deep conversations but you also know when to distract me with adventures. It has been a privilege to have you by my side as we navigate the highs and lows of life and graduate school. Operation "The Doctors Webster," phase 1: Complete!

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Chesapeake Bay

The Bay as a complex socio-ecological system

Chesapeake Bay (Figure 1), located on the east coast of the United States, is one of the largest and most productive estuaries in the world (Lane et al., 2007; Oxnam & Williams, 2001). The Chesapeake Bay watershed is 166,000 km^2, and encompasses parts of six states and the entire District of Columbia (Gillelan et al., 1983). Compared to other estuaries, Chesapeake Bay has a relatively large watershed in relation to its volume (Linker et al., 2012). The Bay's major freshwater sources are located as far north as upstate New York, at the headwaters of Susquehanna River, and to the west of the Bay at the headwaters of the Potomac River at the Maryland-West Virginia border. The Bay's meandering tidal tributaries account for over 12,900 kilometers of shoreline, which is longer than the entire western coast of the United States (Boesch & Goldman, 2009). It is the Chesapeake Bay's connectedness to the surrounding landscape that gives rise to many of the Bay's defining characteristics—its ecological diversity, vulnerability to anthropogenic threats, and cultural value for human residents.

Figure 1. A map of the Chesapeake Bay watershed. Image by Jane Thomas and used with permission of the Integration and Application Network (ian.umces.edu/media-library).

The Bay is an ecologically diverse resource due in large part to its intimate connectivity with both inland aquatic ecosystems and oceanic ecosystems. These connections allow the Bay to support more than 2,400 species of plants and animals, as well as a variety of environmentally and economically significant ecosystems (Oxnam & Williams, 2001). The Bay's mouth connects the estuarine system to enormous Atlantic fisheries and global ecosystems (Houde, 2011). Many anadromous and catadromous species travel in and out of the Bay as they progress through different life stages (Oxnam & Williams, 2001). The relatively shallow mainstem of the Bay is lined with regionally iconic wetland habitats and its waters support species across a multitude of salinity regimes, including submerged aquatic vegetation, the

Atlantic blue crab, and the Eastern oyster. Rivers and streams support freshwater and terrestrial organisms, and supply the Bay's mainstem with a constant stream of nutrients that run off from the watershed and fuel primary production.

Chesapeake Bay is home to more than 18 million people (Bilkovic et al., 2019). The watershed's population has grown rapidly over the last several decades, increasing by 119% between 1950 and 2019, with further growth expected (CBP 2021). Watershed residents maintain a relatively high level of consumption and pollution (Horton, 2013), and the land-based and water-based activities of the Bay watershed's residents drive nutrient input (Testa et al., 2017) and ecosystem health. Over the course of many decades, land use across the Chesapeake Bay watershed changed from predominantly forested landscapes to a more agricultural and urban patchwork (Brush, 2008). Elevated levels of urban development are especially associated with the fall line between the watershed's coastal plain and piedmont regions. The Chesapeake Bay's dendritic tributary system, in combination with its high watershed-to-water ratio, make the Bay especially vulnerable to anthropogenic pressures (Boesch & Goldman, 2009). These include land use changes, as well as excess runoff of sediments, toxins, and nutrients that contribute to the Bay's seasonal eutrophication and hypoxia (Kemp et al., 2005; Testa et al., 2017). Other anthropogenic stressors and behaviors, such as overfishing of piscivorous fish and filter-feeding shellfish, compound to propel environmental degradation in the Bay.

The Bay connects human populations throughout the watershed and is widely valued as both a natural and cultural resource. The Bay's network of freshwater streams is so expansive that a person almost anywhere in the watershed can access a stream, creek, river, or shore within 10 minutes (Oxnam & Williams, 2001). This geographical connection to the Bay has shaped the region's history, economy, and culture. Chesapeake Bay is rich in indigenous history, and the region was once home to approximately 50,000 Native Americans (Arnold et al., 2021). As the birthplace of the United States, the Chesapeake region also played a large role in the nation's history. Many significant sites associated with the Revolutionary War, the Civil War, and the nation's history of slavery are located near the Bay's shores and major tributaries. Both historically and contemporarily, Chesapeake Bay is a hub of economic activity, providing jobs and other important resources to residents. The Bay's shipping channel commercially connects cities along the East Coast, its fisheries provide a regional protein source and a significant economic export, its water provides power to millions of residents and sustains sprawling agricultural operations, and its shores host dozens of military bases and large industries (Lane et al., 2007). The Bay and its streams also support diverse recreational activities, such as fishing, sailing, and exploring natural environments. Finally, Chesapeake Bay imparts on the surrounding area a vibrant regional culture and maritime heritage, and provides its residents with a strong local sense of place (Tillman, 2009). The Bay "seeps into the very souls of the people who call it home" (Van Dolah, 2018, p. 15) and contributes to a rich cultural heritage, or a shared bond and local identity among members of the Chesapeake Bay community.

In the Chesapeake Bay region, human society and the natural world are intertwined; therefore, the Bay can be described as a complex socio-ecological system. This characterization is especially pertinent for estuaries, in particular.

Because estuaries are such productive and important features of a landscape, human societies are generally situated in close proximity to them, which contributes to the formation of a tightly-coupled socio-ecological system (Testa et al., 2016). A socio-ecological system is composed of ecosystems and institutions that are intricately linked through nonlinear interactions between biophysical, ecological, sociocultural, and political processes (Cote & Nightingale, 2012; Van Dolah et al., 2016). In these types of systems, humans impact ecological function and environmental health, and, in turn, the environment shapes the way that humans value, perceive, and govern the natural world (Van Dolah et al., 2016). Because of the complex nature of socio-ecological systems, a wealth of expertise is required in order to effectively understand and sustainably manage them (Rittel & Webber, 1973).

Chesapeake Bay environmentalism

Especially in areas located closer to the tidal region, there is a generally high level of interest, knowledge, and concern for Chesapeake Bay among residents of the watershed, which can be understood as Chesapeake Bay Environmentalism (Paolisso, 2006). This shared environmental ethic arises from a mutual sense of connectivity to the landscape, as well as a shared appreciation for the Bay as a valuable cultural, natural, and economic resource (Paolisso, 2006). This deeply-rooted sense of environmentalism also results in widespread interest in the Bay as a natural resource, place of leisure, source of food, and means of making a living. The residents of the watershed are also generally informed about the Bay—they are aware of the many services it provides and they are knowledgeable about different threats to Bay health. A widespread commitment to sustainable management of the Bay permeates through society in various ways.

For example, both Virginia and Maryland offer popular Chesapeake Bay-themed license plates that label drivers as a "Friend of the Chesapeake" or encourage citizens to "Protect the Chesapeake," respectively. Throughout the watershed, storm-water drains remind citizens to avoid dumping waste because it "Drains to the Chesapeake Bay," and signs along major highways announce to travelers, "Entering Chesapeake Bay Watershed. Please treasure the Chesapeake". In the Bay area, multiple annual events attract thousands of watershed residents and visitors to come together to celebrate various aspects of Bay culture. Some of these events are the popular Across the Bay 10k Chesapeake Bay Bridge Run, the internationally-famous U.S. Sailboat and Powerboat Shows, the Maryland Seafood festival, and the Watermen's Appreciation Day celebration. Residents are also kept updated on Bay science and management activities with several Bay-focused printed publications, such as the Watermen's Gazette and the Bay Journal, as well as hundreds of environmental pages on social media, including Baltimore's beloved anthropomorphized water wheel quartet, led by "Mr. Trash Wheel".

Chesapeake environmentalism is also prevalent in more formal settings, such as courtrooms, businesses, and classrooms. In the Chesapeake region, decision makers often prioritize policies that protect the Bay, generally adhering to the belief that "What's good for the Bay is good for politics" (Paolisso, 2006, p. 3). Businesses often partner with environmental groups to increase their sustainability and contribute towards Bay restoration. For example, restaurants and breweries host coastal cleanup events, sponsor environmental conferences, offer Bay-themed brews, and participate in "Bay to Table to Bay" oyster shell recycling programs. Finally, Chesapeake environmentalism is also taught in classrooms across the watershed. Educators in Chesapeake states are required to foster environmental literacy and stewardship in younger generations by providing Meaningful Watershed Educational Experiences for every K-12 student in the Chesapeake Bay watershed (O'Neil et al., 2020; Zint et al., 2014). These experiences are multiple-day research projects that teach students about the Bay and their local watersheds, in the context of their local communities, and through hands-on fieldwork and classroom integration.

Although many watershed residents share an environmental ethic and interest in the Bay's health, this does not mean that Bay stakeholders value the Bay in the same ways, or agree on management priorities and decisions. A stakeholder can be described as "any person or group who influences or is influenced by" a topic of interest (Durham et al., 2014, p.12); therefore, Chesapeake Bay stakeholders are people who are affected by the Bay and people who are in a position to impact the Bay. Stakeholders have diverse ways of relating to and understanding the natural world, and similarly, have different needs, values, and priorities that inform their perspective of how the environment ought to be managed. Beyond the traditional understanding of environmentalism as a green ideology social movement, environmentalism can also be defined as a philosophy on protecting and improving the environment (Milton, 1993; Paolisso, 2006). Multiple environmentalisms exist. Environmentalisms are cultural constructions of the environment, meaning that a person's culture shapes their perspectives of how the environment should be valued, used, and managed. Culture can be understood as the everyday knowledge that helps people make decisions and recognize others who share their values. Spencer-Oatey (2008) defines culture as "a fuzzy set of basic assumptions and values, orientations to life, beliefs, policies, procedures and behavioral conventions that are shared by a group of people, and that influence (but do not determine) each member's behavior and his/her interpretations of the 'meaning' of other people's behavior" (p. 3).

In considering environmentalisms, it is important to acknowledge that Nature itself is a cultural construct (Cronon, 1996; Johnson & Clisby, 2009; Potts 2007). What qualifies as Nature or 'natural' varies from person to person and reflects human values, cultures, and judgements. People experience the natural world differently—there is not one single universal cognitive understanding of Nature; rather, there are many different versions of Nature that have emerged throughout many cultures over the course of human history (Cronon, 1996). Paolisso et al. (2011) explain that there are "multiple Chesapeake Bays at the cultural level" (p. 9) because the Bay is not just a natural resource, but a cultural-environmental construction (Paolisso, 2006). Different constructions of the Bay, or of Nature more broadly, can be based on socio-cultural factors such as heritage (Van Dolah, 2018), identity, values, behavior, and social institutions, all of which influence how people experience the natural world. The Bay's diverse stakeholders have different knowledge and experience of the Bay, which form different cultural constructions of the environment and lead to different variations of Chesapeake environmentalism. These environmentalisms are all continuously shaped by discourse or changes in how people use or transform their environment (Ellen, 2008; Milton, 1993; Paolisso, 2006). Different environmentalisms lead to diverging theories regarding issues like best management practices and conservation priorities, such as which aspects of the environment are most threatened or valuable, and what strategies should be employed to protect natural resources and the communities that are linked to them.

Chesapeake Bay environmental management, like many other environmental decision-making contexts, is largely dominated by scientific environmentalism. Scientific environmentalism stems from a culture shared by many scientists, which values discovering universal truths and ensuring minimal uncertainty (Forsyth, 2004; Haklay, 2013). A central tenet of scientific environmentalism is that critical environmental problems in nature can be objectively identified, measured, and managed through scientific observations of the natural world and use of the scientific method (Forsyth, 2004; Grove-White, 1993; Milton, 1993). However, scientists' academic epistemology, personal biases, political climates, research trends, and funding situations, among other social and cultural factors, all influence the way that this group of stakeholders characterizes environmental problems, as well as their recommendations for how to address them (Goldman et al., 2011; Griffith, 1999; Milton, 1993). Thus, scientists are not a group of people with objective insight on the natural world; rather they represent an additional group of environmental stakeholders with their own unique form of environmentalism.

Although many groups of stakeholders have vested interests in the environment, scientific environmentalism currently holds more power and political influence. Scientific environmentalism serves as the benchmark for understanding all other environmental discourses and effectively silences alternative environmentalisms, despite its own limitations (Forsyth, 2004; Grove-White, 1993; Kapoor et al., 2001; Paolisso, 2006). In Chesapeake Bay, this act of privileging the scientific version of environmentalism grants authority to scientists and ultimately discounts the validity of other stakeholders' ways of valuing and caring for the Bay. Delegitimizing other environmentalisms disempowers non-scientist stakeholders who share in the regional ethic for protecting the Bay, but have different perspectives on the Bay's ideal management strategy (Paolisso, 2006). This practice divides the Chesapeake Bay environmental community and represents a missed opportunity for engagement and collaboration among all those who "treasure the Chesapeake" in different ways. This dissertation will further discuss various implications of the devaluation of diverse environmentalisms in later sections, and also explore potential solutions for addressing this problem.

A brief history of environmental science and management in Chesapeake Bay

Chesapeake Bay has a rich history of environmental science due to its cultural and ecological significance, as well as its proximity to the nation's capital and its exceptional vulnerability to the region's rapidly growing human population. A century of academic scientific research has made Chesapeake Bay one of the most well-understood bodies of water in the world. The scientific study of the Bay was initiated in 1925 with the establishment of the University of Maryland Center for Environmental Science's Chesapeake Biological Laboratory in Solomons, Maryland

(Arnold et al., 2021). Chesapeake Biological Laboratory was the first state marine laboratory, and is now emulated throughout the world. In 1940, Virginia followed suit with the establishment of what is now the Virginia Institute of Marine Science, and Johns Hopkins University created the Chesapeake Bay Institute in 1949. The first estuarine science society, Atlantic Estuarine Research Society, originated in the Chesapeake area in 1950, and eventually merged with other regional societies to form the Coastal and Estuarine Research Federation. The scientific journal Chesapeake Science, started in 1960, eventually became the academic journal *Estuaries and Coasts*. Throughout the early- and mid-20th century, scientific investigations of the Bay primarily focused on characterizing the basic physics, chemistry, geology, and biology of the estuary.

Over the decades, researchers were able to provide increasing amounts of evidence that human behavior and management decisions were affecting the overall ecological health of Chesapeake Bay, and scientific research gradually began to play a larger role in informing Bay management and policy decisions. In 1967 the Chesapeake Bay Foundation was formed and adopted the energetic motto, “Save the Bay,” imparting a call to action to the Bay’s residents and implying a focus on improving water quality and habitat within the physical Bay (Oxnam & Williams, 2001). In 1972, enormous amounts of stormwater runoff from Tropical Storm Agnes led to a noticeable decrease in the Bay’s water quality and prompted researchers to study eutrophication issues, such as nutrient cycling and the decline of key species like submerged aquatic vegetation (Orth & Moore, 1983). To mark the start of this new era of scientific research focused on studying eutrophication, the University of

Maryland Center for Environmental Science was established in 1972, combining Chesapeake Biological Laboratory with Horn Point Laboratory and the Appalachian Laboratory. In the late 1970's, empowered by the passage of the Clean Water Act in 1972, Congress funded a five-year interdisciplinary study to discern the causes of Chesapeake Bay degradation (Costanza & Greer, 1995). The study concluded that the Bay's declining health could be attributed to excess nutrient pollution.

The Chesapeake Bay Commission was formed in 1980 as environmental managers and elected officials began to recognize the value of interjurisdictional collaboration to more effectively manage and restore the ecosystem (McCarthy, 2000). This partnership was formalized with the signing of the first Chesapeake Bay Agreement in 1983 (Figure 2). The Agreement specified that cooperation throughout the watershed would be key to accomplishing the shared goal of addressing pollution challenges and ultimately increasing the health of Chesapeake Bay (Hennessey et al., 1994). Signatories included the governors of Maryland, Virginia, and Pennsylvania, the mayor of the District of Columbia, the chair of the Chesapeake Bay Commission, and the administrator of the United States Environmental Protection Agency (USEPA). Also in 1983, the Chesapeake Bay Program (CBP) was formed to lead restoration efforts in the Bay. This partnership included federal and state agencies, local governments, academic institutions, and non-profit organizations, among other stakeholders. During this timeframe, from the advent of Tropical Storm Agnes, to the signing of the Chesapeake Bay Agreement, science in Chesapeake Bay evolved to be more applied. The focus shifted from predominantly studying the Bay for the sake of better understanding the ecological system to conducting research with the distinct purpose of providing data and other knowledge that could inform management plans and policy decisions.

Figure 2. The first Chesapeake Bay Agreement was signed in December 1983 by Virginia Governor Charles Robb, Maryland Governor Harry Hughes, Pennsylvania Governor Richard Thornburgh, District of Columbia Mayor Marion Barry, and U.S. Environmental Protection Agency Administrator William Ruckleshaus. Image used with permission of the Chesapeake Bay Program.

Following the formation of the CBP in 1983, a new era of scientific research began, which can be characterized by a focus on integrated monitoring and environmental modelling (Hood et al., 2021). A coordinated long-term monitoring program was established to track Bay water quality and other environmental parameters. Researchers also built a large physical model of Chesapeake Bay to investigate circulation patterns, as well as a computational model of the watershed to understand nutrient pollution sources (Trombley, 2017). At the same time, the Chesapeake Bay Agreement continued to evolve, mirroring scientists' focus on integrated monitoring throughout the watershed. The 1987 Chesapeake Bay Agreement was updated to acknowledge the critical role of local government in pollution control (McCarthy, 2000). This version of the Agreement also included the first numeric goals for reducing nutrient pollution, with a deadline of the year 2000. Through its emphasis on quantifying impacts, the 1987 Agreement demonstrated a commitment to using science to inform management actions and track restoration progress. The Agreement later extended the nutrient reduction program in 1992 and then soon afterward, the CBP broadened its scope to place more emphasis on Bay-wide restoration and watershed-wide management beyond the Bay's mainstem and brackish tributaries (McCarthy, 2000). The 1987 Agreement also emphasized the importance of educating the public about the Bay and incorporating public input into management decisions (McCarthy, 2000). To this day, the CBP is advised by three committees— the Science and Technical Advisory Committee, Local Government Advisory Committee, and Citizens Advisory Committee— which represent scientific and technical experts, local governments, and citizens, respectively.

At the turn of the century, the CBP partners signed Chesapeake 2000. The governors of Delaware, West Virginia, and New York joined as signatories. For the first time in the Bay's management history, political leaders representing the entire watershed committed to restoring and protecting living resources, vital habitats, and water quality, as well as promoting sound land use practices, and increasing stewardship and community engagement. This version of the Agreement again emphasized the importance of high-quality science and public involvement in management. Still, environmental policy remained very technocratic and oriented towards scientific expertise, and management decisions were heavily based on computer simulation models and scientists' 'objective' input (McCarthy, 2000). The 2000 Agreement also included over 100 specific goals that were meant to guide the Bay Program's restoration strategy for the subsequent 10 years. Just after the publication of the updated Agreement, experts on the Chesapeake Bay Scientific and Technical Advisory Committee reflected on the successes and failures of Bay management over the previous decades. These scientific experts made projections for how Chesapeake Bay might look in the future, under different management scenarios of varying intensities (Boesch & Greer, 2003). Boesch and Greer (2003) called attention to the growing problems of sprawling development and increasing human population, and hypothesized that even under the most optimistic scenario, effective environmental management must directly acknowledge the significant influence that humans have on the Bay ecosystem.

Ecosystem-based management (EBM) emerged as a dominant approach to more comprehensively understand and integratively manage the Bay in its entirety. This type of management relies on systems-based science that acknowledges the complexity and uncertainty of socio-ecological systems (McCarthy, 2000). In contrast to other management approaches that focus on individual species or human activities of particular concern, EBM emphasizes the importance of interconnectedness among systems and interactions between species, processes, and ecosystem services (McLeod et al., 2005). Furthermore, EBM is grounded on the idea that environmental decision makers should manage the influence that people have on ecosystems, rather than the ecosystems themselves (McLeod & Leslie, 2009). In his article reflecting on the impact of EBM on Chesapeake Bay restoration, Boesch (2006) suggested that EBM could be improved by orienting scientific research to predict potential restoration outcomes and more directly provide management solutions. Furthermore, Boesch (2006) also noted that even with EBM's broader approach, humans were rarely portrayed as integrated parts of the Chesapeake Bay system; instead, they were more often cast as external factors of the Bay ecosystem—as agents of urbanization or sources of pollution. More specifically, although humans were increasingly being acknowledged as key drivers of ecosystem deterioration, few environmental studies were considering the active role that humans could potentially play in the Bay's management.

In 2010, the USEPA established a new regulatory framework called the Total Maximum Daily Load (TMDL), following President Obama's 2009 Executive Order 13508 to renew protection and restoration efforts in the Bay (United States Environmental Protection Agency [USEPA], 2010). This new watershed-wide regulation, nicknamed the "Bay's nutrient diet," provided calculations of the maximum quantity of nutrients that could be added to the Bay's waters while still meeting water quality standards (Shenk & Linker, 2013; USEPA, n.d.). Once the TMDL was enacted, each Bay jurisdiction developed a Watershed Implementation Plan (WIP) to outline their restoration strategy for meeting the newly mandated nutrient reductions by the year 2025. An updated Chesapeake Bay Watershed Agreement was signed in 2014 and later amended in 2020 (Figure 3). This most recent version of the Agreement laid out a more aggressive and specific strategy for implementing the TMDL and accelerating Bay restoration.

CHESAPEAKE BAY WATERSHED AGREEMENT

The Chesapeake Bay Program partners envision an environmentally and economically sustainable Chesapeake Bay watershed with clean water, abundant life, conserved lands and access to the water, a vibrant cultural heritage and a diversity of engaged citizens and stakeholders.

2 0 1 4

As amended, January 24, 2020

AFFIRMATION

As Chesapeake Bay Program Partners, we recognize the need to accelerate implementation of actions necessary to achieve the Goals and Outcomes outlined herein and realize our shared Vision of a healthy and vibrant Chesapeake Bay watershed.

As Chesapeake Bay Program Partners, we acknowledge that this Agreement is voluntary and subject to the availability of appropriated funds. This Agreement is not a contract or an assistance agreement. We also understand that this Agreement does not pre-empt, supersede or override any other law or regulation applicable to each signatory.

We, the undersigned members of the Chesapeake Executive Council, re-affirm our commitment to support the Goals of this Agreement and to work cooperatively in its implementation. We agree to work both independently and collaboratively toward the Goals and Outcomes of this Agreement and to implement specific Management Strategies to achieve them. Every citizen of this great watershed is invited to join with the Partnership, uniting as a region and embracing the actions that will lead to success.

Date: June 16, 2014

For the Chesapeake Bay Commission

For the State of Delaware

For the District of Columbia

For the State of Maryland

For the Commonwealth of Pennsylvania

For the State of New York

For the Commonwealth of Virginia

For the State of West Virginia

For the United States of America
on behalf of the Federal Government and the Federal Leadership Committee for the Chesapeake Bay
U.S. Environmental Protection Agency
U.S. Department of Agriculture
U.S. Department of Commerce
U.S. Department of Defense
U.S. Department of Homeland Security
U.S. Department of the Interior
U.S. Department of Transportation

Chesapeake Bay Program
Science. Restoration. Partnership.

Figure 3. The front page of the most recently-signed Chesapeake Bay Watershed Agreement, along with the CBP's vision for the Bay (left), and the page of signatories (right).

Contemporary priorities and trajectories for Chesapeake Bay management

The 2014 Chesapeake Bay Watershed Agreement established 10 interrelated goals to guide the restoration and protection of the Bay. Each goal is linked to several outcomes, which are measurable, time-bound targets to increase accountability and track progress towards reaching the goals (Chesapeake Bay Program [CBP], 2014). The goals listed in the 2014 Agreement represent the current management priorities for the watershed. These priority goals are to support sustainable fisheries, preserve vital habitats, improve water quality, decrease toxic contaminants, protect smaller watersheds in the Bay region, advance regional climate resiliency, conserve priority landscapes, expand public access to waterways throughout the watershed, and increase both citizen stewardship and environmental literacy. Furthermore, the 2014 Agreement also provided a vision statement that describes the overall long-term aspirations for Chesapeake Bay and its management: "The Chesapeake Bay Program partners envision an environmentally and economically sustainable Chesapeake Bay watershed with clean water, abundant life, conserved lands and access to the water, a vibrant cultural heritage and a diversity of engaged citizens and stakeholders" (CBP, 2014, p. 2).

Throughout the 2014 Agreement, the signatories again renewed their commitment to science-based decision making and coordinated watershed-wide monitoring and research. Importantly, the CBP specifically listed adaptive management as one of the partnership's core principles. Adaptive management is an approach to managing ecosystems that emphasizes incrementally adjusting management strategies over time in light of new information (Holling, 1978). Instead of making long-term decisions despite gaps in scientific understanding or uncertainty about how the ecosystem might respond to changing conditions brought about by climate change, the adaptive management approach allows decision makers to treat management and policy making as an ongoing and somewhat experimental process, and continually reevaluate management directions as new information becomes available (Walters, 1986).

The CBP's cyclical approach to adaptive management begins with setting goals and identifying challenges and gaps in existing management efforts in order to develop a new management strategy (Figure 4). The next steps are to develop a monitoring program to determine the effectiveness of management actions, assess performance compared to the original goals, and then determine whether adaptations to the management strategy are needed (CBP, n.d.). Following this cycle, when the 2014 Agreement was signed, the CBP realized that existing monitoring efforts were insufficient for detecting the efficacy of management actions enacted in response to the TMDL. Therefore, it became a priority to develop additional monitoring frameworks in order to track changes at finer spatial and temporal scales.

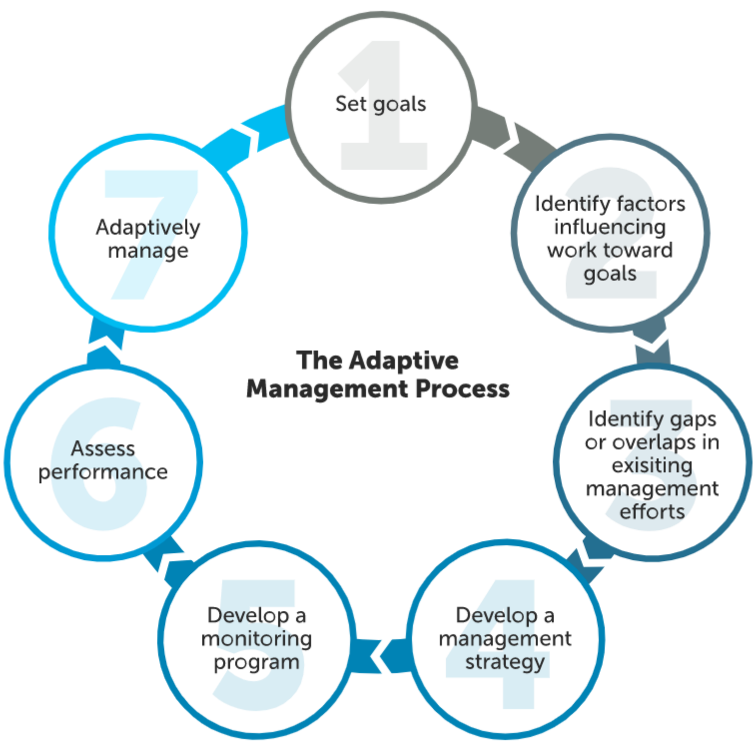


Figure 4. The CBP approach to adaptive management is cyclical and iterative. Image used with permission of the Chesapeake Bay Program.

Although the adaptive management framework is widely adopted for environmental management efforts worldwide, evidence of the effectiveness of adaptive management is limited, contradicting, and based on theory, predictive models, and inference (Dreiss et al., 2017). Adaptive management has been criticized for discounting non-scientific forms of knowledge, being difficult to implement, and focusing too much on natural resource management and not enough on the management of entire socio-ecological systems (Armitage et al., 2015; McLain & Lee, 1996). Many researchers suggest that adaptive management efforts would be more effective and yield more obvious positive outcomes if they incorporated knowledge from multiple sources, supported novel forms of cooperation between different stakeholders, and promoted shared interdisciplinary learning amongst stakeholders (Dreiss et al., 2017; McLain & Lee, 1996; Susskind et al., 2011).

Jacobson et al. (2009) expanded on these suggestions, and noted that adaptive management should be both experimental and collaborative. They maintained that effective adaptive management should include stakeholders throughout the entire process, including during the goal-setting, model development, experimentation, and data interpretation stages (Jacobson et al., 2009). This kind of meaningful and iterative engagement increases buy-in for management ideas and improves models and other decision support tools with the inclusion of relevant stakeholder knowledge. Furthermore, engaging stakeholders in adaptive management ensures that experimental management strategies address issues of concern to stakeholders and provides opportunities for those who are affected by management decisions and outcomes to learn and adapt as necessary (Jacobson et al., 2009).

Fortunately, a second noteworthy component of the 2014 Agreement was that the goals and vision strongly suggest a renewed focus on engaging stakeholders in Bay restoration efforts. The CBP's core values that are listed in the Agreement also emphasize broader participation and deeper exploration of various aspects of management that are not based in the natural sciences. Among the people-centric core principles were using local-scale place-based approaches that generate benefits for communities, using social science to better understand how human behavior affects management outcomes, involving citizens in restoration activities, and promoting environmental justice by encouraging meaningful engagement of diverse stakeholders in the implementation of the Agreement (CBP, 2014).

The CBP also describes the written Agreement itself as a collaborative effort. In addition to expressing a clear commitment to various management goals and strategies focused on inclusivity and collaboration, the CBP indicated that they incorporated input from various stakeholders to develop an Agreement that is inclusive in the way that it addresses various environmental concerns (CBP, 2014). Stakeholders involved in crafting the 2014 Agreement included academic institutions, local governments, and thousands of citizens (Maryland Department of the Environment [MDE], 2014). In his media release, then-Governor Martin O'Malley described the Agreement as "the most inclusive, collaborative, goal-oriented Agreement the Chesapeake Bay watershed has ever seen" and praised the increase in participation from headwater states and the general public (MDE, 2014). He continued further, saying that the Agreement "builds upon the strength of our diverse citizenry" and "calls to action the nearly 18 million people that call our watershed home."

Despite the CBP's long-standing commitment to engaging stakeholders in aspects of Bay management and restoration, the CBP and others have identified that there is room for improvement in various directions. First, the CBP recently articulated a need to integrate more social science into their restoration strategy and organizational structure in order to more effectively increase environmental stewardship throughout the watershed. According to Britain's Science Council, science can be defined as "the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence" (Science Council, 2009). Management in the Bay; however, though-science-based, has been predominantly situated in the natural sciences and has undervalued the roles that human behavior change, stakeholder buy-in, and social science play in restoration success (CBP, 2020). In 2011, the CBP held a workshop to begin discussions on how to advance the contributions of social science research to Bay restoration efforts (Paolisso et al., 2011). The CBP identified specific needs for more research on behavior change, economics, cultural landscapes, communication barriers, and institutional change, including stakeholder partnerships and impacts of the political environment on stakeholder groups (Paolisso et al., 2011). More recently, in their biennial review of their progress towards accomplishing the goal of increasing stewardship that was outlined in the 2014 Agreement, CBP stated that "Almost all of the Watershed Agreement goals and outcomes boil down to success in engaging and motivating humans, therefore embracing social science is key to successful implementation of the Watershed Agreement and restoration of the Bay" (CBP, 2020, p. 4). Specifically, the CBP recognized that social science frameworks could help them to design more effective public engagement and outreach opportunities (CBP, 2020).

In addition, integrating social and natural sciences will also likely increase stakeholders' ability to understand and manage Chesapeake Bay as a socio-ecological system (Paolisso et al., 2011). Specifically, social science research can help the CBP more strategically design meaningful opportunities for stakeholders to come together and integrate their knowledge. Environmental researchers, managers, and policy makers are increasingly emphasizing the necessity of partnering with diverse non-academic stakeholder groups, such as watermen, homeowner associations, and local policy makers. One example of this change is the 2018 and 2019 Chesapeake Watershed Forum conference themes, which were "Connecting Our Communities: Celebrating Diverse and Innovative Partnerships" and "Better Together: Diverse and Innovative Collaborations for the Chesapeake Watershed," respectively. Both meetings invited environmental stakeholders from across the watershed to highlight, celebrate, critically evaluate, and strengthen various partnerships that accelerate and improve watershed restoration (Alliance for the Chesapeake Bay, n.d.). Similarly, the 2018 Maryland Water Monitoring Council conference also emphasized the importance of engagement with diverse stakeholders and communities in their chosen theme, "Science, Stewardship and Citizen Involvement".

This clear focus on engagement and partnerships within the Chesapeake environmental research and management community is evidence that scientists and decision makers are beginning to place more value on bringing new voices into management conversations and learning more about the complex relationships between humans and the Bay. In his dissertation, McCarthy (2000) suggested that public participation in Bay management was, for all intents and purposes, ad-hoc. The author noted that even though the CBP's governance structure included a Citizen's Advisory Committee, their voices were not necessarily viewed as equally legitimate compared to scientists (McCarthy, 2000). McCarthy suggested that "the democratization of the decision-making process could be greatly enhanced with insights gleaned from a post-normal scientific decision-making perspective," which embraces plural legitimate perspectives and de-emphasizes distinctions between "experts" and non-experts (Funtowicz & Ravetz, 1993; McCarthy, 2000, p.114). Since then, many more efforts have been made– with varying degrees of success– to facilitate collaboration and dialogue between environmental scientists and other stakeholders. For example, ecological models of the Bay have increasingly received a greater degree of input and feedback from non-scientist stakeholders (Hood et al., 2021), which has increased model accuracy and stakeholder buy-in (Arnold et al., 2021).

Thus, Bay management is currently a developing collaborative endeavor with a strong disciplinary base and a long-standing commitment to incorporate citizens' and other stakeholders' input into policy decisions, at least to some degree. Despite all of the progress and recent focus directed towards engaging stakeholders in Bay science and management efforts, there has been minimal research to evaluate or improve knowledge integration processes within the Chesapeake Bay environmental stakeholder community. A more nuanced understanding of post-normal science and deeper dive into the impacts of various stakeholder engagement opportunities in the Chesapeake Bay watershed would support Chesapeake environmental stakeholders in their efforts to more effectively and collaboratively develop new management strategies and create a more holistic and representative understanding of the Bay.

A 2017 survey of over 5,000 Bay watershed residents offers evidence that Chesapeake Bay stakeholders seek additional high-quality opportunities to engage in environmental restoration and protection activities. The survey indicated that while only 14% of residents are currently engaging in environmentally-focused civic engagement, the degree of engagement has the potential to expand significantly because 43% of residents indicated that they could see themselves becoming more involved in environmental causes (CBP, 2017). Additionally, the same study found that 71% of residents wanted to contribute more towards improving the health of the Bay and watershed, yet only about one third of the respondents could name a community group focused on environmental protection, and only about 60% of people believed they would know how to engage in environmental volunteerism if they so desired (CBP, 2017). These results indicate that it would be worthwhile to invest more resources in strategic outreach to stakeholders regarding how they can engage in environmental management processes, environmental advocacy, and environmental volunteer research and clean-ups. People are willing and even eager to become more active environmental stakeholders, but it is evident that strategic recruiting and education is needed.

One type of environmental volunteerism that has developed significantly in the Chesapeake Bay watershed in recent years is citizen science, or volunteer monitoring. For decades, watershed residents have participated in volunteer-based monitoring programs and have collected robust data on a variety of chemical, physical, and biological parameters aimed at answering specific questions about health of local streams, watersheds, or broader ecosystems (Rubin et al., 2017). These programs have traditionally operated independently of one another and the volunteer-collected data have historically been underused by scientists and managers in the region due to factors such as low data comparability, inadequate quality assurance, and a general lack of understanding of volunteer monitoring on the part of decision makers. In 2015, after the CBP determined that their program's existing monitoring efforts were insufficient for informing the adaptive management of the Bay, the CBP established a new partnership with the goal of capitalizing on the existing data collection capacities of volunteer monitoring efforts throughout the watershed (CBP, 2018). If approached strategically, and with stakeholders' perspectives in mind, this partnership, and citizen science more broadly, could help accomplish several CBP goals and improve adaptive management in the Bay region.

Frameworks of stakeholder engagement in scientific research

Citizen science

Citizen science is a means of increasing public participation in the creation and use of scientific data and knowledge (Haklay et al., 2020; Wiggins & Crowston, 2011). Citizen science refers to research collaborations between scientists and volunteers, who work together to collect scientific data and answer real-world, locally-relevant questions (Aceves-Bueno et al., 2015; Dickinson et al., 2012). While citizen science is used within many academic disciplines, it is especially effective in environmental studies that aim to understand and protect or restore natural resources (Dickinson & Bonney, 2012). Citizen science is known by many other terms, including community science (Carr, 2004; Wilderman et al., 2004), volunteer biological monitoring (Lawrence, 2006), and public participation in scientific research (Shirk et al., 2012), among others. Regardless of the label, the movement to include volunteers in scientific research, and even more specifically, in environmental monitoring, has expanded around the world over the last three decades (Conrad & Hilchey 2011; Whitelaw et al., 2003).

In recent years, several organizations have moved away from using the term "citizen science" due to perceptions that these types of research collaborations are limited to only those with legal citizenship. For example, the U.S. National Science Foundation suggested that the term "public participation in scientific research" could be used instead, and several organizations have issued statements explaining their rationale for switching to the term "community science." At the time of writing this dissertation, these terms have not gained wide acceptance (Haklay et al., 2020). For example, both the U.S. and European professional associations of citizen science practitioners, researchers, and facilitators have elected to continue using the term "citizen," as well as the official U.S government website on this topic, named "CitizenScience.gov". Furthermore, citizen science scholars note that using the umbrella term "citizen science" will help researchers and practitioners build upon existing momentum to include members of the public in science and more effectively assess the impacts of public participation in scientific research (Eitzel et al., 2017; Hecker et al., 2018). In all of these circumstances, and throughout this dissertation, the term "citizen science" is used in reference to the broader concept of civic engagement, and is inclusive of research collaborations between scientists and other public stakeholders, regardless of collaborators' legal citizenship status.

Typologies of citizen science

Since the phrase "citizen science" was first introduced, it has carried two different meanings. Researchers at the Cornell Laboratory of Ornithology in 1994 used the phrase to describe a top-down process involving interested volunteers who make observations and share data for use in projects driven by scientists and designed to advance scientific research (Bowser & Shanley, 2013; Eitzel et al., 2017). Simultaneously, Alan Irwin used the phrase to refer to a more bottom-up democratic model in which engaged citizens share personal knowledge, experiences, and data with scientists (Irwin, 1995). In this model, citizens and scientists collaboratively conduct research that is designed to drive policy goals and address specific needs and concerns of a community (Bowser & Shanley, 2013; Eitzel et al., 2017; Irwin, 1995). These two definitions reflect the diversity of citizen science practices that exists today; between and beyond these two definitions exists a broad diversity of approaches to participatory research. Presently there is widespread disagreement among researchers and practitioners as to how citizen science should be defined, how projects ought to be categorized or conceptually grouped together, and how to determine whether or not certain efforts even constitute citizen science (Haklay et al., 2020). A commonly-practiced approach to describing the wide diversity within the field of citizen science is to describe projects based on the degree to which citizen scientists and professional researchers are engaged throughout various stages of the research process (e.g., Bonney et al., 2009a; Danielsen et al., 2009; Shirk et al., 2012).

At one extreme of this range of participant involvement are projects that require the least amount of citizen engagement and local knowledge (Figure 5). These types of projects are described as “contractual,” (Shirk et al., 2012) or “consultative” (Wilderman, 2007). They are characterized by citizens defining a problem or research question and then commissioning professional researchers to conduct scientific research on behalf of the community, without further involvement from the citizens themselves. Environmental justice projects often fit this description, such as with cases that involve a community asking state or federal scientists to first conduct research for the purpose of determining whether or not environmental regulations are being followed and then intervene if data suggest legal enforcement of environmental policies is needed. Moving along the continuum of citizen engagement, crowdsourcing and contributory projects engage citizens as data collectors supporting research efforts that are spearheaded by scientists. Scientists develop research questions using a top-down approach (Bonney et al., 2009b; Danielsen et al., 2009), often with a primary objective of gaining scientific knowledge. While this type of research effort is not often designed with the purpose of solving specific place-based problems or addressing community concerns, participants often use the data for local purposes. This externally-driven approach involves minimal back-and-forth communication between the professional scientists and citizens collecting data (Danielsen et al., 2009; Dickinson et al., 2012), and it is particularly suitable for projects that demand large amounts of regularly-collected data using non-technical protocols over vast geographical areas.

Types of citizen science

	Contractual or consultative	Collaborative	Community-based participatory research
Citizen involvement	Citizens define topics and commision researchers	Citizens collect data and co-produce knowledge	Citizens maintain authority over research
Strengths	Top-down approach reduces transactional cost	Management solutions likely to be co-developed	Scientific results responsive and likely to be applied
Limitations	Can be difficult to maintain high levels of engagement	More labor-intensive with slow decision making	Credibility of results may be questioned

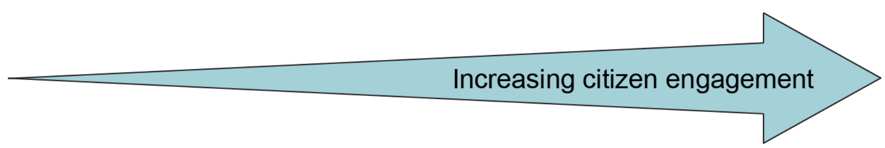


Figure 5. Citizen science projects are often categorized based on the degree of partner engagement or division of labor throughout the research process. All approaches have strengths and limitations.

In the middle of the participation spectrum are “collaborative” projects. In these projects, research questions are still heavily guided by professional scientists, and volunteer participants are involved in data collection and certain other phases of the research process, such as data interpretation (Bonney et al., 2009a; Shirk et al., 2012). Sometimes citizens are also included in management decision-making processes that follow the release of the results (Danielsen 2009). Similarly, in “co-created" projects, citizen scientists and scientific experts share authority and decision-making power throughout all phases of the research process, from project design to after research is disseminated (Bonney et al., 2009a; Shirk et al., 2012). Epistemologically, these types of projects align with the European conceptualization of citizen science, which more commonly emphasizes citizens' roles in knowledge production than the previously discussed approaches (Eitzel et al., 2017, European Citizen Science Association, 2015). Furthermore, these types of partnerships prioritize collecting data of mutual interest and producing actionable results (Figure 5). One advantage of these intermediate approaches is that scientists are able to learn from citizens and community members who possess specialized knowledge of local environments. In addition, democratizing the scientific process can create opportunities for resulting management decisions to be collaboratively developed by the people who will ultimately be affected by management outcomes (Mueller et al., 2012). Projects that involve more extensive collaboration between citizens and scientists earn higher public confidence ratings (Lewandowski et al., 2017), but these types of projects are often more expensive, more labor-intensive for all collaborators, and involve the slowest decision-making processes (Danielsen et al., 2009). Furthermore, these projects require the identification and inclusion of specific stakeholders instead of targeting the public, broadly (Hecker et al. 2018), and this reliance on participant selection increases susceptibility to various biases and challenges (Pettibone et al., 2018).

Finally, projects that have the highest degree of citizen engagement are known as "community-based participatory research" (Wilderman, 2007), or "extreme citizen science" (Haklay, 2013). In these projects, citizens often define the research objectives and maintain authority over various aspects of the research effort, although decision-making power is sometimes shared with professional scientists (Figure 5). Some citizen science efforts consult professional scientists only when their specific expertise is needed, while other efforts do not include scientists in the research process at all, such as in cases when communities conduct autonomous local monitoring (Danielsen et al., 2009; Shirk et al., 2012). A disadvantage of this approach is that not including professional scientists in the research design and implementation stages can potentially decrease a project's perceived credibility, thereby making it difficult for communities to use the research in formal settings to inform environmental management decisions (Danielsen et al., 2009) (Figure 5). These projects are the most resource-intensive for local citizens (Danielsen et al., 2009). For these reasons, these types of projects are usually used when highly-localized research has immediate and high-stakes implications for community members, which ultimately increases citizens' incentive to take on the responsibility of conducting the research (Bonney et al., 2009a; Danielsen et al., 2009). One of the major advantages of this bottom-up, community-driven approach is that the resulting scientific research is, by design, responsive to local concerns and can be more directly applied towards solving real-world environmental problems (Bonney et al., 2009a; Conrad & Hilchey, 2011).

Describing citizen science projects based on the degree of partner engagement or division of labor throughout the research process is helpful for understanding some of the diversity that exists within the scope of citizen science; however, this approach alone is insufficient. A limitation to this framework for describing projects is that it assumes a dichotomy between top-down, data-extractive models and bottom-up, community-empowering models, when in fact projects often have elements of both (Lawrence, 2006). This engagement-focused classification also ignores any discussion of project outcomes or internal changes within participants, both of which are of major importance in the field of citizen science (Lawrence, 2006; Wiggins & Crowston, 2011).

Project objectives and outcomes in the field of citizen science are arguably even more diverse than participation structure. Citizen science objectives and outcomes can vary based on the participatory structure of the project, can be internally or externally valuable, and can include both short-term and long-term impacts (Lawrence, 2006; Shirk et al., 2012; Wiggins & Crowston, 2011). More specifically, citizen science projects can offer external value for communities and ecosystems, as well as internal value for individual participants, such as contributions to their learning, development, or relationships with nature (Lawrence, 2006).

Shirk et al. (2012) expanded on this discussion of project value and outcomes, suggesting that citizen science projects can be divided into those that prioritize goals associated with either scientific research, individual participants, or socio-ecological systems. Scientific research goals include advancing scientific understanding, collecting high-quality data, publishing scientific results, contributing to conservation, discovering innovative research techniques, and producing responsive and actionable science (Shirk et al., 2012). Goals focused on individual participants include developing new skills, improving personal sense of place, establishing a deeper connection with the natural world or other people, developing increased appreciation for local knowledge, increasing knowledge of the scientific process, and learning about specific topics (Lawrence, 2006; Shirk et al., 2012,). Finally, socio-ecological systems goals include influencing policy, improving citizens' access to data, empowering citizens to participate in community-level decision-making processes, building community capacity, changing attitudes towards science or the environment, supporting resilient natural systems, and improving relationships within communities and between community members and external managers (Bonney et al., 2009b; Shirk et al., 2012).

Wiggins and Crowston (2011) used a modelling-based approach to cluster citizen science projects into five distinct categories based on a project's primary goal, as well as various organizational characteristics including a projects' use of enabling technologies. Using this framework, the researchers described action projects as place-based, bottom-up efforts that encourage long-term citizen engagement, with a primary objective of supporting specific local agendas and providing scientific evidence for intervention (Wiggins & Crowston, 2011). In contrast, conservation projects are top-down and characterized by volunteers assisting scientists in the collection of scientifically-valid data to support resource management decision making. Investigation projects also value knowledge production and data collection, however they are comparably larger in scale and rely on a wider variety of funding sources and technologies, and virtual projects are similar except that they rely much more heavily on advanced technology. Finally, education projects prioritize providing informal and formal learning and outreach opportunities for members of the public, and they often are well-funded and, like virtual projects, rely heavily on technology for support (Wiggins & Crowston, 2011).

This plurality of frameworks for conceptualizing and categorizing citizen science efforts is indicative of the heterogeneity of projects in existence and the diversity of opinions about citizen science (Haklay et al., 2020). The diversity of project typologies also provides a glimpse into the variety of benefits that citizen science projects can offer. It is important to also understand that citizen science efforts have the potential to be successful and lead to diverse positive outcomes regardless of the degree of citizen engagement (Pettibone et al., 2018). Those who develop or coordinate citizen science efforts should be mindful and strategic about their project's design and goals. Specifically, leaders of citizen science efforts should consider the various tradeoffs and resource requirements associated with all of these different approaches in order to design and support a project that maximizes the benefits for everyone involved in their particular research effort.

Potential benefits and opportunities

Citizen science projects offer a suite of benefits for environmental science, management, and stakeholder communities (Conrad & Hilchey, 2011; Dickinson et al., 2010; McKinley et al., 2017). Perhaps most obviously, these research collaborations increase the capacity for scientific data collection and enable environmental monitoring at localized, finer-scale resolutions than would have been feasible with only professional scientists (Figure 6) (Barreto et al., 2003; Cohn, 2008). At the same time, research teams can also use citizen science to maintain long-term and large-scale monitoring projects and collect data that allows them to better understand large-scale patterns over time (Cooper et al., 2007; Dickinson et al., 2012). Dickinson et al. (2010) expound on this idea, suggesting that "Citizen science is perhaps the only practical way to achieve the geographic reach required to document ecological patterns and address ecological questions at scales relevant to… impacts of environmental processes like landscape and climate change" (p. 166). Thus, citizen science can also transform traditional management strategies and inform timely management solutions by fulfilling environmental managers' need for high-quality data that fills existing data gaps (Dickinson and Bonney, 2012; Stepenuck & Genskow, 2018).

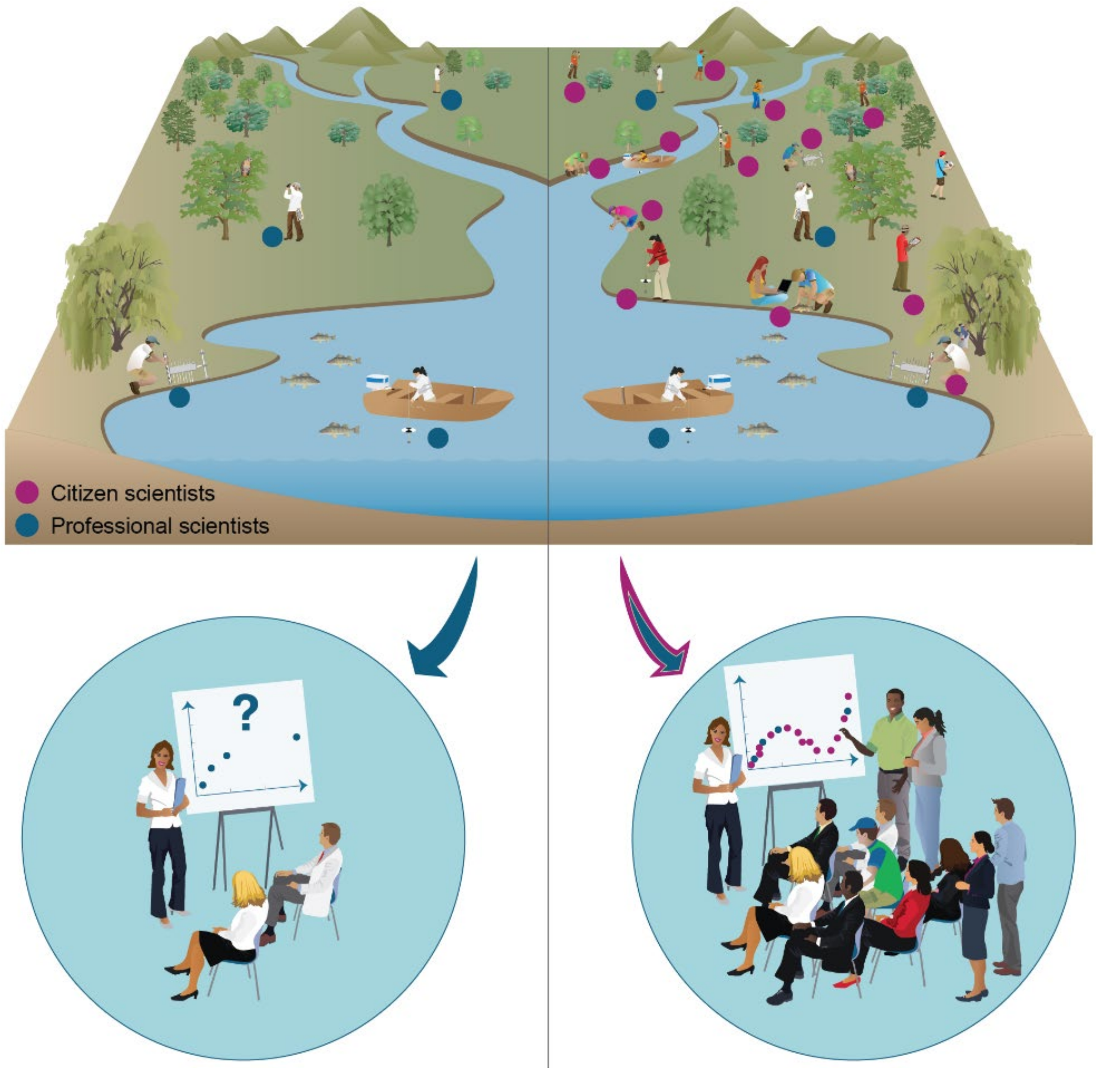


Figure 6. Citizen science enables increased collection of scientific data and a more comprehensive understanding of socio-ecological systems. Symbols used with permission of the Integration and Application Network (ian.umces.edu/media-library).

Traditional approaches to environmental science and management tended to position communities as external obstacles to efficient resource management (Hardin, 1968), but citizen science invites citizens to become central actors in scientific processes and critical actors in management. Citizen science increases scientific literacy by giving participants insight into scientific research processes through direct participation in scientific thinking and data collection (Conrad & Hilchey, 2011; Cooper et al., 2007). Participation in citizen science projects can also increase environmental literacy and build an ethic of stewardship by increasing participants' understanding of local environments and the role they play as residents and environmental stakeholders (Conrad & Hilchey, 2011; McKinley et al., 2017,). In fact, citizens living in communities where a community-based monitoring program exists are more likely to be engaged in local issues and have more influence on policy makers (Lynam et al., 2007, Pollock & Whitelaw, 2005). Citizen science can also provide opportunities for integrating public input into proposed environmental solutions, increase public support of science, and empower public action or advocacy efforts (Johnson et al., 2014; McKinley et al., 2017). Aceves-Bueno et al. (2015) found that citizen science can lead to high levels of citizen engagement that are necessary for effective adaptive management. Scientists and natural resource managers cannot successfully protect the environment without the help of a supportive public that appreciates the value of Nature and is willing to fight or advocate for its protection (Cronon, 1996; Potts, 2007). Therefore, citizen science plays an important role in managing not only the natural environment itself, but also in acknowledging and collaborating with the people who make up the society component of the socio-ecological systems under study.

In a similar vein, another benefit of many citizen science projects is that they have the ability to shift authority structures, which in turn decentralizes political power and enables more democratized management of resources (Freitag & Pfeffer, 2013). Citizen science democratizes the production of scientific knowledge by creating a channel of information-sharing between scientists and non-scientists and engaging new perspectives that can transform the research process and scientific results (Buytaert et al., 2014; McKinley et al., 2017). Knowledge produced as part of such a collaborative and transparent process is also more likely to be used by project partners and external data users due to enhanced feelings of ownership for the scientific data and understanding of the knowledge production process (Meadow et al., 2015). Furthermore, engaged citizen scientists can also help translate scientific research into management recommendations and actions (Ernst 2003; Pollock & Whitelaw, 2005; Sullivan et al., 2017). Additional benefits of citizen science are described throughout the literature.

Organizational and data challenges

Various challenges associated with citizen participation in scientific research have been well documented by citizen science practitioners, scholars, and skeptics, alike. These challenges can be broken into three categories– those occurring at organizational level, during data collection, and concerning data usage (Conrad & Hilchey, 2011). One major organizational challenge is that effective citizen science programs are resource-intensive investments that require adequate funding to support necessities like project maintenance, communication and data collection technology, and data management (McKinley et al., 2017). Citizen science projects also require people who can recruit and retain volunteers, people who synthesize and communicate the scientific results and answer questions, people who ensure that federal and ethical guidelines are followed throughout the duration of the project, and of course, the citizen scientists themselves (McKinley et al., 2017). Many citizen science projects are grassroots efforts and have limited initial resources, thus securing funding and recruiting necessary people can be a daunting task and sometimes even an insurmountable challenge. Success is often more probable if citizen science projects are interwoven into existing institutional structures and have transparent benefits for all involved (Buytaert et al., 2014); therefore, efforts should be made to collaborate with other relevant organizations and clearly communicate citizen science project goals and expected outcomes to potential funders and participants.

There are also challenges associated with the data collection phase of citizen science projects, including concerns about compromised data quality due to a lack of volunteer training or inadequate study design that leads to sampling bias (Dickinson et al., 2010). Research has shown that trained volunteers can produce high-quality datasets that are comparable to those produced by professional scientists (Kosmala et al., 2016). In fact, a study by Barreto et al. (2003) showed that trained volunteers' inexperience can even act as a shield against preconceived scientific biases and allow them to collect data that experts overlook (Barreto et al., 2003). Another challenge is that some people question citizen scientists' ability to remain objective. For example, the U.S. Congress asked that volunteer-collected data be excluded from the 1994 National Biological Survey because they believed that citizens' "environmentalist agenda" could cause biased data collection (Conrad & Hilchey, 2011; Root & Alpert, 1994). Although the U.S. government has since changed its stance towards citizen science, this lasting concern about observer objectivity within the environmental research and management communities remains a challenge for citizen science projects. It is important to remember that even traditional scientific research conducted by only professional scientists is not truly objective; for instance, research priorities can be skewed by personal interests of investigators and funding opportunities (Bidwell, 2009). Scientists can strive for objectivity in their work to a certain degree, but citizen input in the research process should not automatically be a cause of concern— research can simultaneously be engaging, relevant, and scientific, as these characteristics are not mutually exclusive.

Finally, another suite of citizen science challenges is associated with the usage— or lack thereof— of the data. Unfortunately, many citizen science projects find that their data is not used to inform environmental decision making or advance scientific research (Conrad & Daoust, 2008). This is partly due to a lack of data comparability between different citizen science efforts, which can dissuade or even prevent scientists and managers from using localized volunteer-collected data to fill data needs at broader scales (Conrad & Daoust, 2008; Rebele, 1997). Another challenge related to data use stems from the difficulty of measuring environmental management outcomes. Data collected by citizen scientists are useful for broader purposes when they meet current, high-priority scientific or management needs. Similar to adaptive management, adaptive citizen science involves iteratively and continuously analyzing relevant management outcomes, and then making improvements to increase the impact of volunteer-collected data in the future (Cooper et al., 2007). But, as previously discussed, environmental management outcomes are influenced by the interaction of sociological and ecological processes, and are difficult to quantify. To address this challenge, research teams should investigate how to more effectively measure both ecological and social impacts so that citizen scientists can more easily assess the influence of their monitoring efforts and refine their monitoring strategies (Cooper et al., 2007). Finally, another challenge for citizen science and other collaborative research involving stakeholders is the bias that exists within parts of the scientific community against participatory research (Haklay, 2013). While it is certainly necessary to consider all of these concerns and tradeoffs associated with including citizens in environmental research, it is also important to note that steps can be taken to directly address each of these challenges.

Citizen science in the Chesapeake Bay watershed

Citizen science opportunities in the Chesapeake Bay watershed encompass the full range of diversity in terms of participants' degree of involvement, project goals, and beneficial outcomes. For example, community BioBlitzes invite volunteers to collect data for a few concentrated hours, while other projects like Chesapeake Dolphin Watch invite volunteers to submit observations opportunistically. Throughout the watershed, there are also opportunities for citizens to regularly contribute to long-term monitoring programs as members of official volunteer monitoring programs. Some projects are primarily focused on education objectives, and are increasingly integrated into classrooms throughout the watershed. The Chesapeake Bay Water Quality Project is an example of a citizen science opportunity that is frequently used by teachers to provide students with Meaningful Watershed Educational Experiences. Other projects are focused on collecting high-quality data to inform management decisions. Trained volunteers collect data using USEPA-approved scientific protocols and then submit their data for use in scientific assessments and reports, such as the Virginia Department of Environmental Quality biennial Integrated Water Quality Assessment Report (Virginia Department of Environmental Quality, 2018). Finally, other citizen science opportunities are designed primarily to promote environmental stewardship and engage community members in solving specific local problems. There are dozens of community-level watershed organizations, each with their own outreach and research objectives.

Chesapeake watershed residents have participated in volunteer environmental monitoring efforts for decades (Rubin et al., 2017). Various volunteer monitoring programs exist across the watershed, and have traditionally operated independently of one another, each with its own project scope, research goals, and scientific processes. In many cases, community-based monitoring programs partner with scientific organizations or regional volunteer monitoring service providers, such as the Alliance for Aquatic Resource Monitoring or the Consortium for Scientific Assistance to Watersheds. These partnerships can support citizen science groups in establishing specific project objectives and developing sampling protocols that volunteers can use to collect the data that is needed to accomplish their project goals. Even still, like citizen science efforts elsewhere, volunteer monitoring programs in Chesapeake Bay face challenges associated with low-level usage of their data.

Volunteer-collected data has historically been underused due to challenges such as low data comparability between monitoring programs, inadequate quality assurance, and potentially a misunderstanding or bias against citizen science on the part of Chesapeake scientists, managers, and decision makers. Nevertheless, in 2015, the CBP took a significant step towards increasing its use of volunteer-collected data by establishing a new coordinated effort to address some of these challenges (CBP, 2018). This partnership, known as the Chesapeake Monitoring Cooperative (CMC), is a multi-state initiative that provides support to volunteer-based monitoring groups with the primary goals of increasing the cohesion between volunteer, state, and federal monitoring programs and making volunteer-collected data more useable even beyond its originally-intended purpose (Rubin et al., 2017). This partnership has already begun to augment the CBP's monitoring efforts with high-quality volunteer-collected environmental data that has been collected at the temporal and spatial scales. Further monitoring and analysis of local-level water quality conditions will provide the insights needed to inform timely adaptive management (Zhang et al., 2018). Despite this progress, there are other challenges that need to be addressed in order for citizen science to reach its full potential in the Chesapeake Bay region. Strategic citizen science partnerships could not only improve adaptive management in the Bay region, but also lead to many of the other diverse benefits that citizen science has to offer.

Transdisciplinary science

Transdisciplinary science is another approach for engaging non-academic stakeholders in scientific research. Transdisciplinary science has been described as a reflexive, integrative, and methods-driven way of solving societal problems by integrating various knowledge streams and value systems to create new knowledge (Jahn et al., 2012; Lang et al., 2012). Transdisciplinary science is also a post-normal approach to scientific research, as it abandons the expert-driven mode of solving complex problems (Kreuter et al., 2004) and instead extends the deliberative peer community beyond academic research scientists to include other people with interest in the outcome of the research, such as citizens and policy makers (Bidwell, 2009; Lang et al., 2012). Specifically, transdisciplinary research teams are made up of researchers with different epistemological backgrounds, as well as non-academic stakeholders who contribute their own expertise from the domains of science, management, planning, policy and practice (Roux et al., 2010). During the research process, all researchers' knowledge contributions are (at least in theory) seen as equally valuable to traditional scientific knowledge (Mobjörk, 2010). A key aim of transdisciplinary science is mutual learning processes between science and society (Jahn et al., 2012). Researchers work together to collaboratively generate new knowledge that is salient, credible, and legitimate, and ultimately instrumental in addressing global challenges, solving complex real-word problems, and otherwise serving society (Cash et al., 2002; Keeler et al., 2017; Lang et al., 2012). Transdisciplinary research is often facilitated by boundary-spanning organizations (Guston, 2001) that oversee the processes of knowledge sharing, collaborative learning, and knowledge integration.

Transdisciplinary science is distinct from interdisciplinary science. Instead of working to identify common objects in areas of overlap between academic disciplines (Russel et al., 2008), transdisciplinary research teams transcend disciplinary borders to develop “shared conceptual and methodologic frameworks” (Stokols et al., 2008, p. 79) and think about problems in entirely new ways. This approach is driven by demand and is most suitable for solving complex societal problems that cannot be addressed with scientific expertise alone (Klein et al., 2001). In fact, many scholars have stated that addressing problems related to sustainable development requires a transdisciplinary approach (Jahn et al., 2012). Researchers have used a variety of terms to describe a gap that exists between sharing scientific research results and using science to inform changes in environmental policy and management, including the “research-implementation gap” (Knight et al., 2006), the “theory-practice gap” (Cooke et al., 2021), the “science-management gap” (Roux et al., 2006), and the “science-action gap” (Reyers et al., 2010). The transdisciplinary approach is especially useful for research on ‘wicked’ problems that are mired in the political landscape (Douglas et al., unpublished) because it facilitates the collaborative shaping of a new social discourse around a particular complex problem at the intersection of science and policy (Jahn et al., 2012). This solutions-oriented approach leads to the production of new, actionable knowledge specifically designed to close these gaps between research and real-world results.

There are several challenges and limitations associated with transdisciplinarity. First, this approach is resource-intensive and logistically complicated. Gathering research partners and engaging in collaborative learning processes is time consuming, during both the planning and implementation stages. Furthermore, academic, public-sector, and private-sector partners often operate on different timelines with different pressures and constraints, and various funding sources have different lead times, durations, requirements (Simon et al., 2018), which can present challenges for project management and coordination. Transdisciplinary research often demands more labor, energy, and specialized skills from research partners (Roux et al., 2012). Besides requiring a higher degree of interpersonal skills from collaborators, such as listening, openness to learning and compromise, and negotiation, this approach also relies on various skills relating to facilitating knowledge exchange, synthesizing ideas, building consensus, and communicating complex information (Cash et al., 2002; Douglas et al., unpublished). Another potential limitation of transdisciplinary research is that it is difficult to assess impact because these evaluations must take into consideration the expectations and goals of multiple groups of people, including the funders, diverse team of researchers, and end users (Brandt et al., 2013; Roux et al., 2010; Walter et al., 2007). This is especially true in the field of environmental management because of known lag times between interventions and outcomes. An additional challenge is navigating power differentials among co-production participants. Even when all members of transdisciplinary research teams are actively engaged and exchanging knowledge, scientists can dominate the process of defining research objectives and maintain decision-making authority, which can result in unbalanced problem ownership (Lang et al., 2012) and missed opportunities for empowering other actors (Brandt et al., 2013). Finally, the transdisciplinary approach is limited in that it often produces case-specific solutions that lack transferability and can cause conflict between researchers regarding conflicting methodological standards and underrepresentation of certain actors on the research team (Lang et al., 2012). Despite efforts, sometimes knowledge integration is not done effectively, resulting in surface-level "participation" that does not truly incorporate multiple voices but instead perpetuates the dominant discourse (Bäckstrand, 2003; Dove & Carpenter, 2008), and in some cases, further disempower other stakeholders (Brosius et al., 1998).

There are several examples of transdisciplinary research efforts that are focused on collaboratively developing a more comprehensive understanding of Chesapeake Bay as a socio-ecological system. First, the Chesapeake Bay Report Card is an annually-produced science communication tool that synthesizes scientific data from the Bay into a comprehensive measure of ecosystem health (Costanzo et al., 2017, Dennison & Wicks, 2010). The process of creating the report card is transdisciplinary because environmental stakeholders work together to create a shared vision of a healthy Bay, identify and prioritize threats to Bay health, and calculate snapshot scores for various highly-valued aspects of ecosystem health (Laumann et al., 2019; Vargas-Nguyen, 2020). Because a diversity of stakeholders are included in this process, the report card itself calls attention to different elements of the Bay that are important to various people and provides a synthesis of multiple sources of knowledge about the Bay.

Another example of an ongoing transdisciplinary research effort in Chesapeake Bay is the Deal Island Peninsula Project (Paolisso et al., 2019). This project creates an inclusive and collaborative space for scientists, environmental managers, and local community members to co-develop strategies for building social and ecological resilience to climate change impacts, such as sea level rise. Stakeholders contribute a wealth of local knowledge to co-create new scientific knowledge that helps the Deal Island community better understand how it can prepare for and adapt to their changing environment (Johnson et al., 2018). A final example of a transdisciplinary research endeavor in Chesapeake Bay is the OysterFutures project. Throughout this research effort, scientists served as consultants to a group of stakeholders that included watermen, conservation professionals, and representatives from the seafood industry. Stakeholders used a participatory modelling process to forecast oyster fishery outcomes under various management strategies and then establish a set of consensus recommendations for oyster fishery management based on their most highly-prioritized outcomes (Goelz et al., 2020; North et al., 2016). These three projects have different goals and methodologies, but they share the objective of integrating and synthesizing knowledge from stakeholders who have multiple academic and non-academic areas of expertise. All three projects result in new co-produced scientific knowledge that can inform Chesapeake Bay management.

Broadening environmental discourse and the potential role of transdisciplinary citizen science

Scientific knowledge has played an important role in forming society's broader understanding of socio-ecological systems. Similarly, scientific knowledge is also a central component of environmental management. This is due in part to the fact that people with decision-making authority have long accepted scientists' contributions as valuable knowledge upon which to base important decisions. In Chesapeake Bay and beyond, scientists' approach to conceptualizing, valuing, and protecting the environment is often positioned at the core of environmental priority-setting and decision making. This continuous privileging of scientific environmentalism has reinforced cultural barriers between scientists and non-scientists (Haklay, 2013) and strengthened the boundary between what is and is not considered to be credible knowledge in an environmental management context. While scientific knowledge has historically been socially-elevated and respected, other forms of knowledge and environmentalism have been delegitimized (Johnson & Clisby, 2009).

Scientists, by themselves, are not adequately equipped to comprehensively understand complex socio-ecological systems, nor authoritatively address complex socio-ecological problems. One limitation of scientific environmentalism is that it trivializes the public's role in identifying environmental problems (Grove-White, 1993). Instead, environmental priorities are defined by scientists 'objectively,' and often without meaningful consideration of factors that are important to other stakeholders (Grove-White, 1993). When environmental research priorities are defined based on the priorities of scientists, environmental management discourse tends to emphasize the importance of conserving pristine landscapes, maximizing biodiversity, and protecting ecosystem services (Paolisso et al., 2013; Paulson et al., 2005). Another related shortcoming of scientific environmentalism is that it inflates the role of science by reducing any unknown or socio-cultural components to scientific uncertainty or an "error" term (Grove-White, 1993). Ultimately, this practice of discounting other types of knowledge decreases society's collective ability to holistically understand and manage socio-ecological systems (Griffith, 1999). In reality, Chesapeake Bay stakeholders do tend to share a core value of protecting the Bay's natural resources (Paolisso et al., 2011), but this does not mean that all stakeholders share the same questions, knowledge, concerns, or priorities (Potts, 2007). Therefore, when environmental problem definition is limited to scientists, and environmental research ignores socio-cultural factors, this results in research that is less socially-relevant informing management solutions that are not as responsive to the concerns of the entire Chesapeake Bay environmental community.

Furthermore, the dominance of scientific environmentalism also contributes to environmental injustice through the disengagement and disempowerment of other environmental stakeholders (Johnson & Clisby, 2009). Setting ethical considerations aside (temporarily), this is problematic from a pragmatic standpoint because the success of environmental management and policy is dependent on its ability to engage the public (Eden, 2016) and empower more resilient communities that can collaboratively work together to manage their environment (Berkes, 2009). Empowered stakeholders not only have a heightened sense of personal control over their lives (Rappaport, 1987) and a better understanding of their environments (Zimmerman et al., 1992), but they also have more equitable access to resources and increased willingness to participate in their communities (Perkins & Zimmerman, 1995; Rappaport, 1987; Zimmerman & Rappaport, 1988). When stakeholders are empowered to contribute to environmental science and management, there are increased levels of support and trust in environmental management practices (Goldman et al., 2011; Gray et al., 2012; Renn et al., 2013) and increased involvement in environmental governance (Ernst, 2003). In this sense, by allowing scientific environmentalism to monopolize environmental discourse, scientists and decision makers are losing trust and support of other environmental stakeholders and missing out on the opportunity to increase local environmental stewardship and share governance, all of which have been shown to improve management outcomes (Anderies & Janssen, 2016).

Citizen science and transdisciplinary science are both participatory research approaches that can open environmental discourse to people outside of the traditional scientific community. Citizen science and transdisciplinary science are both participatory research approaches that can open environmental discourse to people outside of the traditional scientific community. These co-production approaches, used in tandem, result in a post-normal method of scientific knowledge production that addresses several of the limitations of traditional environmental science and management, which is dominated by scientific environmentalism (Pettibone et al., 2018). Specifically, transdisciplinary forms of citizen science join academic and nonacademic actors together to collaboratively conduct scientific research that produces socially-robust scientific knowledge. Transdisciplinary citizen science does this by encouraging deeper participation of all co-researchers throughout the process of conducting research that "connects with more general discourses on political participation in democratic societies" (Thomas et al., 2021). Transdisciplinary citizen science efforts create opportunities for volunteers to influence research priorities, methodologies, and real-world application of results, rather than primarily focusing on producing scientific data, and participants' social needs and concerns are integrated into the project design and impact engagement dynamics (Senabre

Hidalgo, 2019). Co-created citizen science projects, in particular, can foster transdisciplinarity by offering an inclusive horizontal space for knowledge sharing and co-production (Thomas et al., 2021). In his 2019 thesis, Senabre Hidalgo suggests that co-creation contributes to a more collaborative and engaging form of citizen science and serves as a "way to effectively orchestrate the dynamic nature of transdisciplinary knowledge creation" (Senabre Hidalgo, 2019). Importantly, transdisciplinary citizen science is distinct from other forms of transdisciplinary research because there is a focus on the co-production of new scientific data and knowledge, specifically, which is achieved through the broader integration of diverse knowledges, environmentalisms, and methodological frameworks. Furthermore, unlike many other forms of citizen science, transdisciplinary citizen science efforts incorporate people with expertise in diverse academic fields, and social science can play a central role. For instance, citizen social science is a type of citizen science that positions citizens as co-learners within the research process and encourages transdisciplinarity and integration of different ways of knowing (Kythreotis et al., 2019). Citizen social science projects feature communicative spaces facilitated by academic researchers, and a goal is to share perspectives and produce knowledge that can contribute to scientific, social and political discourses (Thomas et al., 2021). In Chesapeake Bay, transdisciplinary citizen science has the potential to fill data gaps, increase stakeholder engagement, and provide a new platform for co-producing scientific knowledge that blends and balances diverse environmentalisms.

Transdisciplinary citizen science involves engaging stakeholders in collaborative learning processes to co-create new knowledge. Scientists and non-scientific partners can collaboratively conduct new scientific research that is inclusive, engaging, and useful for a wider diversity of environmental stakeholders. Citizen science programs can act as boundary organizations in this context by establishing partnerships between the traditional research community and other societal actors. These boundary organizations provide a space where stakeholders can share environmental data and bridge together many knowledge streams (Berkes, 2009) to accomplish shared goals. These "third spaces" operationalize transdisciplinarity by inviting people from different cultural frameworks and epistemological backgrounds to stitch together their individual contributions and collaboratively shape a more inclusive and representative environmentalism that builds upon a plurality of knowledge systems and environmental values (Berkes, 2007; Freitag & Pfeffer, 2013; Irwin, 1995).

Of course, there are many approaches for facilitating collaborative learning and integrating or co-creating knowledge (Raymond et al., 2010), and transdisciplinary citizen science is but one option of many. In a context where such scientific knowledge is valued and privileged, as is the case for Chesapeake Bay environmental science and management, transdisciplinary citizen science could provide a means of rebuilding trust between citizens, scientists and others (Nardi et al., 2021). Increasing stakeholder engagement in environmental management decisions is one of the CBP's priorities; however, stakeholder engagement outcomes are influenced by power dynamics and judgements on which types of knowledge are considered valid (Reed et al., 2018). By uniting all stakeholders around a common goal of producing new scientific knowledge, transdisciplinary citizen science has the potential to democratize knowledge production while also providing space for integrating other environmentalisms.

Regardless of the exact approach used, there are clear benefits of broadening scientific discourse through stakeholder engagement and knowledge integration. Engaging people who have diverse skill sets and perspectives in collaborative knowledge generation and problem-solving will likely result in more robust and widely-representative science that incorporates multiple environmentalisms and more comprehensively describes the world (Cooper et al., 2007; Freitag & Pfeffer, 2013). For example, Philipson et al. (2012) also found that research outcomes, broadly, are positively impacted when stakeholders contribute to objective setting, project design, and knowledge production, in particular. Other researchers have shown that scientific research that incorporates multiple forms of knowledge is more salient, credible, and legitimate (Cash et al., 2002; Forsyth, 2004; Turner et al., 2016). This is because acknowledging and blending multiple environmentalisms and diverging priorities allows research teams to broaden their view of environmental conflicts and think more collaboratively about potential solutions (Berkes, 2007; Paolisso 2006). Co-developed, integrative knowledge is more user-oriented, has buy-in from a more diverse audience, is more practically useful for decision-making and management purposes, and is more reflective of complex environmental values and realities (Goldman et al., 2011; Jasanoff & Martello, 2004).

Beyond improving science and knowledge output, the processes of integrating knowledge and collaborative learning can improve relationships within a stakeholder community and empower non-scientist stakeholders to play a more active and influential role in environmental management decisions in which they, too, have a stake (Berkes, 2009). Participatory collaborative science can facilitate relationships of trust among various environmental stakeholders, including scientists, citizens, management professionals, and policy makers (Johnson et al., 2018). Citizen science, in particular, can also serve as an entry point into environmental politics for members of the public who are directly affected by political decisions but often have little power to influence policy (Bäckstrand, 2003; McKinley et al., 2017). Citizen science and collaborative learning can advance environmental justice by building capacity in communities, facilitating integration of community concerns into research agendas, and generating more granular data that enables a higher degree of shared environmental governance (Buytaert et al., 2016; Shepard et al. 2002). Promoting environmental justice is one of the CBP's core principles, and this value could be further explored through the creation of opportunities that enable Chesapeake Bay watershed citizens to contribute to science and collaboratively develop management decisions.

Overview of research studies

This dissertation is centered on three novel research studies. Each of the studies investigates complementary aspects of stakeholder engagement in knowledge co-production, in the context of Chesapeake Bay research and management. A common thread that connects the three studies is an exploration of Chesapeake Bay environmental stakeholders' perceptions and experiences with citizen science within the watershed.

Used effectively, citizen science is a tool that can help increase stakeholder engagement in Chesapeake Bay management while also generating scientific knowledge to inform environmental management decisions that are more adaptive, holistic, collaborative, and innovative. A primary goal of this dissertation is to provide evidence-based recommendations that help Chesapeake Bay environmental stakeholders more effectively leverage citizen science to accomplish diverse research and management goals. This dissertation investigates various barriers that currently limit the use and potential impact of citizen science in Chesapeake Bay, and provides new information and approaches that enable more collaborative, productive, and empowering partnerships between stakeholders within the environmental monitoring and management community. While this body of work is directly responsive to the CBP's call for more social science research that informs the design of effective public engagement and outreach opportunities (CBP 2020), it is also broadly applicable to other socio-ecological systems.

The three studies are as follows:

- Part I: Stakeholder perspectives on the roles of science and citizen science in Chesapeake Bay environmental management
- Part II: Identifying and harmonizing the priorities of stakeholders in the Chesapeake Bay environmental monitoring community
- Part III: Co-creating and evaluating a citizen science program for monitoring submerged aquatic vegetation in Chesapeake Bay

Part I investigates stakeholders' perceptions of how power is distributed across the socio-political landscape of Chesapeake Bay environmental science and management. This study employs a watershed-wide survey of over 350 Chesapeake Bay environmental stakeholders to gain a deeper understanding of stakeholders' level of familiarity and perceptions of Chesapeake Bay science, management, and citizen science as individual entities. Next, the study reveals Chesapeake Bay environmental stakeholders' perspectives on the roles of both science and citizen science in the management of the Bay. The research also explores stakeholders' perspectives on the level of influence that various stakeholder groups currently and ideally should have in Bay management. Additionally, this research provides specific recommendations for how the broader Chesapeake Bay environmental community can empower non-scientists to contribute to scientific knowledge production and environmental discourse. Furthermore, this study provides evidence in support of continued expanded stakeholder engagement in Chesapeake environmental research and decision making.

Part II has a narrower focus of highlighting some of the key priorities of stakeholders within a network of volunteer monitoring organizations and data users called the Chesapeake Monitoring Cooperative (CMC). This study surveyed CMC-affiliated scientists, managers, volunteers, coordinators, and service providers to identify key similarities and differences in how stakeholder groups prioritize various monitoring goals. Furthermore, this research uses a quantitative anthropological approach called cultural consensus analysis to explore the extent to which cultural knowledge about environmental monitoring is shared amongst members of this environmental monitoring community. The research also investigates stakeholders' perspectives of the CMC's objectives, as an organization, and synthesizes stakeholders' feedback on the value of various CMC resources. Finally, this study provides recommendations that can improve volunteer monitoring efforts in Chesapeake Bay and inform the design and coordination of other large-scale environmental monitoring programs that integrate volunteer-collected and traditional datasets.

Part III has the most targeted scope of the three studies, as it shines a spotlight on a single volunteer monitoring program within the Chesapeake Bay region. This study describes the process of collaboratively developing a volunteer monitoring program with the input of various stakeholders within the Chesapeake Bay environmental monitoring community. Additionally, the study synthesizes stakeholders' feedback on their experience engaging in the program development process, as well their perceptions of the final program. This research employs the most personal qualitative research methodologies of the three studies, including participant observation and interviews. The results reveal that engaging stakeholders in establishing broader program goals and methodologies can lead to positive outcomes for the stakeholders and citizen science efforts. This study concludes with several recommendations that inform the creation and expansion of other collaboratively-developed participatory research programs, especially those that simultaneously prioritize engagement, education, and the collection of high-quality data.

This dissertation is interdisciplinary and integrative, and draws from existing peer-reviewed literature in several disciplines, such as estuarine science, environmental anthropology, science communication, citizen science, and transdisciplinary science. Data for this research was collected directly from a wide diversity of stakeholders in Chesapeake Bay, including academic scientists, citizen scientists, volunteer monitoring coordinators, environmental managers, and people involved in other professions that impact the environment. Numerous qualitative research methodologies are used, such as semi-structured interviews and participant observation, as well as several more quantitative approaches, such as online surveys and cultural consensus analysis. This research involving human subjects was approved by the University of Maryland Institutional Review Board [1436359-1].

Part I: Stakeholder perspectives on the roles of science and citizen science in Chesapeake Bay environmental management

Suzanne E. Webster & William C. Dennison

Abstract

The Chesapeake Bay restoration effort has been active for nearly 40 years, and is centered around a robust monitoring program conducted by agency scientists. More recently, an effort to integrate volunteer monitoring into the formal research program has been established. We sought to develop a better understanding of Chesapeake Bay environmental stakeholders' perspectives on stakeholder engagement within the context of Bay research and management. Specifically, this study explores stakeholders' perspectives on the roles of both science and citizen science in Bay management, as well as thoughts on the level of influence that various stakeholder groups currently and ideally should have in Bay decision-making processes. This study employs a watershed-wide survey of over 350 Chesapeake environmental stakeholders, including managers, scientists, educators, waterkeepers, and citizen scientists, among others. Overall, survey respondents felt that they should have more influence in environmental management decisions, but the degree of this desired influence varied among stakeholder groups. Stakeholders broadly agreed that professional scientists should influence public policy, and that citizen scientists should influence policy to a lesser degree. It was, however, recognized that citizen scientists can play an important role in protecting Chesapeake Bay, in that they can serve as advocates for change, help fill data gaps, and engage more community

members. This study provides evidence in support of expanded stakeholder engagement in Chesapeake environmental research and decision making. Based on these findings, we encourage more participatory research efforts and recommend that stakeholders work together to overcome the challenges of integrating citizen science data.

Introduction

Chesapeake Bay science and management are coupled tightly and have evolved substantially over the past hundred years. The first phase of Estuarine Science was initiated in 1925 with the establishment of the Chesapeake Biological Laboratory in Solomons, Maryland. The basic physics, chemistry, geology and biology of estuaries was investigated with interdisciplinary research during this Estuarine Science phase. The next phase was initiated in 1972 after Tropical Storm Agnes caused the highest recorded freshwater flows into Chesapeake Bay (Boesch & Goldman, 2009; Davis, 1977). The realization that water quality degradation was affecting the Bay was brought into clear focus, stimulating the Eutrophication Science phase (Orth & Moore, 1983). The Environmental Protection Agency, empowered by the passage of the Clean Water Act in 1972, funded a large multi-disciplinary study to discern the causes of Chesapeake Bay degradation (Costanza & Greer, 1995).

In 1983, a federal partnership program known as the Chesapeake Bay Program was created, which led to the Integrated Monitoring and Modelling Science phase (Hood et al., 2021). A large physical model of Chesapeake Bay was built to investigate circulation patterns, along with a computational model of the watershed to better understand nutrient pollution sources (Trombley, 2017). A coordinated, long-term monitoring program was established, and tracking Bay water quality and other features became possible (Hood et al., 2021). In 2010, the Total Maximum Daily Load (TMDL), also known as the "nutrient diet," was established. The TMDL provided a regulatory framework to replace the voluntary approach that had not been achieving the desired results (Shenk & Linker, 2013), and each jurisdiction enacted Water Quality Improvement Plans to outline their restoration strategy for meeting the newly-mandated nutrient reductions. The Citizen Science phase was initiated with the realization that the monitoring results were not sufficient in spatial and temporal scales to detect the efficacy of management actions taken in response to the TMDL. This stimulated the establishment of the Chesapeake Monitoring Cooperative in 2015 (Webster et al., 2021b).

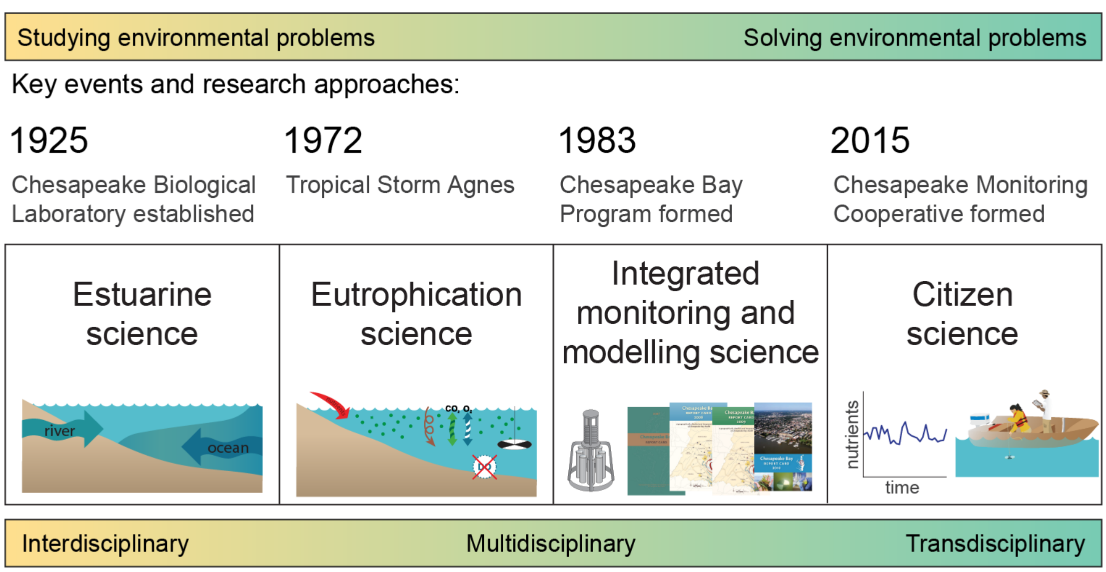


Figure 7. The evolution of Chesapeake Bay science, broken down into four phases beginning in 1925. These phases represent a shift from studying to solving environmental problems as well as a shift from interdisciplinary science to multidisciplinary science and transdisciplinary science.

There are several features of the Chesapeake region that promote an engaged citizenry (Tillman, 2009). The geography of the Chesapeake watershed, with a myriad of dendritic streams and rivers, allows ready access to a waterway that is ultimately connected to the Bay (Oxnam & Williams, 2001). In addition, the Bay and its tributaries have over 12,900 km (8,000 mi) of shoreline (Boesch & Goldman, 2009). These features of the watershed and shoreline means that people in the Chesapeake region are geographically connected to the Bay. Another feature of the Chesapeake watershed that promotes citizens' connection with the landscape is the high biological productivity of the watershed and the Bay. The watershed includes highly fertile soils that support productive agriculture, and the Bay is highly productive in terms of fish and shellfish production (Houde, 2011; Roman et al., 2005). This productivity has supported people in the Chesapeake region for thousands of years.

The Chesapeake watershed includes the Appalachian mountains, a ridge and valley system, a piedmont region of soils eroded from the mountains, and a coastal plain of low lying soils adjacent to Chesapeake Bay (Gillelan et al., 1983). This diversity of landforms is characteristic of a watershed that spans different physiographic regimes. These different landforms have promoted a diversity of traditional cultural groups in the region, which include people living in the

Appalachian Mountains, farmers in the valleys and coastal plain, fishers along the Chesapeake shoreline and on islands in the Bay, and traders who use the waterways for commerce. These cultural groups have remained relatively intact since European settlement and the resulting cultural diversity gives rise to different motivations and capabilities of citizen scientists in the region.

The establishment of the Chesapeake Bay Program in 1983 gave rise to an integrated monitoring program in the Bay. The original watershed monitoring program focused on a River Input Monitoring (RIM) network that concentrated sampling at the mouths of the nine major Chesapeake tributaries, but this monitoring program was eventually expanded into the watershed to include over 100 stations (Ator et al., 2020; Moyer & Langland, 2020). But in spite of this extensive and sustained monitoring effort on the Bay and in the watershed, the spatial resolution and sampling frequency of the monitoring program can only detect long-term changes over large areas. This is one of the key factors why the Chesapeake Bay Program has embraced the establishment of citizen science monitoring.

Citizen science refers to research collaborations between scientists and volunteers, who work together to collect scientific data and answer real-world, locally-relevant questions (Aceves-Bueno et al., 2015; Dickinson et al., 2012). Also known as volunteer monitoring, this movement to include volunteers in environmental research has expanded around the world over the last three decades (Conrad & Hilchey, 2011; Whitelaw et al., 2003). In Chesapeake Bay, scientists and environmental managers have started to explore citizen science as an option for augmenting the temporal and spatial sampling intensity of the Chesapeake Bay

Program's formally-established monitoring program. More localized sampling intensity would provide more responsive feedback on various management actions (Zhang et al., 2018). Another factor contributing to the rise of citizen science in the Chesapeake region is the growing awareness of the social and economic inequities amongst the watershed residents. In order to understand and address the environmental justice issues associated with disadvantaged communities, citizen science programs can help detect inequities and empower citizens to act on this information.

Chesapeake watershed residents have participated in volunteer environmental monitoring efforts for decades (Rubin et al., 2017). Various volunteer monitoring programs exist across the watershed, and have traditionally operated independently of one another, each with its own project scope, research goals, and scientific processes. In the Chesapeake region, volunteer-collected data has historically been underused in management and policy-making contexts due to challenges such as low data comparability between monitoring programs, inadequate quality assurance, and potentially a misunderstanding or bias against citizen science on the part of Chesapeake scientists, managers, and decision makers. In 2015, the Chesapeake Bay Program established a new coordinated effort called the Chesapeake Monitoring Cooperative in order to address some of these challenges (CBP, 2018) and make citizen science data more broadly usable. Despite this progress, there are other challenges that need to be addressed in order for citizen science to reach its full potential in the Chesapeake Bay region.

In the present study, we explored Chesapeake environmental stakeholders' perceptions of how power currently is (and ideally ought to be) distributed across the socio-political landscape of Chesapeake Bay environmental science and management. We surveyed members of the Chesapeake environmental community to investigate stakeholders' level of familiarity and overall perspectives of the entities of science, management, and citizen science in the Chesapeake region. One objective of this analysis was to gain insight into stakeholders' characterization and delineation of these overlapping concepts. We also asked Chesapeake stakeholders to share their perceptions on the role of science and stakeholder engagement in the management of the Bay. This analysis provided deeper understanding of stakeholders' valuation of science and scientists, as well as their feelings of empowerment or disempowerment in science and management discourse. Finally, we synthesized stakeholders' perspectives of the value of citizen science and the role of citizen scientists in both environmental science and management. Our results provided evidence that encourages continued and expanded stakeholder engagement in Chesapeake environmental research and decision making. We also laid out several recommendations for how the broader Chesapeake environmental community can leverage participatory research to empower non-scientists to contribute to future scientific knowledge production and Chesapeake environmental discourse.

Methods

We developed a survey to explore environmental stakeholders' perspectives on environmental science, management, and citizen science within the Chesapeake Bay watershed. We provided definitions of key terms used throughout the survey (Figure 8). The term 'environmental stakeholder' was used to refer to people who 1) have an interest in or a concern for the environment, 2) are impacted by decisions or changes that affect the environment, and/or 3) are influential in making such decisions or changes. Each respondent was asked to consider their own role as an environmental stakeholder, and self-categorize themselves as a member of one of nine listed stakeholder groups. These groups included environmental managers, consultants, and educators, scientists within or outside of academia, program managers, and policy makers. Waterkeepers and volunteer coordinators, and volunteer monitors and citizen scientists were combined into two additional stakeholder groups, respectively. Respondents were also given the option to indicate that they did not identify as a member of any of the listed stakeholder groups and provide a description of their role. In these cases, respondents were assigned to a listed stakeholder group if their description clearly fit into one of the roles. For example, respondents who described themselves as a "scientist within the federal government" and a "private sector social scientist" were both labelled as "Scientists outside of academia." In cases where stakeholders' descriptions did not clearly match with one of the listed roles, such as "Military officer" or "Land use attorney," the responses were labelled as "Other."

Environmental stakeholder
Someone who 1) has an interest in or a concern for the environment, 2) is impacted by decisions or changes that affect the environment, and/or 3) is influential in making such decisions or changes

Environmental science
The study of Earth's environments and how humans interact with the environment

Environmental management
Making decisions and taking actions that influence how environmental resources are used, protected, modified, and valued

Citizen science
Research partnerships between scientists and volunteers that provide opportunities for community members to contribute to scientific research and access scientific information

Figure 8. Definitions for key terms that were used throughout the survey. Respondents were given these definitions before they were asked to provide their perspectives.

Respondents were asked a series of Likert-scale (multiple choice) and sliding scale questions, and were permitted to skip questions throughout the survey if they felt uncomfortable answering a particular survey item or were unable to provide answers for any reason. To start, stakeholders indicated their level of familiarity with various concepts and processes related to Bay research and management. A Likert scale ranging from 1 to 5 was provided for these questions (1=Not at all familiar, 2=Slightly familiar, 3=Moderately familiar, 4=Very familiar, 5=Extremely familiar). Respondents were also asked questions about the relationships between Chesapeake Bay science, management, and citizen science, as well as the roles of various stakeholder groups in these contexts. A Likert scale ranging from 1 to 4 was provided for these questions (1=Not at all, 2=Very little, 3=Somewhat, 4=To a great extent). For these questions, stakeholders were also given the option to select “I do not know” from the list of response choices. This option was provided in order to minimize low quality data resulting from forced responses. Additionally, the survey requested that stakeholders share their perspectives on how much influence various stakeholder groups– including their own– currently and ideally should have on Chesapeake science and management. A sliding scale ranging from 0 to 100 was provided for these questions (0=No influence, 100=Very high influence). We indicated to respondents that for the purpose of this study, signs of having influence, or power, include having control over environmentally-focused policy making, research priorities, funding decisions, or conversations.

To analyze the quantitative data, we first removed all returned surveys that were less than 50% complete. A mean response and corresponding standard deviation was then calculated for each Likert scale and sliding scale question, using all available responses. In cases when respondents selected “I do not know,” their answers were excluded from aggregate calculations of the mean response and treated as missing data for statistical analyses that required paired responses. Finally, we conducted two-tailed paired t-tests to determine whether or not the difference between the mean responses of two related questions was statistically significant. For example, related questions were those that compared stakeholders’ current and ideal levels of influence or the ideal level of influence for two distinct stakeholder groups. The sample sizes for all t-tests were equal to the number of respondents who answered both of the questions under comparison for each individual test. For the few t-tests that were missing more than 5% of the total possible paired responses, data were determined to be randomly missing across stakeholder groups.

The survey also contained several free response questions. Respondents were asked to share three words that came to mind when they thought about Chesapeake Bay research, management, and citizen science, sequentially. We compiled all survey responses into a single list for each of the three key terms. We then standardized similar words that were used by multiple respondents to create clean lists of the most-shared words. For example, all usages of the words ‘volunteers’ and ‘volunteering’ were changed to match the frequently-used root word, ‘volunteer.’ We did not alter conceptually-similar terms such as ‘volunteer’ and ‘non-professionals,” nor did we combine terms with overlapping words, such as ‘water’ and ‘water quality.’ The website WordItOut was used to create a word cloud for each key term, using the 20 most-used words from each of the three lists of survey responses. Finally, respondents were encouraged to provide additional comments at the end of each grouping of Likert-scale survey items. All written responses were analyzed using qualitative data analysis techniques, which involved sorting free response text from each question into emergent themes and then coding the text fragments to identify ideas that were shared by many respondents and/or of particular interest to this study.

The web-administered survey was distributed to approximately 800 individuals via email, from July 31 to September 9, 2020. To develop the list of potential respondents, we began with our list of nine stakeholder roles. For each stakeholder role, we created a list of organizations across the watershed where individuals within that particular stakeholder group might be employed or otherwise affiliated. For example, to target volunteer coordinators, we compiled a list of volunteer monitoring organizations, waterkeeper associations, and environmental outreach programs that varied in scale and geographic location. To target policy makers, we compiled a list of city, county, and state-level political organizations, as well as various multi-jurisdictional legislative groups, such as the Chesapeake Bay Commission. We then contacted a sample of individuals who were listed on each organizations' staff webpages, using publicly-available email addresses. We supplemented these initial lists with names and email addresses sourced from contact sheets that are provided to attendees at regional conferences, particularly those that draw diverse stakeholder participation, such as the Chesapeake Watershed Forum. Furthermore, we also contacted individuals listed as board members of regional environmental organizations, members of various environmentally-focused advisory committees, and a selection of other organizations. Throughout the whole process, our aim was to be as inclusive as possible and ultimately contact a representative sample of all Chesapeake environmental stakeholders.

Results

Demographics

We received 372 qualifying questionnaire responses from Chesapeake environmental stakeholders. We estimate that our overall questionnaire response rate was approximately 46.5%, with 96% of returned questionnaires completed in full. Respondents represented at least 190 organizations from across the watershed (Appendix 1), ranging in scale from regional environmental committees to state-level governments to hyper-local community organizations. Respondents held a wide diversity of environmental stakeholder roles, including scientists, policy makers, program managers, volunteer monitors, waterkeepers, consultants, educators, managers, and other roles that were not pre-defined on our questionnaire, such as funders, non-profit directors, policy advisors, and environmental lawyers (Table 1). Collectively, respondents indicated that they spent the majority of their time on activities related to program management, outreach, education, and scientific research. Finally, the environmental stakeholders also had a large array of career experience in their stakeholder roles, ranging from early-career professionals with only a few months of experience in their current positions, to individuals who have worked in the same role for over 45 years.

Table 1. Respondent demographics by their self-described stakeholder roles and the number of years in their current role.

Respondent characteristic	**Number of responses**	**Percentage of study respondents**
Stakeholder role		
Program manager	89	23.9
Environmental manager	44	11.8
Scientist outside of academia	40	10.8
Scientist within academia	39	10.5
Environmental educator	35	9.4
Volunteer monitor or citizen scientist	25	6.7
Policy maker	25	6.7
Environmental consultant	20	5.4
Waterkeeper or volunteer coordinator	16	4.3
Other	39	10.5
Years in current stakeholder role		
< 2	44	11.8
2 to 5	130	34.9
6 to 10	71	19.1
11 to 15	44	11.8
16 to 20	28	7.5
21 to 30	27	7.3

31 to 40	13	3.5
> 40	7	1.9
No response	8	2.2
Total	372	100.0

Familiarity

We asked respondents to describe Chesapeake Bay science, management, and citizen science, and then reflect on their own level of familiarity with each of the three concepts. Participants' responses provided support for our hypothesis that Chesapeake environmental stakeholders share a rather sophisticated understanding of Bay science and management (Figure 9). As an aggregate group, stakeholders claimed a moderately high level of familiarity with the processes involved in researching the Bay, emphasizing Bay science's focus on water quality and monitoring for the purpose of research, as well as the importance of ecology, models, and nutrients. Stakeholders claimed a slightly higher level of familiarity with the processes involved in managing the Bay and the same level of familiarity with the role that environmental science plays in Chesapeake Bay management. Their descriptions of Bay management drew attention to the emphasis that management places on protection, regulation, and conservation, and stakeholders once again mentioned the importance of water quality, but this time for the purpose of restoration and policy.

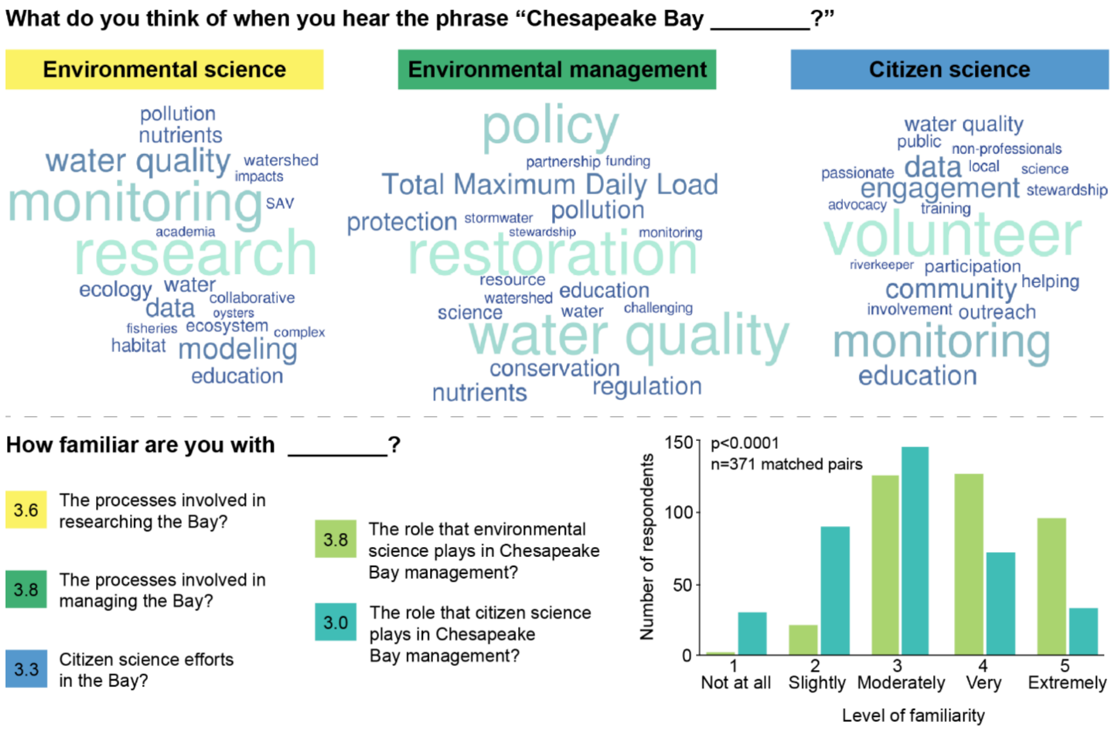


Figure 9. Word clouds provide a visual representation of stakeholders' conceptualization of Chesapeake environmental science, management, and citizen science. Respondents' mean self-reported level of familiarity with various processes associated with researching and managing the Bay is specified on the figure (n=371). Standard deviations ranged from 0.9 to 1.1. Most stakeholders reported that they were either 'moderately' or 'very' familiar with the role that traditional science plays in management, but significantly less familiar with the role of citizen science (t-test; $p< 0.0001$).

When describing citizen science, stakeholders again emphasized the importance of monitoring, but this time with a distinct focus on community, engagement, and education. Stakeholders also called attention to the fact that citizen science involves volunteers, differentiating it from both science and management. Interestingly, despite the fact that 66% of respondents indicated that they had participated in a Chesapeake Bay citizen science effort within the last five years, environmental stakeholders had somewhat lower levels of familiarity with citizen science efforts in the Bay. Compared to their level of familiarity with the role of traditional science in environmental management, stakeholders were significantly less familiar with the role that citizen science plays in managing Chesapeake Bay ($p<0.0001$).

Perspectives on the role of science and scientists in Bay management

We found that stakeholders were generally enthusiastic about the utility and power of Chesapeake Bay science in the context of environmental management. In fact, an overwhelming 91% of respondents said that public policies should be based on the best available science "to a great extent." Although stakeholders largely agreed that scientific research should play some role in environmental policy and management, stakeholders shared varying perspectives regarding the degree to which science (and scientists) should ultimately be able to influence policy decisions. Many respondents argued that science should be "front and center" and dictate management decisions, and likewise specified that scientists should have the "primary voice" in policy development, with the power to vet all management decisions before their implementation. On the opposite side of the spectrum, other respondents believed that "scientists should focus on their research" rather than become directly involved in management processes, and shared a number of concerns over emphasizing science when making management decisions. For example, some respondents argued that the utility, novelty, and even the credibility of scientific research is limited because the scientific community follows funding priorities that are influenced by politics.

Respondents professed that this dependence on funding can lead to an "outsized influence" of certain types of research, such as computer modelling, and can cast doubt upon scientists' ability to be "objective" in their research and resulting management recommendations.

The majority of respondents, however, fell in the middle of these two extremes, saying that "science should guide public policy, not dictate it" and that scientists, like other stakeholder groups, should have a specific role and accompanying responsibilities associated with Bay management. Many respondents specified that scientists should serve as subject matter experts for politicians. One respondent explained this division of labor, saying "Scientists are there to tell us the closest thing there is to absolute truth, and policymakers are there to decide what to do with that information." Other stakeholders believed that scientists should not be restricted to the role of information providers and "nonpartisan observers of the decline of the Chesapeake Bay." Instead, some stakeholders argued that scientists should be encouraged to "speak up" and advocate for Bay protection, perhaps by serving as members of a government-mandated scientific committee that is consulted about policy involving the Bay. Finally, one of the most often-shared perspectives about the role of scientists in management was that "Scientists should have as much influence as anyone else at the table;" therefore, while science should inform policy, "Final decisions should be part of the democratic representative system."

Many respondents noted that scientists have a key responsibility to effectively communicate their findings to managers, policy makers, and the public. Most stakeholders agreed that management decisions should take science into account to some degree; therefore, it follows that scientists should keep policy makers and managers informed on the latest Bay science in order to enable timely and evidence-based management decisions. Through communicating about their research, scientists play a crucial role in closing the gap between research and management by minimizing the "disconnect between current scientific understanding and how fast that science is incorporated into management and policy decisions." Furthermore, respondents indicated that scientists should also share their science with broader audiences, specifically Bay communities affected by environmental management decisions. Respondents suggested that in order to do this effectively, scientists must heed the pithy advice of marine conservationist Jacques Cousteau and remember that "People protect what they love". Therefore, scientists should work to "shape stories that people can connect with" and communicate the relevance and importance of their work in a way that respects community values and motivates people to do their part in supporting environmental decisions that help the Bay.

Perspectives on stakeholders participation in Bay management

Respondents expressed strong support in favor of increasing the degree to which stakeholders and stakeholder perspectives are included in Chesapeake Bay management decisions. Most stakeholders shared the belief that Bay management currently somewhat takes into account a wide diversity of stakeholders' concerns; however, as an aggregate group, respondents said that stakeholder perspectives should ideally be considered to a significantly greater extent than they are now ($p<0.0001$) (Figure 10). Indeed, in their written responses, many individuals expressed feelings of frustration or resignation at the current state of stakeholder involvement in Bay management. One respondent wrote, “Stakeholders are often asked to participate in conversations, some of which involve a lot of time and effort, but my experience has been that most of the suggestions, ideas, and information presented during those dialogues doesn't find its way into policy”. Respondents also noted that incorporating a greater diversity of people into the environmental management community “would improve management discussions and plans as more perspectives and lived experiences would be brought to the table” and result in environmental policies that have “equitable and truly resilient outcomes,” as well as increased public acceptance.

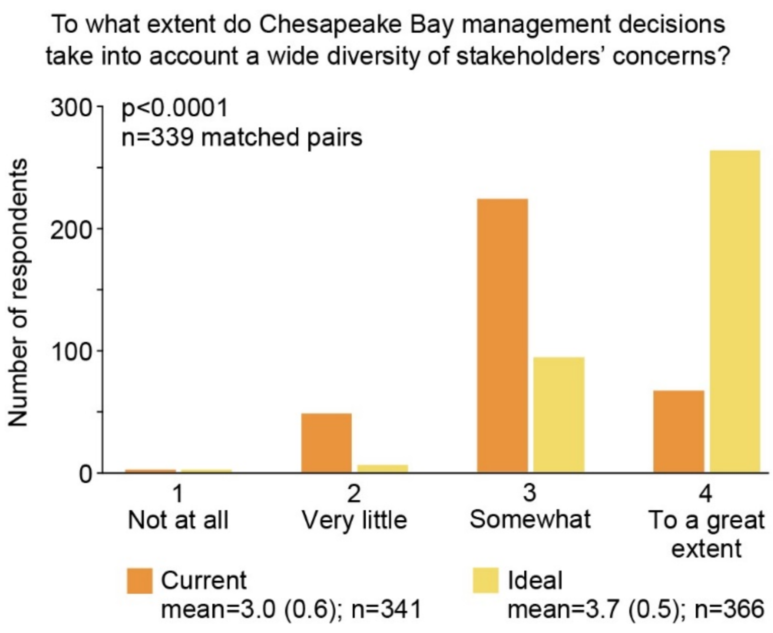


Figure 10. Respondents indicated that they would like to see diverse stakeholder concerns be taken into account to a significantly greater extent than they are currently, when making management decisions (t-test; $p<0.0001$). The mean responses for each question, along with corresponding standard deviation in parentheses, are reported in the figure legend.

Respondents were also asked to reflect on their own involvement in Bay management. Specifically, respondents were asked to quantify the level of influence that they, as well as others with the same stakeholder role, currently have in Bay management. They were also asked to identify how much influence they should have, ideally. Across the board, within every stakeholder group, respondents perceived that they should be significantly more influential in Bay management, by an average of 19.2 points on a scale of 100 (p<0.0001) (Figure 11).

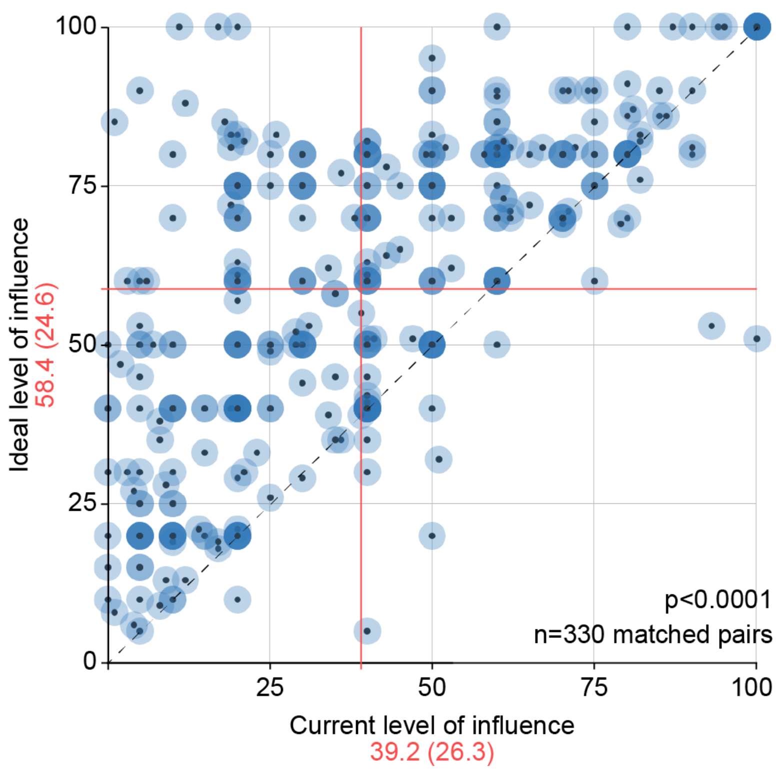


Figure 11. Respondents' current and ideal levels of influence in Chesapeake Bay management. Stakeholders believed that they, along with others who share their stakeholder role, should have approximately 49.0% more influence than they do currently (t-test; p<0.0001). Darker-colored dots

indicate multiple overlapping responses. The mean response for each variable is reported in red text, along with the corresponding standard deviation in parentheses.

Although these feelings of disempowerment were evident across all respondents as an aggregate group, there were some compelling differences between stakeholder groups (Table 2). For example, we found that scientists within academia and waterkeepers or volunteer coordinators experienced the highest degrees of disempowerment, meaning that these stakeholders perceived the greatest mean difference between their ideal and current levels of influence ($p<0.0001$ and $p=0.0027$, respectively). Environmental managers and policy makers perceived the smallest mean difference between their ideal and current levels of influence, and also reported the highest levels of current influence out of all the stakeholder groups. This suggests that while these stakeholders believe that they should have more influence than they do, they feel the most empowered of all the listed stakeholder groups. Finally, through their written responses, many respondents also drew attention to other stakeholder groups that they believed have a lot of potential to contribute towards environmental management but are currently unempowered or undervalued, including environmental educators and members of the business community.

Table 2. Stakeholder reflections on their own level of influence in environmental management, broken out by stakeholder role. Using a scale of 0 to 100, stakeholders were asked to indicate the degree of influence that they, along with others with their stakeholder role, currently have and should ideally have in Chesapeake Bay management. Mean responses are reported, along with corresponding

standard deviations in parentheses. The variable n represents the number of responses included in the paired t-test.

Stakeholder role	**Current influence**	**Ideal influence**	**Difference between ideal and current influence**	**95% Confidence limit for the difference**	**T-test p-value**
Scientist within academia (n=35)	34.4 (23.7)	60.7 (23.4)	26.4 (17.9)	20.2 - 32.5	<0.0001
Waterkeeper or volunteer coordinator (n=13)	33.9 (24.8)	57.5 (28.4)	23.6 (22.6)	9.9 - 37.3	0.0027
Environmental consultant (n=20)	38.4 (24.1)	61.7 (22.9)	23.3 (23.5)	12.3 - 34.3	0.0003
Program manager (n=78)	42.2 (26.2)	62.9 (22.3)	20.6 (20.0)	16.1 - 25.1	<0.0001
Scientist outside of academia (n=35)	42.0 (27.2)	60.3 (21.6)	18.3 (25.9)	9.4 - 27.2	0.0002
Environmental educator (n=29)	34.5 (25.1)	51.6 (25.3)	17.1 (18.2)	10.2 - 24.1	<0.0001
Volunteer monitor or citizen scientist (n=22)	20.4 (21.0)	35.9 (23.5)	15.5 (16.2)	8.3 - 22.7	0.0002
Policy maker (n=24)	47.0 (31.8)	61.8 (28.1)	14.8 (22.7)	5.2 - 24.4	0.0040
Environmental manager (n=41)	49.8 (25.5)	61.5 (23.7)	11.7 (16.9)	6.4 - 17.0	<0.0001
Other (n=34)	34.5 (23.8)	55.6 (25.9)	22.0 (21.3)	14.5 - 29.5	<0.0001
All respondents (n=330)	39.2 (26.3)	58.4 (24.6)	19.2 (20.6)	17.0 - 21.5	<0.0001

Interestingly, many respondents suggested that the integration of people and ideas into environmental management should be facilitated, or even spearheaded by scientists, perhaps partly due to their above-average current levels of influence. Respondents indicated that they would like to see environmental scientists directly reaching out to elevate and empower other stakeholder groups, especially local communities. Specifically, stakeholders suggested that scientists should take the initiative to “coordinate with a broad spectrum of stakeholders to help identify knowledge gaps and the most important questions," and be actively engaged in understanding others' perspectives. Repeatedly, respondents stated that effective environmental management should pair environmental science alongside local and cultural knowledge, community-based participatory research, and approaches from other disciplines, such as socio-economics and behavioral science.

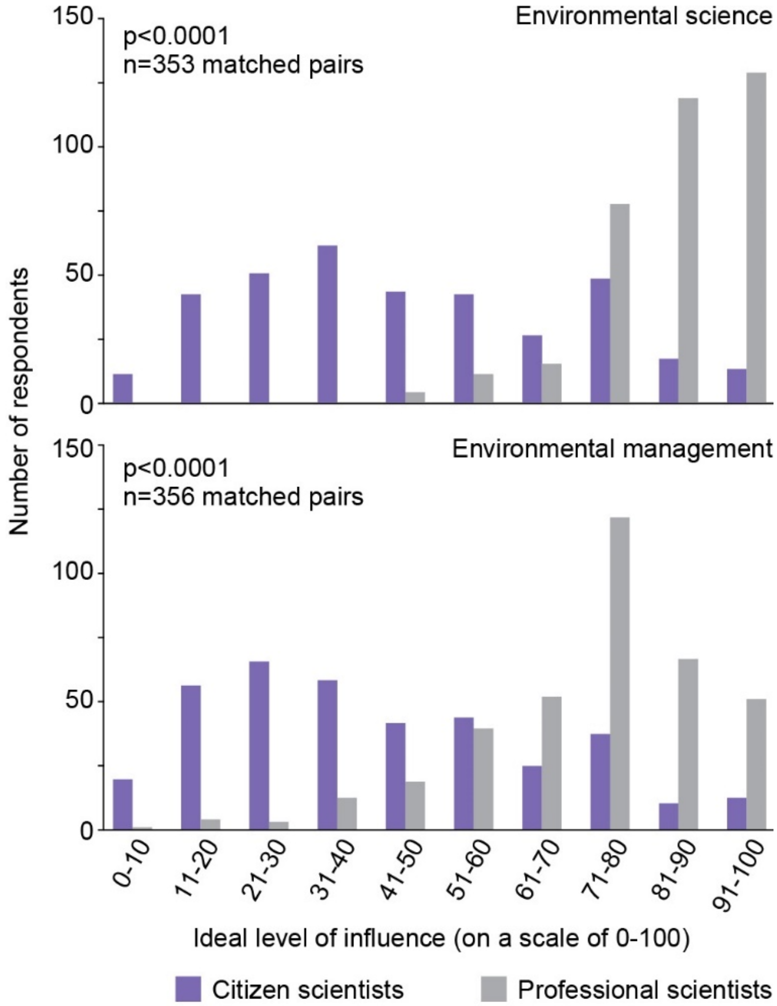
Perspectives on citizen science

Following up on our questions about the influence of science, scientists, and other environmental stakeholders in Bay management, we were interested in understanding stakeholders' perspectives on Chesapeake Bay citizen science, as a potential avenue for interested members of the public to contribute to the science and ultimately the management of the Bay. As an aggregate, respondents said that citizen scientists and volunteer monitors 'somewhat' increase our scientific understanding of the Bay, with an average score of 3.1 points on a scale of 4 (n=365). Stakeholders' responses to various survey questions revealed that stakeholders as an aggregate believed that citizen scientists should have some degree of influence in both Bay science and management.

In both their written and multiple-choice responses, stakeholders as an aggregate group revealed mixed feelings and diverse perspectives about the role of volunteers in scientific research. For example, stakeholders had differences in opinion about the overall utility of citizen science with respect to Chesapeake Bay environmental science. Some stakeholders suggested that while citizen science augments other scientific research efforts in the watershed, it is currently underutilized, in part due to the fact that other environmental stakeholders – especially professional scientists – lack trust for volunteers or have personal biases against their contributions. Other stakeholders' responses confirmed these suspicions. These stakeholders argued that citizen science should only be used in situations where professionals are unable to conduct the study themselves, and that citizen scientists' role should be strictly limited to data collection for the purpose of supporting professional scientists' research. Some stakeholders held a more absolute view, arguing that science should be strictly reserved for professionals because they have "spent years in school to adequately learn how to sample," and therefore have the authority over that line of work. One responder hinted at this territoriality and competitive mentality, commenting that "there is nothing more frustrating than investing time, research, and money into a profession and then having volunteers squeeze you out because they do what you could do for free".

Furthermore, some respondents expressed concern about the quality of volunteer-collected data, saying that volunteers' contributions "should not be valued as much as research conducted by scientists who stick to protocols." Other stakeholders opposed this view and argued that "Science is science" and therefore, assuming volunteers are trained, "there is no reason their data is different from those collected by someone with a formal science education." Finally, stakeholders also shared different perspectives about the impact that citizen science has had, or could have, on Bay science. For example, some respondents were concerned that volunteers might "use science as a political weapon" and generate flawed data to support their own agendas, which “could potentially undermine the objectivity and legitimacy” of not only their research, but the institution of science. On the opposite end of the spectrum, other stakeholders perceived that citizen scientists are undervalued and have already increased the capacity of the scientific community by expanding data collection efforts across the watershed. These respondents recognized citizen scientists’ contributions, saying that “Most of the current scientific research on the Bay would not have been possible without countless hours of volunteer effort.”

Perhaps unsurprisingly, stakeholders as an aggregate believed that citizen scientists should have a significantly lower level of influence in environmental science than their professional counterparts, with a mean difference of 38.1 out of 100 ($p<0.0001$) (Figure 12). Respondents’ assessments of how much influence volunteers should ideally have in Chesapeake environmental science echoed the wide diversity of perspectives that were shared in the free response questions. While the majority of stakeholders agreed that professional scientists should have high levels of influence in environmental science, stakeholders expressed a notably larger range of perspectives about the ideal role of citizen science, ranging all the way from 0 to 100, with a perfectly centralized median of 50.



Science	49.2 (23.3); n=355	87.3 (11.4); n=366
Management	44.5 (23.5); n=357	74.4 (16.9); n=370

mean (std dev); sample size

Figure 12. The level of influence that citizen scientists and professional scientists should have in Chesapeake Bay science (top) and management (bottom), according to the broader stakeholder community. Mean responses are reported in the legend, along with corresponding standard deviations in parentheses.

On average, stakeholders assessed that citizen scientists should ideally have even less influence in environmental management than they should have in science (p<0.0001, n=353), though responses again ranged across the board (Figure 12). Respondents also agreed that volunteers should have a comparatively lower level of influence in management than professional scientists (p<0.0001), with a mean difference of 29.9 out of 100 between the two stakeholder groups. Regardless of stakeholders' perspectives on the relative influence of volunteer and professional scientists in environmental management, respondents as an aggregate group indicated that citizen scientists should ideally be able to influence management decisions to a greater extent than they are able to currently, with a mean difference of 0.8 on a scale of 4 (p<0.0001, n=313).

When asked to indicate to what extent various stakeholder groups should be able to influence Chesapeake environmental management decisions and public policy, respondents indicated that citizen scientists should have the least amount of influence (Figure 13). Perhaps unsurprisingly, stakeholders as an aggregate group again indicated that citizen scientists should have significantly less influence than professional scientists (p<0.0001), as well as less influence than members of respondents' own stakeholder groups (p<0.0001). Stakeholders also indicated that citizen scientists should be able to influence public policy and management decisions to a lesser extent than individuals who are not formally-trained environmental professionals (p<0.0001, n=351). It is especially noteworthy that the degree of influence deemed as appropriate for an unspecified, untrained stakeholder was significantly higher than the influence granted to citizen scientists, who are very often highly trained to participate in specific research activities. This particular discrepancy suggests a bias against citizen science, generally, or the volunteers who participate in these efforts.

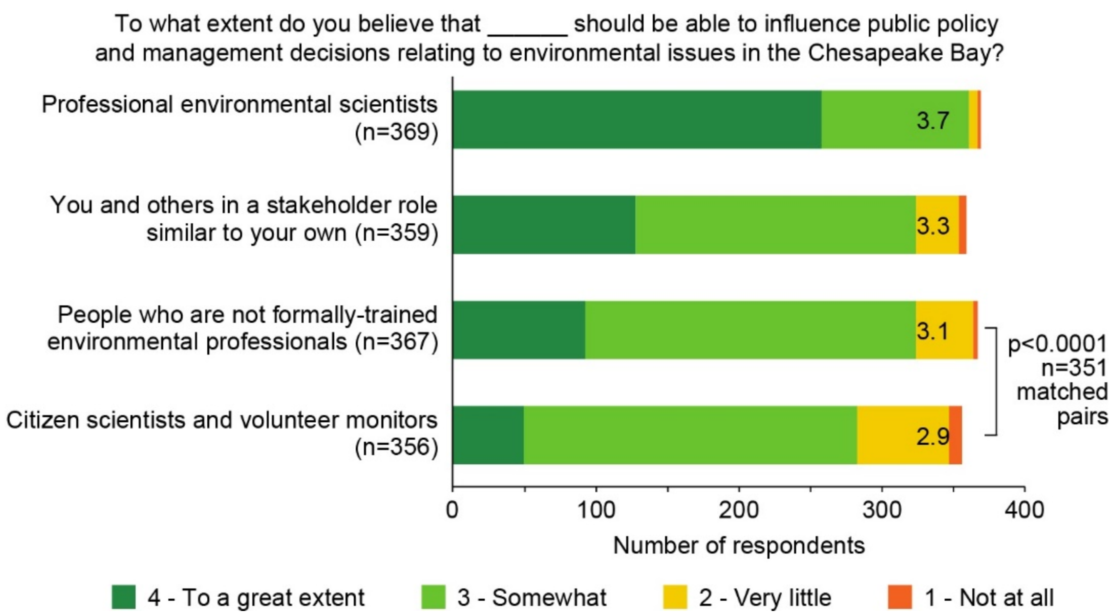


Figure 13. The relative extent to which various stakeholder groups should be able to influence environmental policy and management decisions. Mean responses are reported on the graph, and corresponding standard deviations ranged from 0.5 to 0.7. Stakeholders as an aggregate group perceived that scientists should have the highest levels of interest, even compared to members of their own stakeholder group. Also notably, Stakeholders indicated that people who are not formally trained environmental professionals should be able to influence policy and management to a significantly greater extent than citizen scientists (t-test; p<0.0001).

Again, stakeholders' written survey responses further explored the nuances of environmental stakeholders' breadth of perspectives about the role of volunteers in environmental management. Several respondents argued that citizen scientists should be treated like any other stakeholder interest group, and should therefore have a role in contributing to management because “the Bay belongs to everyone, not just a few ‘experts’.” One respondent summarized this perspective, explaining that “everyone's needs, values, perspectives, and experiences matter and should be part of management decisions.” Some respondents acknowledged that while citizen scientists might be able to contribute to management at a local level, they “lack a broad understanding of the entire Bay,” and very rarely appreciate the complexity of the issues and trade-offs that must be factored into management decisions. Other respondents agreed that citizen scientists should not necessarily have a seat at the metaphorical table, but “the scientific data that volunteers collect should play a strong role” in management decisions.

Stakeholders also acknowledged that volunteers already contribute to Chesapeake Bay management in various ways, even beyond collecting environmental monitoring data. For example, citizen scientists often have deep knowledge of a particular geographic area and “can supplement scientific knowledge with stories that can truly help drive change and connect people through deeper engagement.” Others elaborated on this concept, suggesting that while management decisions should be made by elected officials and panels of technical experts, citizen science is particularly valuable for management because of its ability to transform volunteers into environmental leaders who can “influence their neighbors to be better stewards and lean on elected officials to make Bay restoration a higher, better-funded priority.” Respondents further explained that citizen science should not drive policy decisions, but volunteers can “be even more impactful as advocates than they can as scientists” because they can work with their volunteer organizations to identify priority issues, educate and engage others in their communities, and advocate for certain environmental decisions to be made.

<u>Discussion</u>

Our research determined that the Chesapeake Bay environmental community especially values science in the context of environmental decision making. According to our survey responses, 100% of Chesapeake environmental stakeholders believed that public policies should be based on the best available science, with 91% of respondents agreeing that science should influence policy “to a great extent” (n=372). When Research!America asked the same question as part of their 2018 national survey, they found that 67% of U.S adults agree that public policies should be based on the best available science (Research!America, 2018). Both surveys suggest that a majority of stakeholders support science influencing policy decisions, but the differential in responses between the two surveys suggests that this is especially the case within the Chesapeake environmental community. The discrepancy between the present study and the national survey are perhaps unsurprising, given Chesapeake Bay’s nearly 40-year history of science-based management that began with the formation of the Chesapeake Bay Program in 1983.

The majority of Chesapeake environmental stakeholders also believed that scientists themselves should have a substantial level of influence in environmental management decisions; however, the exact nature of scientists’ role in management was debated throughout survey responses, and is also hotly contested in the academic literature. Many scholars have proposed frameworks describing specific roles that scientists can potentially play when navigating the science–policy interface (e.g., Lach et al., 2003; Milkoreit et al., 2015; Pielke, 2007). These defined roles range on a spectrum. At one end are ‘pure scientists’ and ‘truth seekers’ who report value-neutral scientific facts but provide no additional insights that might influence how the science is interpreted or ultimately used. At the other end of the spectrum are ‘change makers’ and ‘issue advocates’ who share scientific results and also make the case for preferred management decisions based on their scientific expertise. Some scholars argue that ethical scientists must focus on providing scientific facts while remaining objective and apolitical. For example, Lackey (2007) says that scientists should avoid using value-laden words like “degradation” and “ecosystem health” because they imply a desired ecological state or preferred management decision. Indeed, several respondents in our study also appeared to prefer this prescribed role for scientists. However, considerably more studies (including the present study) reveal that people generally prefer scientists to be more active participants in management decisions (e.g., Lach et al., 2003; Nelson & Vucetich, 2009; Pew Research Center, 2020). Kotcher et al. (2017) maintain that by engaging in certain forms of advocacy, scientists do not negatively impact their own credibility or the trustworthiness of their science. The authors suggest that instead of debating whether or not scientists should or should not advocate, it would be more productive to work together to better understand what appropriate and ethical advocacy looks like (Kotcher et al., 2017).

Our results suggest that many Chesapeake environmental stakeholders would like to see scientists take an active role in changing the way that environmental knowledge is communicated and used. Respondents emphasized the importance of effective science communication and generally agreed that scientists should be involved in interpreting their science and helping to integrate it into the context of potential management decisions. Lach et al. (2003) recommend that scientists who play more active roles in management decisions also have the responsibility to effectively communicate their research findings so that other stakeholders can adequately understand the scientific information and integrate it into decision-making processes in more accurate and meaningful ways. Reed et al. (2014) impart a similar challenge on scientists, urging researchers to "go beyond simply producing and communicating new knowledge" and instead work together to co-produce and more effectively apply knowledge in order to solve environmental problems (p. 343). By deliberately spanning the boundaries between science and decision making, scientists can facilitate a more inclusive knowledge exchange process in which relevant research is produced faster, accepted by more stakeholders, and swiftly integrated into decision-making processes (Bednarek et al., 2018).

The Chesapeake environmental community must also welcome environmental anthropologists, economists, political ecologists, and other social scientists to the table to ensure that environmental decisions are indeed informed by the best available science. The present study focused on the roles that environmental science and environmental scientists play in environmental management, but we also recommend integrating social science research and researchers into environmental decision-making processes. As other scholars have already pointed out, many environmental challenges are, in fact, human problems; therefore, environmental management is as much about understanding people as it is about understanding ecology, physical geography, and other natural sciences (Martin, 2020; Mascia et al., 2003). Furthermore, environmental management is a human-centric endeavor and environmental policies are social phenomena— stakeholders come together to share relevant information, consider competing values and priorities, and ultimately make decisions in hopes of achieving socially-desired outcomes as a result of human behavioral change (Doremus & Tarlock, 2005; Mascia et al., 2003). Although social scientists have historically had fewer opportunities to meaningfully contribute to these types of decision-making processes than their natural science counterparts (Bennett et al., 2017; Freudenburg, 1989), the value of social science in environmental management contexts is acknowledged with increasing frequency (Bennett et al., 2017). For example, studies on perceptions, similar to the present research, can give some indication of stakeholders' attitudes and level of support for management decisions and also provide insight into whether or not policies are likely to result in socially equitable outcomes (Bennett, 2016; Bennet et al., 2017).

Our study provides evidence of widespread feelings of disempowerment throughout the Chesapeake environmental community. Regardless of their individual stakeholder role, most respondents believed that they should ideally have a higher level of influence in environmental management than they perceived they had at the time of this study. Furthermore, members of the Chesapeake environmental community agreed that stakeholder perspectives should be considered more during decision-making processes. This perspective is also common throughout the academic literature. Many researchers have found that engagement with diverse stakeholders is essential for addressing complex environmental challenges (e.g., Reed, 2008). In order to increase the chances that stakeholder engagement in environmental management results in beneficial outcomes, Reed (2018) specifies that power dynamics must be understood and effectively managed so that all stakeholders feel empowered to contribute knowledge and influence decisions in an equitable way.

Our research clearly shows that Chesapeake environmental stakeholders across the board would like to have a higher level of influence in management decisions, even if not quite as high as the level they would grant to scientists. In the Chesapeake Bay area, even though citizen committees and other stakeholders have been included in the management framework since the early years of the Chesapeake Bay Program (Hennessey et al., 1994), scientific knowledge (and therefore scientists' voices and research priorities) is still relatively privileged over other types of knowledge. As a result, management decisions and priorities are heavily influenced by scientific research and those who contribute science-based knowledge, while other sources of expertise, such as tacit knowledge and indigenous knowledge, are undervalued or overlooked (Boiral, 2002). This disempowerment of other environmental stakeholders has been shown to contribute to environmental injustice (Johnson & Clisby, 2009), and eventually puts scientists at risk of losing the trust and support of other environmental stakeholders (Berkes, 2009). In contrast, when stakeholders are empowered to contribute to environmental management, there are increased levels of support and trust in environmental management practices (Goldman et al., 2011; Gray et al., 2012).

Strategic knowledge integration processes, such as participatory research, could help the Chesapeake management community create additional space for other types of knowledge contributions and further empower Chesapeake environmental stakeholders. Fortunately, there is no shortage of knowledge integration products, processes, frameworks, and toolkits that can help facilitate stakeholder engagement, guide collaborative learning and decision making, and integrate different forms of knowledge into environmental decision-making processes (e.g., Alexander et al., 2019; Brouwer et al., 2019; Raymond et al., 2010). Participatory research is a knowledge integration approach that challenges traditional power structures and abandons the expert-driven approach to solving complex problems (Kreuter et al., 2004) by empowering non-scientist stakeholders to contribute to the creation of new scientific knowledge. This approach involves incorporating local knowledge and local people into all stages of the scientific research process (Calheiros et al., 2001). Collaborators involved in a participatory research effort help to define research hypotheses and priorities, collect and interpret data, and disseminate research results.

Participatory research could be especially productive and appropriate for engaging Chesapeake environmental stakeholders and other groups of people who value the role of science in management decisions but simultaneously want to have more influence in management, themselves. In the context of Chesapeake Bay management, this approach of bringing people together in a research-focused context could be a way of capitalizing on a point of convergence within the Chesapeake environmental community. Participatory research is beneficial because it can increase the rigor, relevance, and reach of science (Balazs & Morello-Frosch, 2013), and often results in research that is more widely accepted by broader communities (Calheiros et al., 2001). Participatory research also offers stakeholders the opportunity to co-develop a more comprehensive understanding of their environment and the management of socio-ecological systems (Calheiros et al., 2001). Participatory research is not a substitute for other opportunities that invite stakeholders to meaningfully contribute their own diverse forms of knowledge, experiences, and perspectives to environmental management in non-research contexts, but it could offer a supplemental avenue for empowering non-scientists.

Transdisciplinary research is a participatory approach that aims to produce solution-oriented science that responds to societal needs (Lang et al., 2012; Roux et al., 2010). To accomplish this goal, the transdisciplinary research approach not only recognizes the importance of integrating social and natural sciences (Bennett et al., 2017; Heberlein, 1988), but also extends the deliberative peer community beyond academia to include other individuals with interest in the outcome of the research (Bidwell, 2009; Lang et al., 2012; Reed et al., 2018). Members of transdisciplinary research teams work together to synthesize their diverse expertise and co-produce new knowledge that more holistically characterizes socio-ecological systems and solves “wicked” problems of common interest (Milkoreit et al., 2015). The transdisciplinary approach broadens the scope of which sources of knowledge are considered legitimate and valuable in the context of scientific research. In doing so, transdisciplinary research empowers environmental stakeholders whose expertise has been historically undervalued by incorporating often-overlooked information such as community values, historical context, and personal experiences (Bidwell, 2009). In this sense, transdisciplinary research creates a space for an inclusive discourse and continuous blending of knowledges (Milton, 1993). The process of blending diverse stakeholder knowledge, including traditional scientific knowledge, can support the creation of a new, more holistic approach to knowing, valuing, and managing the environment (Milton, 1993). Because the new co-created approach is more reflective of diverse environmental values and realities, it is often more practically useful for decision-making and management purposes (Goldman et al., 2011).

Citizen science is another form of participatory research that offers non-scientists the opportunity to contribute to scientific research and knowledge production, to varying degrees. In contrast to transdisciplinary research projects, wherein participants are most often selected by the project coordinators, citizen science efforts are usually open to all interested individuals (Pettibone et al., 2018). Citizen science therefore allows for broader societal involvement in scientific knowledge production, and is less dependent on participant selection processes (and biases) that determine which stakeholders are included or excluded (Pettibone et al., 2018). Citizen science projects vary on a continuum in the degree to which participants are involved throughout various phases of the research effort (e.g., Danielsen et al., 2009; Shirk et al., 2012). For example, some citizen science research limits volunteer contributions to data collection, while other research is more community-driven and transdisciplinary, and includes volunteers in other phases of research, such as problem definition, data analysis, and communication of results. The ideal scope of volunteer inclusion depends on the specific goals of a particular research project and its participants (Pettibone et al., 2018). Regardless of the exact nature of volunteers' roles in particular projects, citizen science contributes to a better understanding of environmental systems and benefits environmental science, management, and stakeholder communities (Conrad & Hilchey, 2011; Dickinson et al., 2010; McKinley et al., 2017).

In certain circumstances, the benefits of citizen science increase when volunteer participation expands beyond environmental data collection (Buytaert et al., 2014, Freitag & Pfeffer, 2013; Jollymore et al., 2017). In these situations, citizen science functions as a platform for different stakeholders to synthesize local-scale data and bridge together multiple knowledge streams (Irwin, 1995). Citizen science programs serve as boundary-spanning organizations by facilitating knowledge integration and helping to establish and maintain collaborative partnerships between various stakeholders (Berkes, 2009; Webster et al., 2021b). Beyond empowering non-scientists to participate in scientific knowledge creation, this more iteratively collaborative, transdisciplinary version of citizen science can also create opportunities for non-scientists to actively contribute to environmental discourse and work together to translate their integrative research into management recommendations. When the production of scientific knowledge is collaborative and democratized, the resulting science-based management recommendations are more reflective of the needs and knowledge of a diverse public and more representative of the environment as a complex socio-ecological system (Buytaert et al., 2014; McKinley et al., 2017). Citizen scientists' contributions can, therefore, give them more influence as actors at the science-policy interface, rather than passive recipients of environmental policy (Bäckstrand, 2003). This is especially true in the context of Chesapeake Bay, where stakeholders share the perception that science should play a large role in environmental decision making. Thus, citizen science can shift authority structures, decentralize political power, and enable more democratized management of resources (Freitag & Pfeffer, 2013).

Chesapeake environmental stakeholders have mixed perspectives on the utility of citizen science for Chesapeake environmental research and management, despite the clear potential that citizen science has in the Chesapeake Bay area, as well as its proven benefits elsewhere. In order to fully take advantage of citizen science as a tool to empower more stakeholders and improve Bay management, members of the Chesapeake environmental community must first acknowledge and overcome their biases against citizen science and their distrust or misunderstanding of the volunteers who participate in these efforts. Specifically, stakeholders in aggregate believed that citizen scientists should enjoy lower levels of influence than other stakeholder groups, including generic "people who are not formally-trained professionals." Even so, respondents also specified that citizen scientists should ideally be able to influence management decisions to a greater extent than they are able to currently. This perspective indicates that Chesapeake environmental stakeholders are indeed open to expanding the role of citizen science and its participants in environmental management.

We offer four recommendations that could help the Chesapeake environmental community make citizen science participatory research more impactful and empowering in the Chesapeake region. First, stakeholders should work together to increase the degree of coordination and data comparability between various citizen science efforts in the watershed. Greater comparability between individual monitoring efforts will help stakeholders meet multiscalar data needs and make the best use of data collected through various citizen science efforts (Conrad & Daoust, 2008; Webster et al., 2021b). Second, stakeholders should encourage additional support of volunteer efforts (financial or otherwise) from influential science and management authorities, such as the Chesapeake Bay Program and other regional partnerships. Effective capacity building of citizen science requires the engagement of stakeholders who represent science, policy, and society communities (Richter et al., 2018). Third, Chesapeake environmental stakeholders should reach out to underserved communities to include these stakeholders in participatory research efforts. Improving the accessibility of citizen science will increase inclusion and environmental justice within the Chesapeake environmental community, while also increasing scientific data representation and knowledge integration across the watershed (Blake et al., 2020; Hermoso et al., 2021). Finally, particularly if transdisciplinary citizen science efforts become more common within the Chesapeake environmental community, stakeholders must bear in mind that the process of integrating different forms of knowledge is a difficult undertaking (Buytaert et al., 2014). Multi-stakeholder knowledge integration, when done ineffectively, can result in surface-level public "participation" that does not truly incorporate multiple voices, but instead perpetuates the dominant discourse, and further disempowers participants (Bäckstrand, 2003; Brosius et al., 1998; Pettibone et al., 2018,).

Conclusion

Chesapeake Bay scientific research has become increasingly interdisciplinary over time in order to inform adaptive management of the Bay as a complex socio-ecological system. In recent years, the Chesapeake environmental management community has identified a need for more fine-scale environmental data and multi-stakeholder engagement, and has turned to citizen science as a tool for meeting these needs. Though studies have demonstrated numerous positive outcomes of participatory research in other systems, citizen science is not yet fully leveraged as a source of data and knowledge production within the context of Chesapeake Bay management. Furthermore, despite a long history of efforts to engage stakeholders in Chesapeake Bay management, stakeholders continue to feel disempowered.

This study presents a more complete understanding of Chesapeake environmental stakeholders' perspectives of the roles that science and citizen science currently and ideally should play in Bay decision-making processes. This research is a productive step in helping the Chesapeake environmental community identify and address existing barriers to engaging stakeholders and expanding public engagement in scientific research. Still, additional research is needed to more fully understand how Bay managers can strategically use citizen science to address existing data gaps, empower stakeholders to play a more influential part in scientific knowledge production and environmental discourse, and ultimately improve Chesapeake Bay science and management. Citizen science appears to be a promising new frontier that could help Chesapeake science and management continue to progress along its present trajectory towards more inclusive and holistic transdisciplinary decision-making processes.

Acknowledgements

We would like to thank all of the Chesapeake environmental stakeholders who participated in this study. We are also grateful to Natalie Spitzer for her statistical assistance and Drew Webster for his thoughtful comments on earlier versions of the manuscript. We also thank Michael Paolisso, Astrid Caldas, Andrea Grover, and Judy O'Neil for their comments and suggestions on the study and survey design, as well as their mentorship and support.

Author contributions

Suzanne E. Webster: Conceptualization, Methodology, Investigation, Formal analysis, Visualization (lead), Writing - Original draft (lead), Writing- Reviewing and Editing (equal). **William C. Dennison:** Visualization (supporting), Writing - Original draft (supporting), Reviewing and Editing (equal), Funding acquisition.

Part II: Identifying and harmonizing the priorities of stakeholders in the Chesapeake Bay environmental monitoring community

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(Under review, submitted August 2021)

Abstract

Research collaborations between volunteer monitoring groups and environmental scientists and managers are instrumental for understanding and managing complex socio-ecological systems. In the Chesapeake region, the Chesapeake Monitoring Cooperative (CMC) helps coordinate volunteer monitoring efforts throughout the watershed, and facilitates collaboration between environmental stakeholders. However, stakeholders perceive their environment and their own role in different ways, and these perceptions affect how they prioritize problems and respective solutions. We conducted a survey to explore the extent to which cultural knowledge about environmental monitoring was shared across the CMC community, pinpoint key similarities and differences in how stakeholder groups prioritized various environmental monitoring goals, and understand stakeholders' perspectives of the CMC's objectives and various resources. We learned that stakeholders drew from a shared system of cultural knowledge surrounding environmental monitoring and prioritized goals related to collecting actionable data and improving environmental conditions. There were also compelling differences in how stakeholder groups prioritized increasing knowledge and building a sense of community. Furthermore,

stakeholders perceived that the CMC prioritized increasing the quality, quantity, and accessibility of volunteer-collected data, and especially valued the CMC's resources associated with these priorities. Based on our results, we developed recommendations to inform the design and coordination of other collaborative environmental monitoring programs. We argue that cultural consensus can provide a foundation for collaboration, and stakeholders' highest-priority monitoring goals can inform organizational priorities and strategic outreach. Furthermore, efforts to build social capital and understand stakeholders' changing priorities over time will be important for ensuring the continued success of the research partnership.

Introduction

As the environment responds to increasing threats due to climate change and other anthropogenic pressures, it is extremely important to understand how environmental health is changing over time. Data from environmental monitoring programs can help scientists, managers, policy makers, and other stakeholders understand environmental changes and trends, identify areas of greatest concern, and prioritize restoration and conservation action (Brydges, 2004; Lovett et al., 2007; Sparrow et al., 2020). Chesapeake Bay is threatened by nutrient and sediment pollution from development and agricultural practices, overfishing, and climate change, and data and coordinated monitoring are needed to inform management decisions (Bilkovic et al., 2019; Boesch & Greer, 2003; CBP, 2009). Policy makers and environmental managers have known for decades that effective management of the Bay requires a sustained monitoring program and coordination among stakeholders (Gillelan et al., 1983).

The U.S. Environmental Protection Agency's Chesapeake Bay Program was established in 1983 and is one of the most notable scientific management efforts in the world (Boesch & Goldman, 2009). The Bay Program initiated their monitoring program in 1984 after the prior year's inaugural Chesapeake Bay Agreement outlined the need for a comprehensive, cooperative, and coordinated approach towards Bay management and restoration (Hennessey et al., 1994). The monitoring program includes data collected by federal, state, and local governments, academic institutions, and non-governmental organizations. These groups contribute physical, chemical, and biological data that address the specific management goals and environmental outcomes outlined in the Chesapeake Bay Watershed Agreement (Matuszeski, 1995). These goals include, for example, protecting vital habitats, improving water quality, and conserving landscapes (CBP, 2014).

The Chesapeake Bay Program's monitoring effort is robust and extensive; nevertheless, many spatial and temporal data gaps exist (Scientific and Technical Advisory Committee [STAC], 2005). These data gaps can impede scientific understanding of baseline and trend information and lead to lag times in management response (STAC, 2009). Volunteer-collected data can help fill data gaps and inform timely management solutions in estuarine and freshwater systems (Fisher, 1993; Hiller, 1991; Stepenuck & Genskow, 2018). There are multiple definitions for volunteer environmental monitoring (Kerr et al., 1994; Pfeffer & Wagenet, 2007; Stepenuck & Genskow 2018), but for the purposes of this study, volunteer monitoring means engaging individuals or monitoring groups that have not traditionally been included in the Chesapeake Bay Program's monitoring program. These entities include individual volunteers, non-profit organizations, watershed organizations, local governments, conservation districts, and others, and may include paid staff.

For decades, the Chesapeake Bay watershed has been home to many volunteer-based monitoring programs. The programs collect robust data on a variety of chemical, physical, and biological parameters aimed at answering specific questions about health of local streams, watersheds, or broader ecosystems (Rubin et al., 2017). Organizations within the watershed invest in water quality monitoring programs for a variety of reasons and at a variety of scales based on community interests and needs (Rubin et al., 2017). For example, in response to elevating community concerns over the rapid growth of the shale gas extraction industry in Pennsylvania, the Alliance for Aquatic Resource Monitoring (ALLARM) developed a volunteer-friendly monitoring protocol specifically for the purpose of detecting surface water contamination caused by shale gas extraction (Wilderman & Monismith, 2016).

The volunteer monitoring programs in the Chesapeake region have traditionally operated independently of one another using a variety of equipment and techniques based on each group's specific motivations for collecting data and their access to resources. This lack of coordination and continuity between monitoring programs has contributed to data comparability issues across the region. Data comparability plays a critical role in bridging the gap between fulfilling individual data collection motivations and addressing data needs assessed at a broader scale

(Conrad & Daoust, 2007; Rebele, 1997). For example, in the case above, ALLARM's volunteers originally collected data on water quality and physical parameters in order to monitor the impacts of shale gas extraction; however, increased data comparability between ALLARM's protocol and other regional sampling methodologies makes it easier for their data to be used in broader monitoring contexts and regional waterway assessments. When data comparability is lacking, it is difficult and time-intensive to use the data beyond the intended local-scale use or integrate the data with more traditional datasets. This is especially true when those datasets stretch across a geographically expansive, multi-jurisdictional and ecologically-heterogeneous area like the Chesapeake Bay watershed.

In 2015, the Chesapeake Bay Program initiated a project called "Integration of Citizen-based Monitoring and Nontraditional Monitoring Partners into the Chesapeake Bay Program Partnership" to increase data comparability and usability throughout the region (CBP, 2018). This program, known as the Chesapeake Monitoring Cooperative (CMC), is a multi-state initiative that supports volunteer-based monitoring groups in order to integrate volunteer-collected data with formal datasets that are traditionally used in policy and decision-making processes. The CMC provides various tools and resources that help ensure the quality, comparability, and usability of environmental data collected throughout the Chesapeake Bay watershed. With the philosophy that "all data of known quality are useful," the primary directive of the CMC is to increase the cohesion between volunteer, state, and federal monitoring programs and make volunteer-collected data more accessible for various intended uses (Rubin et al., 2017).

The complexity of relationships within the volunteer monitoring community and between the volunteer community and local, state, and federal agencies is a challenge the CMC needs to overcome. Different stakeholders perceive their environment and their own role in different ways, and these perceptions affect how they prioritize problems and respective solutions (Verbrugge et al., 2017). In the Chesapeake region, the diversity of monitoring priorities, coupled with the lack of cohesion between monitoring efforts, has led to a widely-held perception that every group has fundamentally different monitoring goals and intended data uses. This perceived misalignment of interests between stakeholder groups is a historic and pervasive problem that hinders compromise and growth at all levels. Therefore, in addition to being tasked with integrating volunteer data within the watershed into traditional datastreams, the CMC also faces the challenge of reconciling a wide diversity of monitoring priorities, balancing multi-scalar stakeholder needs, and ultimately fostering a more collaborative mentality amongst members of the Chesapeake environmental monitoring community by finding the common ground between stakeholder groups.

Many researchers have investigated volunteers' motivations and goals for participating in environmental monitoring programs (e.g., Alender, 2016; Robinson et al., 2020, Wright et al., 2015); however, motivations and goals are often context-dependent and vary by stakeholder group (Verbrugge et al., 2017). Furthermore, studies exploring other stakeholders' priorities surrounding these collaborative scientific efforts are uncommon, especially ones that investigate the perspectives of data consumers (e.g., Cooper et al., 2017). Still, it is important to understand different stakeholder perceptions and motivations in order to successfully recruit and engage participants and accomplish programmatic objectives (de Groot et al., 2014; Luyet et al., 2012; Wright et al., 2015). A detailed understanding of stakeholders' monitoring goals also allows volunteer programs to more effectively serve members by emphasizing shared priorities and strategically aligning programmatic resources. For the CMC, this detailed knowledge of stakeholders' priorities, coupled with the foundation of the CMC framework, could unlock enormous potential for increased collaboration and data use within the Chesapeake environmental monitoring community.

In the present study, we explored the extent to which cultural knowledge about environmental monitoring is shared across the CMC community. We surveyed scientists, managers, volunteers, coordinators, and service providers within the CMC network to identify key similarities and differences in how stakeholder groups prioritize various monitoring goals. We also investigated stakeholders' perspectives of the CMC's objectives, as an organization, and synthesized their feedback on the value of various CMC resources. Finally, we provided four recommendations that can improve future CMC efforts. Beyond helping the CMC, our methodology and resulting recommendations could be applied to inform the design and coordination of other regional-scale or even national-scale environmental monitoring programs that include volunteer-collected data alongside traditional datasets.

Methods

Study area

Chesapeake Bay, located in the Mid-Atlantic region of the United States, is the nation's largest estuary. The Bay's drainage basin covers 166,000 km^2 in six states and the District of Columbia (Gillelan et al., 1983), and is home to more than 18 million people (Bilkovic et al., 2019). Chesapeake Bay has a dendritic tributary system, which combined with the Bay's mainstem, accounts for approximately 12,900 km of shoreline (Boesch & Goldman, 2009). This tributary system is so expansive that every resident within the watershed lives within a few miles of at least one of the more than 100,000 streams or rivers that flow into the Bay (Oxnam & Williams, 2001). Additionally, Chesapeake Bay is shallow and has a relatively small volume in relation to its watershed size (Linker et al., 2012). This elevated land-to-water ratio and high level of interconnectedness between people and the water mean that the Bay is especially susceptible to anthropogenic effects that stem from human activities in the watershed (Boesch & Goldman, 2009).

Active management is therefore crucial in order to ensure that Chesapeake Bay's long-term health is prioritized so that the Bay can continue to support ecosystems, communities, and economies throughout the watershed. The Chesapeake Bay Program is a regional partnership that directs the restoration of the Bay. Since the Bay Program's early years, committees of scientists, managers, and citizens have contributed their expertise (Hennessey et al., 1994), and this diverse stakeholder input has allowed the Program to evolve into one of the most notable scientific management efforts in the world (Boesch & Goldman, 2009). As the threat of climate change grows and anthropogenic pressures on the Bay continue to increase, the management approach for Chesapeake Bay continues to evolve (Bilkovic et al., 2019), and stakeholder coordination continues to be an essential component.

Study population

The CMC started in 2015 as a partnership between the Chesapeake Bay Program and the Alliance for the Chesapeake Bay, the Izaak Walton League of America, the Alliance for Aquatic Resource Monitoring (ALLARM), and the University of Maryland Center for Environmental Science. The main directive of the CMC was to unify volunteer-based monitoring organizations across the Chesapeake region and integrate the data into the Chesapeake Bay Program partnership. The first few years of the partnership were spent laying the foundation of a cohesive monitoring program by developing resources for volunteer monitoring organizations, such as standardized monitoring methods, training protocols, a tiered framework, and a centralized and publicly-accessible database— the Chesapeake Data Explorer. The tiered framework classifies data into three tiers and provides the key structure needed to easily compare data that was collected using an assortment of methods. The Chesapeake Data Explorer provides easy access to data collected throughout the watershed and allows users to quickly filter the data based on the intended data use.

At the outset, the CMC conducted a survey to identify the existing monitoring activities in the region. Over 120 organizations responded and the CMC team was able to identify a wide variety of physical (e.g., water clarity and temperature), chemical (e.g., dissolved oxygen and nutrients), and biological (e.g., bacteria and macroinvertebrates) parameters that were being monitored in non-tidal streams and tidal areas of the Chesapeake Bay watershed. Since this initial survey, the CMC has worked with over 80 organizations, including approximately 2000 volunteers, to integrate data into the Chesapeake Data Explorer. As of January 2021, the Chesapeake Data Explorer had over 365,000 data points and included data from all seven Bay jurisdictions. These data have already been used across the watershed at a variety of scales. For example, the volunteer-collected data were incorporated into the Chesapeake Bay Program's 2020 assessment, the Maryland Department of the Environment's 2020-2022 Integrated Report, the Virginia Department of Environmental Quality's 2022 Integrated Report, and various smaller-scale assessments such as tributary report cards.

Survey design

We conducted a pilot study to begin learning about the monitoring goals and motivations of CMC stakeholders. The pilot study involved distributing an exploratory survey to leaders of non-traditional and volunteer monitoring groups across the Chesapeake Bay watershed during the summer of 2016, as well as conducting informational interviews with scientists and managers during the spring of 2017. With the knowledge gained from these exploratory studies, we designed a targeted web-administered survey, which we distributed from November 25, 2019 –

February 13, 2020 to stakeholders within the CMC network who played a role in contributing data to the CMC or using volunteer-collected data.

Respondents were asked to self-categorize themselves as members of one of five stakeholder groups: professional scientists, environmental managers, volunteer monitors or citizen scientists, waterkeepers or volunteer coordinators, and service providers. Respondents were also given the option to indicate that they did not identify as a member of any one of the five listed stakeholder groups and provide a description of their role. Responses from these individuals who described themselves as “other” types of stakeholders were included in our aggregate analyses of CMC stakeholders as a whole, but were not considered in analyses of individual stakeholder groups. We did not provide definitions of the five stakeholder groupings on the survey itself, so as to allow respondents to interpret the categorizations for themselves; however, we now define these stakeholder groups for the purpose of this manuscript.

Professional scientists were defined as people who were paid to conduct scientific research for the primary purpose of producing new scientific knowledge. Environmental managers were individuals who used existing scientific knowledge to perform tasks or inform decisions that promoted sustainable use of natural resources, such as generating environmental reports and enforcing regulations. Volunteer monitors and citizen scientists were combined into a single category for this study, which we refer to as volunteers throughout this manuscript. Volunteers were people who elected to participate in environmental monitoring activities, in their role as unpaid members of a local environmental organization. Waterkeepers and volunteer coordinators were also combined into a single stakeholder group for this study, which we named coordinators. Coordinators were those who were employed to maintain specific local bodies of water or lead non-traditional and volunteer monitoring groups. Finally, service providers were members of the CMC administrative leadership team, responsible for coordinating CMC activities and providing resources and support to CMC-affiliated monitoring groups and data users.

The survey asked respondents to consider their personal and professional motivations for participating in environmental monitoring. We provided a list of 44 distinct monitoring goals, which we created using insights gained during an earlier investigation. The investigation involved informal discussions and participant observation with volunteers, informal interviews with several scientists and managers, and a survey sent to volunteer coordinators, which included an open-ended question that asked "Why do you monitor?" The list of 44 goals were organized into five categories that represent distinct themes, in a dual-purpose effort to develop a balanced survey and also to enable us to conduct analyses at multiple scales (by individual goal and by broader thematic category). The categories were known to the research team but were not revealed to participants during the study. The goals were listed in a randomized order for respondents.

The five categories that were included were 1) Data, 2) Environment, 3) Management, 4) Knowledge, and 5) Community. The Data category included goals relating to establishing baseline water quality data, collecting longitudinal data to monitor trends over time, and providing scientists and agencies with credible data. The Environment category contained goals pertaining to identifying impaired waters, improving watershed health, and addressing a concern for habitat or waterway condition. Goals within the Management category were relevant to monitoring restoration and conservation progress, conducting impact assessments, influencing environmental policy or advocating for compliance, and determining risk to public health and human recreation. The Knowledge category included monitoring goals relating to learning about the local environment and educating others on environmental issues. Finally, the Community category encompassed goals pertaining to providing opportunities for community engagement and promoting stewardship and protection of local waterways. We acknowledge that these categories do not represent completely distinct and unrelated concepts; indeed, one could argue that several of the monitoring goals could feasibly fit into multiple categories. For the purposes of this study, we sorted the goals into the single category that we believed best captured the core essence of each particular goal.

Survey distribution and respondent demographics

The web-based survey was distributed to CMC stakeholders using the CMC monthly enewsletter listserv. At the time the survey was sent out, the listserv had approximately 250 subscribers, consisting primarily of coordinators, managers, and scientists. CMC service providers also sent targeted emails to volunteers who were members of the three largest monitoring programs within the CMC network: Alliance for the Chesapeake Bay RiverTrends, ALLARM Stream Team, and Izaak Walton League of America Save Our Streams. These groups, in particular, were contacted because our research team had access to volunteers through CMC service providers who work directly with these groups. We also asked various coordinators to consider sending the survey to their volunteers; however, we do not have a record indicating to what extent this method of distribution occurred. Service providers also sent targeted emails to scientists and managers who were professional contacts or members of the Chesapeake Bay Program's Scientific, Technical Assessment and Reporting Team.

Survey analysis

Survey participants were asked to consider their own motivations and goals for participating in environmental monitoring, and use a 7-point Likert scale to indicate to what degree they personally prioritized each of the 44 listed monitoring goals (Appendix 2). The Likert scale ranged from 1 "not a priority for me," to 4 "medium priority for me," to 7 "top priority for me," with the intermediary numbers unlabeled but provided as additional options.

We used Anthropac software to conduct a cultural consensus analysis to identify patterns in how monitoring goals were shared or distinct amongst survey respondents. Cultural consensus analysis is a cultural theory and method that uses a series of related questions to identify the cultural beliefs of a group and then quantify the degree to which individuals share those beliefs (Romney et al., 1986; Weller, 2007). This approach can be conducted with small sample sizes (Weller, 2007), used to determine the degree of consensus within and between stakeholder groups, and identify patterns in the distribution of cultural knowledge (Dengah, 2013; Paolisso, 2015). We conducted a cultural consensus analysis for the entire study population as one aggregate group, as well as individual analyses for each of the five stakeholder groups.

Our cultural consensus analysis provided estimates of how much of the variation in each grouping of survey responses could be explained by either a single underlying cultural consensus (factor 1), or by patterns of agreement beyond what was captured by the consensus (factor 2). By convention, if the ratio of the first to second factor eigenvalues was at least three to one, the study population's responses have enough shared variance to suggest that participants' responses can be represented with a single set of answers (Weller, 2007). We determined that the formal cultural consensus model, rather than the informal model, was more appropriate and made the most ethnographic sense with our Likert-scale data.

In addition to the cultural consensus analysis, we conducted a priority ranking analysis of stakeholders' monitoring goals. For each of the monitoring goals that were included in our survey, we used respondents' Likert-scale ratings to calculate the mean survey response for all CMC stakeholders as an aggregate population, as well as for each of the five individual stakeholder groups. These mean responses allowed us to rank the monitoring goals according to their priority level for all stakeholders as an aggregate group, and for volunteers, coordinators, service providers, scientists, and managers, as independent groups. We also calculated the mean survey response for each goal category by averaging stakeholders' responses for all of the questions within each of the five categories. These calculations allowed us to determine the relative priority level of the goal categories for all CMC stakeholders overall, as well as for each stakeholder group. For the seven instances when a respondent did not provide an answer for one particular monitoring goal, that non-answer was treated as missing data and was removed from statistical analyses. These missing data were distributed across the goal categories and occurred within multiple stakeholder groups, so we do not expect that these non-answers pose a significant limitation for our analysis.

We conducted a Kruskal-Wallis test for each of the five goal categories in order to determine whether the five stakeholder groups represent statistically identical populations (Appendices 2 and 3). Again, respondents who self-identified as not belonging to any of the listed stakeholder groups were not included in these analyses. A significant Kruskal-Wallis test result signified that respondents belonging to at least one stakeholder group prioritized a particular monitoring goal category differently than members of at least one other stakeholder group. For each test yielding significant differences between stakeholder groups' mean responses, we conducted Dunn's multiple comparisons test to determine which specific means were different (Appendix 4). We chose this particular post-hoc test, along with the conservative Bonferroni correction in order to minimize Type 1 error, or inaccurate identification of differences between stakeholder groups (Lee & Lee, 2018). Finally, we also conducted Kruskal-Wallis tests for each of the stakeholder groups to determine whether their answers varied significantly between the goal categories. A significant Kruskal-Wallis test indicated that the particular stakeholder group had non-identical mean responses across the five goal categories, and a Dunn's multiple comparison test with a Bonferroni correction was again used to identify specific statistically-significant differences.

Respondents were administered a second set of questions if they indicated that they were either "very familiar" or "familiar to some extent" with the CMC and its mission. These respondents were asked to share their perceptions of the CMC's programmatic priorities (Appendix 8). Respondents were again given a 7-point Likert scale with options ranging from 1 "not a priority for the CMC" to 4 "medium priority for the CMC," to 7 "top priority for the CMC," and were asked to indicate the level of importance of 25 distinct organization-level objectives. These objectives were also derived using the pilot study, and overlap somewhat with the individual monitoring goals. We used respondents' Likert-scale ratings to calculate the mean survey response for each of the 25 programmatic objectives that were included in our survey.

Finally, a third set of questions was administered to all survey participants, regardless of whether they answered the second set of questions. The third set of questions asked participants to share their thoughts on how effective the Chesapeake Monitoring Cooperative has been in helping them achieve their primary environmental monitoring goals. Respondents were given a comprehensive list of CMC resources and services and asked to choose up to five that have been the most effective in helping them accomplish their monitoring goals. For each resource or service listed, we counted the total number of respondents who selected that option and determined which resources and services were the most valuable for CMC stakeholders, overall. Respondents were also invited to further describe how their involvement with the CMC helped them achieve their highest-priority goals and were asked to share ideas for additional resources that would benefit the CMC community. All qualitative survey data were analyzed by inductively sorting free response text into emergent themes. We then used codes to identify subthemes and key ideas of interest.

Results

For each type of analysis, we begin by sharing results in which all respondents were aggregated into one group. These aggregate analyses were performed in order to detect patterns across the entire study population. We then share results from analyses that grouped respondents according to their stakeholder group. Finally, we conclude this section with a discussion of how CMC stakeholders understand the CMC's organizational objectives, and share stakeholders' feedback on CMC resources.

Respondent demographics

We received 75 responses from a diversity of CMC participants and partners, including members of all five stakeholder groups. The highest proportion or responses came from members of the Volunteer stakeholder group, while the service providers had the highest response rate (Table 3). Respondents represented over 40 organizations across the watershed, including local watershed associations, Master Naturalist chapters, regional non-profit environmental organizations, schools and colleges, research institutions, state departments, and federal agencies. Respondents had a large array of career experience, ranging from early-career professionals with several months of experience, to individuals who have worked in their fields for over 30 years. Respondents also possessed varying levels of familiarity with the CMC as an organization-- some had been members or supporters of the Cooperative since its inception in 2015 and others became members within the weeks prior to the survey being distributed, or were considering partnering with the CMC sometime in the future. About 90% of respondents indicated that they had collected or used at least one type of CMC data, spanning all three tiers of data quality (Appendix 10).

Table 3. Respondent demographics by stakeholder group. Estimated population contacted values were determined by assigning stakeholder categories to subscribers of the CMC enewsletter. The survey was also distributed to three listservs of volunteers (Alliance for the Chesapeake Bay RiverTrends, ALLARM Stream Team, and Izaak Walton League of America Save Our Streams), so the estimated number of volunteers in those groups was added to estimate the total number of volunteers contacted.

Stakeholder group	**Number of survey respondents**	**Percentage of study participants**	**Estimated population contacted**	**Estimated response rate**
Scientists	9	12.0	40	22.5
Managers	9	12.0	20	45.0
Volunteers	27	36.0	450	6.0
Coordinators	15	20.0	50	30.0
Service providers	8	10.7	8	100.0
Other	7	9.3	10	70.0
Total	75	100.0	578	13.0

Cultural consensus analysis

We conducted a cultural consensus analysis for all CMC stakeholders as one aggregate group using respondents' Likert-scale ratings of 44 listed environmental monitoring goals. Our cultural consensus analysis revealed that stakeholders' responses were patterned enough to suggest that all CMC stakeholders were drawing upon one shared, underlying system of knowledge as they responded to the questions (Table 4). More specifically, the eigenvalue ratio of 3.25 indicated that there was enough shared variance between respondents' answers to suggest that stakeholders' perspectives could be represented with a single set of modeled answers (Table 4). The modeled response was calculated by assigning heavier weight to answers from "culturally competent" stakeholders, or stakeholders whose responses most closely aligned with the group's as a whole (Appendix 2). This "culturally correct" modeled response functions as a sort of answer key, which indicates to what extent CMC stakeholders, as a group, prioritized each individual monitoring goal.

Table 4. Cultural consensus analysis results. The cultural consensus analysis provided evidence of cultural consensus among all respondents as a whole, as well as among volunteers, coordinators, and service providers as individual stakeholder groups. The modeled response represents the "culturally correct" answer key that indicates the extent to which all CMC stakeholders, as an aggregate, prioritized each of the 44 monitoring goals. The relatively consistent high Likert scale values in the modeled response suggests that CMC stakeholders share an underlying cultural understanding that environmental monitoring is valuable for a wide variety of reasons.

Grouping	**Number of respondents**	**Eigenvalue ratio**	**Consensus? (EV ratio > 3.0)**
All stakeholders	75	3.25	yes
Stakeholder groups			
Scientists	9	1.93	no
Managers	9	2.61	no
Volunteers	27	3.11	yes
Coordinators	15	5.22	yes

Service providers	8	4.29	yes
Other	7	—	—

Modeled response for all stakeholders
These numbers represent stakeholders' consensus answers for each of 44 monitoring goals:

7 7 7 7 6 7 7 7 7 7 7 6 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 4 7 6 7 4 7 7 7 7 7 7
Likert scale: 1 (lowest priority) to 7 (highest priority)

Looking at the modeled response in Table 4 (see also Appendix 2), we see that of the 44 monitoring goals included in the survey, all but five goals received the highest possible response on our seven-point Likert-scale. In fact, only two of the goals received a modeled response below a six, and these goals were 1) to collect the first data on a new parameter in a particular area and 2) to answer a specific research question on a particular location, species, or environmental threat of interest. At first glance, this seemingly homogenous result might appear to be uninteresting and suggest that stakeholders rated almost every goal as "Top priority for me," with minimal variability both within and across individual respondents' answers; however, the reality is more nuanced.

Sharing a modeled response, or in other words, having cultural consensus, does not mean that all respondents answered in the same way for each question, or that they did not have disagreements. Indeed, there was variability in the way that different stakeholders prioritized certain monitoring goals, and we will tease apart many of these nuances in the next section. Instead, the strikingly homogenous modeled response indicated that CMC stakeholders, overall, shared an underlying cultural understanding that environmental monitoring in Chesapeake Bay is useful for accomplishing a wide diversity of very important goals. This affirmative cultural consensus result meant that CMC stakeholders belonged to a group that shared an appreciation for the importance of almost all of the listed monitoring goals, even though individual stakeholders might not prioritize each particular monitoring goal for themselves.

Although the cultural consensus analysis suggested that there was cultural consensus amongst all respondents as one aggregate group of CMC stakeholders, analyses of individual stakeholder groups provided evidence of cultural consensus within some groups but not others. Interestingly, coordinators had the highest eigenvalue ratio (5.22), meaning that they had a more uniform cultural understanding of monitoring goals than any of the other more heterogeneous groups (Table 4). We also found evidence of cultural consensus among both service providers (4.29) and volunteers (3.11). The higher variance in volunteers' responses could be due to increased sample size of volunteers relative to the other stakeholder groups, or it could indicate that volunteers as a group had a less uniform cultural understanding of monitoring goals.

Interestingly, our analyses did not support evidence of cultural consensus among managers (2.61) or scientists (1.93), with scientists exhibiting the lowest eigenvalue ratio of all stakeholder groups. The higher variability in scientists' and managers' responses means that there was no indication that individual respondents within either stakeholder group were drawing from an extensively-shared cultural understanding when reflecting on their reasons for participating in environmental monitoring. The lower eigenvalues could perhaps be attributed to the fact that scientists and managers, in particular, often partner with the CMC in order to access volunteer-collected data for very specialized restoration and research purposes, which are not necessarily shared widely by peers and partners or included on the survey. The lack of cultural consensus could reflect the wide diversity of research questions and management priorities within the professional scientific and management community.

Priority ranking analysis of stakeholders' monitoring goals

To better understand CMC stakeholders' specific monitoring goals, we first identified the five most highly-prioritized goals for all stakeholders in aggregate (Table 5). To do this, we used respondents' Likert-scale ratings to calculate the mean survey response for each of the 44 monitoring goals that were included in our survey. We then used these mean responses to create a ranked list of all the goals, ordered from highest to lowest priority (Appendix 2). The highest-rated goal across all respondents, on average, was to collect data that are useful for watershed managers and decision-makers. Other highly-prioritized goals included contributing credible data to environmental assessments and reports, learning about the health of a local waterway, improving water quality and habitat, and collecting long-term data on waterways.

Table 5. The top five most highly-prioritized monitoring goals for all survey respondents as an aggregate group (n=75). The mean survey response (Likert-scale 1-7) and standard deviation are reported for each goal.

Monitoring goal	**Overall rank**	**Mean response**
Collect data that are useful for watershed managers and decision-makers	1	6.51 (0.96)
Contribute credible data to environmental assessments and reports	2	6.43 (1.02)
Learn more about the health of a local waterway	3	6.37 (1.05)
Improve water quality or waterway habitats	4	6.31 (1.08)
Collect long-term data on waterways	5	6.20 (1.01)

We wanted to discern if there were any broader patterns in how CMC stakeholders rated goals with overlapping themes. To do this, we grouped the goals into one of five designated goal categories. Each category contained a collection of 8 or 9 monitoring goals that all related to one of five themes: Data, Knowledge, Environment, Community, and Management. Again, respondents' Likert-scale ratings of the individual monitoring goals were used to calculate a single mean survey response for each of the five aggregated goal categories. We used the mean responses to rank the categories based on their overall priority level for CMC stakeholders as a whole (Appendix 3).

We found that the Data category was prioritized higher, on average, than any other category, though only statistically significantly higher than the Management category (p=0.002), which received the lowest mean response (Appendix 3). Still, the higher mean response assigned to Data-related monitoring goals indicated that CMC stakeholders highly valued collecting baseline and long-term data and participating in science. The Environment category received the second-highest mean response, also statistically higher than the Management category (p=0.008). This indicated that CMC stakeholders were also highly motivated to accomplish goals relating to identifying and addressing environmental problems, as well as improving environmental conditions.

Organizing the responses by CMC stakeholder groups allowed us to identify compelling differences between the groups that supplement the key findings from the aggregate analysis. We again used respondents' ratings of the individual goals to identify the five highest-priority monitoring goals for each stakeholder group (Figure 14) (Appendix 4). Several goals were rated high enough to rank among the top five highest priorities for only one stakeholder group. In Figure 14, these goals that were unique to one group are positioned nearest the perimeter of the diagram. Conversely, many goals were ranked among the top five priorities by at least two stakeholder groups. These shared goals are positioned towards the center of the figure in areas where the circles representing the individual stakeholder groups overlap.

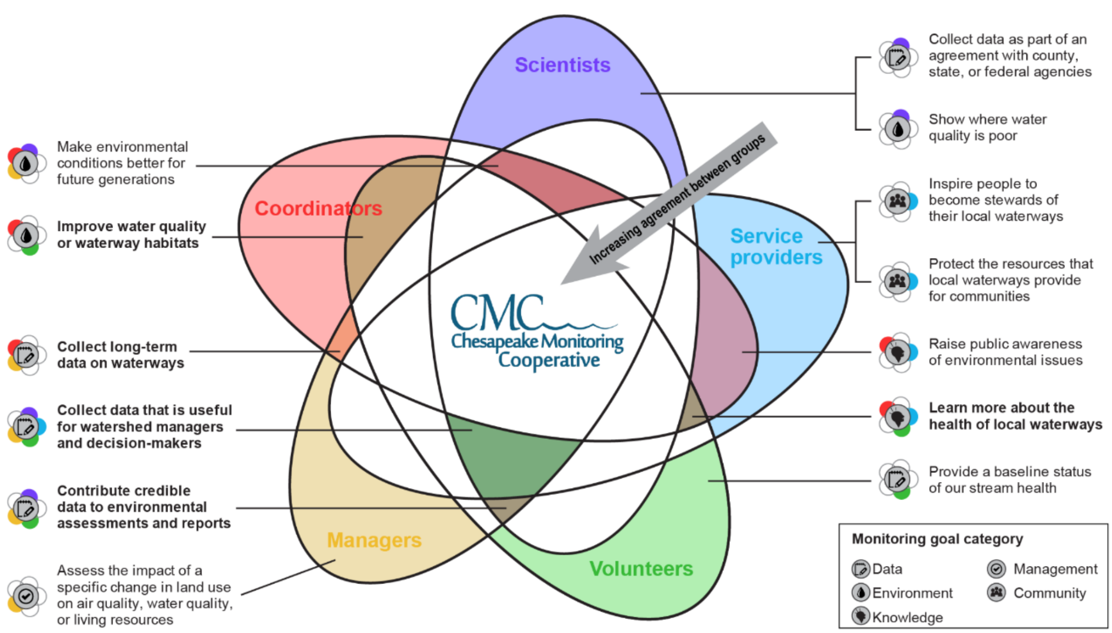

Figure 14. The five most highly-prioritized monitoring goals for each CMC stakeholder group. Goals that are included within overlapping areas of the diagram were prioritized highly by multiple stakeholder groups, whereas goals nearest the periphery of the figure were uniquely prioritized by a single stakeholder group. Icons indicate the goal category. Bolded text indicates that the goal was among the top five highest-rated priorities for all CMC stakeholders as an aggregate group.

The goal that was prioritized by the highest number of stakeholder groups was to collect data that are useful for watershed managers and decision-makers (Figure 14). Perhaps unsurprisingly, this was the same goal that was rated the highest, on average, across the entire CMC stakeholder population as an aggregate. This monitoring goal, alone, was rated among the five highest priorities by all but one of the individual stakeholder groups. Interestingly, volunteers rated this goal as their single-highest priority. One volunteer captured some of this sentiment, writing "It's more about helping CMC and local government achieve their goals than addressing goals that I would have - I view myself as a support role." Understandably, managers also prioritized this goal above all others.

To complement our exploration of individual goals that were shared and unique among stakeholder groups, we also looked for patterns in how each of the stakeholder groups prioritized the five goal categories. To do this, we once again used respondents' ratings for the individual monitoring goals to calculate a mean response for each of the five goal categories, this time with the respondents disaggregated by stakeholder group (Figure 15). Furthermore, we compared the mean responses across stakeholder groups and goal categories to identify whether or not there were any statistically significant differences 1) across stakeholder groups within each goal category and 2) across goal categories within each stakeholder group (Figure 15). By combining observations from the analyses presented in Figures 14 and 15, we can explore stakeholders' response patterns for each of the five goal categories and identify some key differences and similarities between the stakeholder groups.

	Data	Environment	Knowledge	Community	Management	Kruskal-Wallis p-value across goal categories
Scientists	5.92 (0.76)	5.41 (0.97)	4.80 (1.30)	4.16 (1.22)	4.90 (0.83)	0.025 (*)
Managers	5.33 (0.70)	5.24 (0.91)	4.78 (1.09)	4.73 (1.18)	4.98 (0.97)	0.649
Volunteers	5.66 (0.77)	5.63 (1.01)	5.33 (1.06)	5.18 (1.25)	5.07 (1.41)	0.358
Coordinators	5.88 (0.94)	5.92 (0.94)	5.93 (0.76)	5.76 (0.81)	4.99 (1.34)	0.141
Service providers	5.73 (0.89)	5.83 (0.71)	5.63 (0.79)	6.28 (0.39)	5.06 (1.37)	0.197
Kruskal-Wallis p-value across stakeholder groups	0.344	0.395	0.066	0.002 (**)	0.967	

Figure 15. The mean response (and standard deviation) for each stakeholder group, for each of the five goal categories. Data-related goals were rated highest priority for scientists, managers, and volunteers. Coordinators rated goals within the Knowledge category highest, on average, while service providers prioritized Community-related goals. Kruskal-Wallis tests (bottom row) indicated that the average ratings were not statistically distinct across stakeholder groups for each of the goal categories, with the exception of the Community category. Additional Kruskal-Wallis tests (right column) indicated that the average ratings were not statistically distinct across goal categories for each of the stakeholder groups, with the exception of Scientists. Asterisks indicate level of significance, with (*) meaning $p \leq 0.05$ and (**) meaning $p \leq 0.01$. Multiple comparisons tests determined which distinct differences existed within the Community category (Appendix 5) and within the Scientist stakeholder group (Appendix 6).

First, the Data category was the most highly prioritized category, on average, for scientists, managers, and volunteers. Scientists prioritized Data-related goals higher than all of the stakeholder groups, though their mean responses were not statistically higher than the other groups' responses (Figure 15). In relation to the other goal categories, scientists prioritized Data-related goals significantly higher than Community-related goals (p=0.018) (Appendix 5), but otherwise, there were no other statistically significant differences in how any of the stakeholder groups rated the Data category compared to the other categories (Figure 15). Still, these groups' general affinity for Data-related goals was evident, as scientists, managers, and volunteers each rated three Data-related goals among their top five highest priorities. Taking a closer look at some of these most highly-prioritized goals within this category, we discovered that a shared priority for all three stakeholder groups was to contribute credible data to environmental assessments and reports (Figure 14). Furthermore, volunteers uniquely prioritized providing a baseline status of stream health, while scientists were the only group to prioritize collecting data as part of an agreement with county, state, or federal agencies.

Although none of the stakeholder groups prioritized the Environment goal category above every other category, it is interesting to note that Environment-related goals were rated as the second-highest priority for every individual stakeholder group, on average, without exception (Figure 15). In the case of volunteers and coordinators, the average response for goals within the Environment category only very narrowly trailed the groups' average response for their highest-prioritized category. The Environment goal category was also ranked second-highest by CMC stakeholders as an aggregate, narrowly following the Data category (Appendix 3). Four individual stakeholder groups rated Environment-related goals within their top five priorities (Figure 14). Scientists prioritized showing where water quality is poor, while volunteers and coordinators both valued improving water quality or waterway habitats. In fact, improving water quality stood out as coordinators' single-highest priority. The most widely held Environment-related goal was to make environmental conditions better for future generations, which was shared by scientists, managers, and coordinators.

The Knowledge category was the highest-rated goal category for coordinators, who rated Knowledge-related goals higher, on average, than every other stakeholder group, though not quite statistically higher than the other groups (Figure 15). Coordinators, along with service providers, rated two Knowledge-related goals among their top five priorities (Figure 14). These shared goals were focused on increasing people's knowledge of the environment, either by raising public awareness of environmental issues or by learning more about the health of a local waterway. In fact, coordinators rated the second of these two goals as their highest priority overall (Appendix 3).

Service providers, or the people coordinating the CMC, were the only stakeholder group to prioritize monitoring goals within the Community category above all other goal categories, on average (Figure 16). Furthermore, service providers were the only stakeholder group to rank Community-related goals anywhere within their top five priorities (Figure 14), and indeed not one, but two of this group's top-five highest rated goals fell within the Community category

(Appendix 4). These goals were to inspire people to become stewards of their local waterways and to protect the resources that local waterways provide for communities. Unlike other more subdued differences in how the stakeholder groups prioritized the five goal categories (Figure 15), service providers' average rating of Community-related goals was statistically higher than both scientists' (p=0.004) and managers' (p=0.039) (Figure 16), who both rated the Community category as their lowest priority overall (Appendix 6).

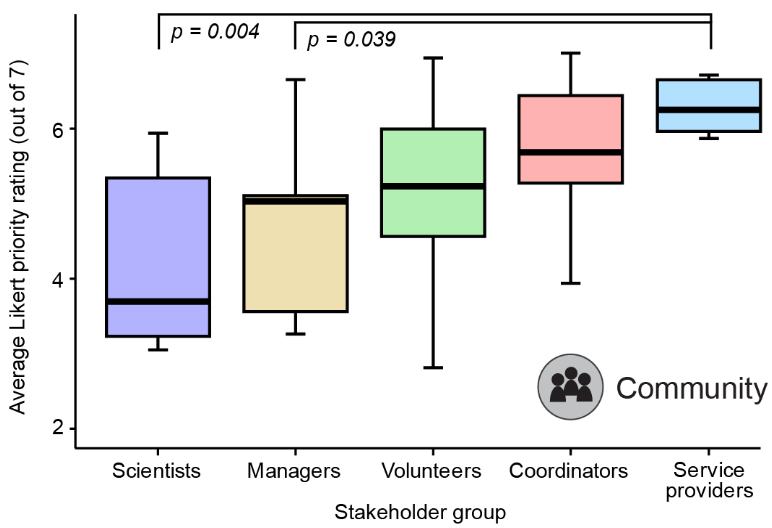

Figure 16. Stakeholder prioritization of goals within the Community category. Service providers rated Community-related goals higher, on average, than all other stakeholder groups, and statistically higher than both scientists and managers.

Finally, the Management goal category, relative to the other categories, was not highly prioritized by any of the stakeholder groups. In fact, this category was ranked as the lowest-priority category, on average, for volunteers, coordinators, and service providers (Figure 15). Managers were the only group to rate a Management-related goal among their group's top five priorities (Figure 14), which was to assess the impact of a specific change in land use on air quality, water quality, or living resources.

Stakeholder perspectives of CMC organizational objectives and resources

To understand stakeholders' perceptions of the CMC's objectives, we asked stakeholders to reflect on what objectives were most important for the CMC, as an organization. We then asked survey respondents to rate 25 organizational objectives based on the extent to which the CMC prioritizes each objective. Only respondents who indicated that they were familiar with the CMC were asked to answer this second set of questions pertaining to CMC organizational objectives (N=60) (Appendix 7).

Next, we used stakeholders' ratings of each organizational objective to identify the CMC's five most highly-prioritized objectives, according to all stakeholders in aggregate (Figure 17). Again, we calculated the mean survey response for each of the organizational objectives and used these mean responses to create a ranked list of all the objectives, ordered from highest to lowest priority (Appendix 8). On average, stakeholders perceived that the most highly-prioritized objective for the CMC was to increase the amount of monitoring data that is available across the watershed. As a group, respondents also perceived that the CMC placed high emphasis on other objectives relating to increasing the quality and quantity of volunteer-collected data in the Chesapeake region (Figure 17), including providing technical and logistical support and standardizing data collection methodologies.

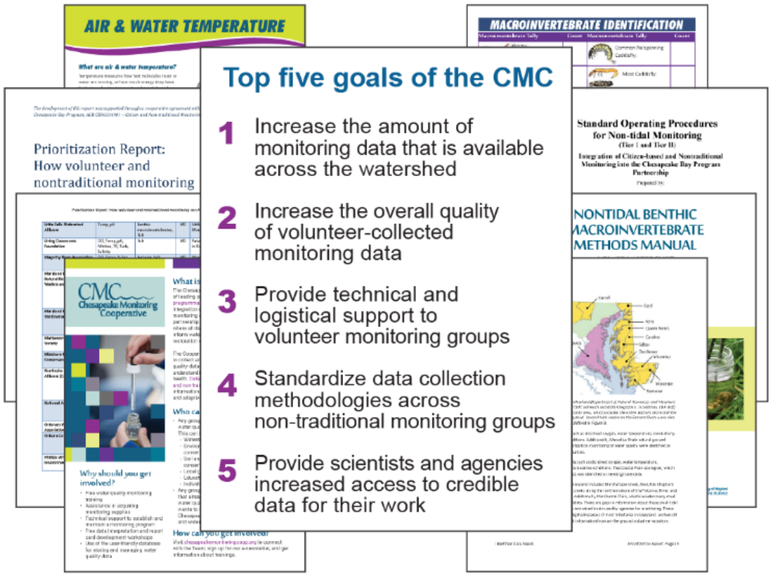

Figure 17. The top five goals of the CMC, as perceived by its stakeholders. These objectives received the five highest prioritization ratings, averaged across all respondents.

Once again, we sorted the responses by stakeholder groups to identify differences in how the groups perceived CMC objectives. We used respondents' mean responses to identify which five objectives each stakeholder group perceived were the highest priorities for the CMC as an organization (Appendix 9). There was a relatively high level of agreement across stakeholder groups regarding the CMC's objectives. In fact, all five stakeholder groups rated increasing the amount of available monitoring data as one of the CMC's top five priorities. It was interesting, however, that service providers' highest-rated objectives overlapped least with the aggregate group's perceptions of the CMC's top priorities– indeed, only two of five highest-rated objectives were shared between service providers and the CMC stakeholder population overall. This indicates that the group coordinating the CMC had a slightly different perspective of the CMC's values, compared to other stakeholders. Specifically, service providers uniquely perceived that the CMC prioritized building community connection to the watershed and empowering communities to analyze and interpret their own data. These results reinforce the group's distinctly high focus on community outcomes that was observed in the preceding analysis of individual monitoring goals, but at the same time, these results highlight that community-oriented objectives were not ultimately perceived as distinct and current organizational priorities by other CMC members.

In addition to rating specific organizational objectives, respondents were asked to consider a list of 20 tools, resources, and services that the CMC offered and select up to five that had been the most effective in helping them achieve their personal monitoring goals. According to CMC stakeholders, the three most valuable resources that the CMC currently offers are data storage and data access through Chesapeake Data Explorer, as well as hands-on water quality training. These perspectives were echoed in the free-response portions of the survey that asked participants to detail how involvement with CMC has had an impact on achieving their highest-priority goals. Respondents repeatedly mentioned that a major contribution of the CMC had been providing a centralized database for organizing, storing, and sharing regional data. Volunteers and coordinators both perceived managing and storing all volunteer-collected data in the Chesapeake Bay watershed to be one of the CMC's highest objectives.

Furthermore, the CMC's various efforts to increase both the quality and quantity of available monitoring data did not go unnoticed. In particular, individuals shared that the CMC had provided them with funding, equipment, training, and certification that ultimately increased their capacity to collect and share larger quantities of higher-quality data. Also widely recognized were the CMC's efforts to work with monitoring groups to fill recognized data gaps and standardize their data collection and reporting so that their data could be integrated into the regional dataset and "more accessible and readily usable for a variety of decision-making needs" (Figure 18). Volunteers perceived that creating a watershed-wide baseline dataset was the second-highest priority, overall, for the CMC.

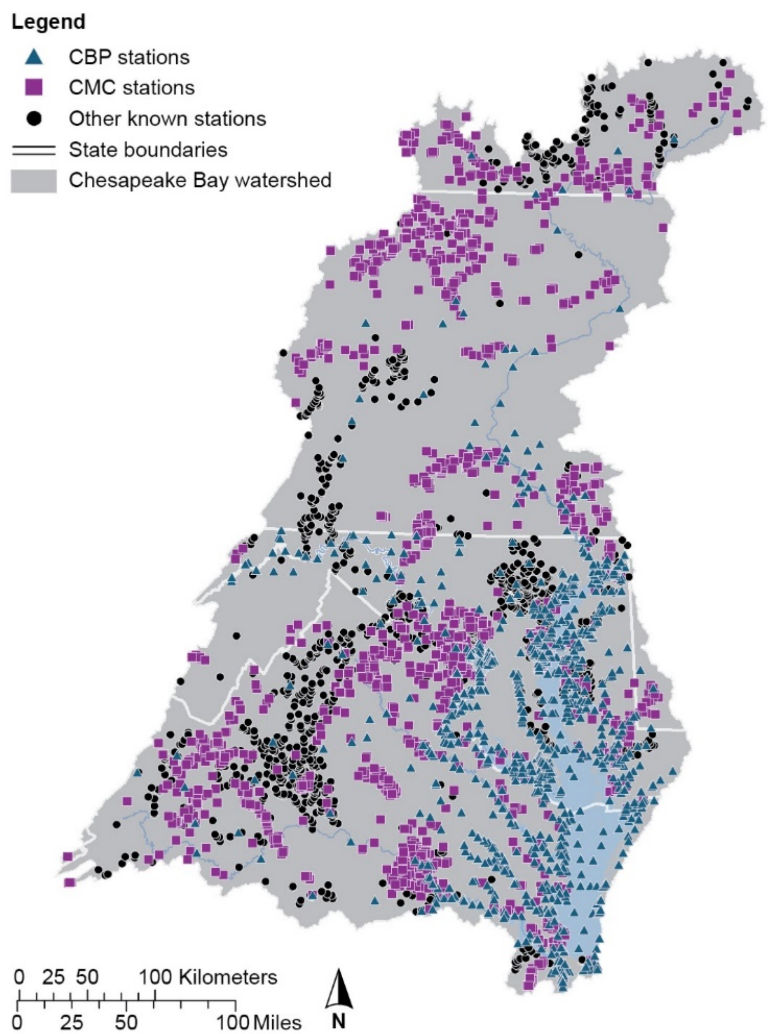

Figure 18. Map of the Chesapeake Bay watershed and environmental monitoring data stations. The CMC helped many groups contribute their data into the Chesapeake Data Explorer platform (purple), where they can be integrated with Chesapeake Bay Program monitoring data (blue). Other known stations (black) are locations where data were being collected by county, city, nonprofit, or non-traditional agencies, but had not yet been incorporated into the CMC framework as of January 2021.

Respondents also expressed appreciation for the CMC "playing the role of mediator" between various stakeholder groups, and "establishing networks…that have not existed in the past, across jurisdictional boundaries." The value of these new partnerships was acknowledged by scientists and managers at the Chesapeake Bay Program and various state agencies, who described benefitting from easier access to a new frontier of standardized and quality-controlled data. In fact, both scientists and managers perceived that one of the CMC's top-five organizational objectives was to increase and promote the use of non-traditionally-collected data in Bay scientific studies and management decisions (Appendix 9). Furthermore, volunteers and coordinators indicated that their affiliation with the CMC "gives credibility to volunteers' efforts and ultimately our data" and has directly aided in recruiting new participants and "reassuring volunteers that the data they collect will be used".

Finally, CMC stakeholders suggested several additional resources that the CMC could potentially offer in the future to help stakeholders achieve their monitoring goals. For example, respondents expressed interest in increased communication from the CMC, including more outreach to increase stakeholders' knowledge of available resources, as well as regular updates that highlight CMC success stories and show examples of how the data are being used and what has been learned. Stakeholders also requested more CMC support with understanding their data, and expressed interest in one-on-one help with data analysis and tools that enable groups to more easily create regional summary reports and visualizations based on data sourced from Chesapeake Data Explorer.

Discussion

While the specific results of this study may be unique to the CMC, we believe that the processes that we used to understand stakeholders' goals and perspectives can be widely applied, and that many of our lessons learned are transferable across other volunteer environmental monitoring programs. In this section, we share four key recommendations that can be used to inform the design and coordination of other collaborative monitoring programs.

Cultural consensus provides a foundation for collaboration

The result that there is cultural consensus amongst CMC stakeholders suggests that, despite their differences, CMC stakeholders share an underlying system of cultural knowledge, from which they draw upon to think about environmental monitoring priorities and objectives in the Chesapeake region. Specifically, the modeled response indicates that members of the CMC share a cultural understanding and appreciation for a wide diversity of environmental monitoring goals. This result is especially important considering the current dynamic that exists within the CMC community; that is, in many cases, stakeholders believe that members of other stakeholder groups have a select number of priorities, which are fundamentally different from their own.

Such perceived misalignments in goals can be barriers to effective collaboration. For example, Burgess et al. (2017) found that when scientists had limited awareness of citizen science efforts that align with their needs, their lack of understanding created a barrier to using available volunteer-collected data in their research. Another study reported that volunteer coordinators were more confident in their project's ability to meaningfully contribute to broader international goals when those goals were easier to directly connect to their own project and its objectives (Sprinks et al., 2021). All of this is not to say that stakeholders must have the same goals in order to have a successful and productive collaboration. Critics of the cultural consensus analysis method indeed worry that in emphasizing the shared nature of culture, the approach presents or even idealizes a homogenized ethnographic representation of culture (Aunger, 1999; Dengah, 2013).

Instead, we argue that the cultural consensus approach is useful for its ability to both highlight sharedness and provide insight on disagreement within a group. Our analysis shows that CMC stakeholders share an understanding of environmental monitoring, despite the fact that they differ in how they prioritize various aspects of it. Cultural consensus suggests that stakeholders have enough overlapping contextual cultural knowledge to be able to understand, though not necessarily agree with, the value of others' priorities (Paolisso, 2015). This overlapping cultural knowledge could stem from a generally high level of interest, knowledge, activity, and concern for the Chesapeake Bay among residents in the watershed, which can be understood as Chesapeake Bay environmentalism (Paolisso, 2006). This environmentalism arises from a shared sense of connectivity to the landscape, as well as a shared appreciation for the Bay as a cultural, natural, and economic resource (Paolisso, 2006). In the case of the present study, an understanding of their shared appreciation for environmental monitoring, specifically, can help stakeholders overcome the barriers presented by their perceptions that others are fundamentally different. Stakeholders can instead foster partnerships in which differences in priorities are viewed as opportunities to embrace a more holistic approach to environmental monitoring, and accomplish multiple and complementary objectives in pursuit of a shared goal.

Shared and unique goals can inform organizational priorities and strategic outreach

Our analyses indicate that CMC stakeholders share a number of environmental monitoring priorities. For example, Data was the most highly-prioritized goal category for scientists, managers, and volunteers, as well as for all stakeholders in aggregate. Furthermore, when respondents were asked to share their perspectives on the organization's goals and most valuable resources, they primarily called attention to the value of the CMC's data-related services, including increasing data quality, quantity, storage, and access. Interestingly, and without exception, all stakeholder groups rated environmental goals as their second-highest priority, overall. These results were consistent with several previous studies on environmental monitoring motivations, in which helping the environment emerged as the strongest motivation among volunteers (e.g., Alender, 2016; Bruyere & Rappe 2007; Jacobson et al., 2012). However, our study takes this recurrent finding one step further, as we found that all stakeholder groups within the CMC community were united by a shared desire to improve environmental conditions in the Chesapeake region.

The CMC can use this detailed knowledge of their stakeholders' priorities to build its brand so that it is clear to all stakeholders how the organization helps them accomplish their specific goals. To start, the CMC could draw from stakeholders' monitoring goals to set their organizational objectives in such a way that strategically allocates the CMC's limited resources towards balancing the needs of various stakeholder groups and maximizing benefits for all members. For example, the present study confirmed that most stakeholders care deeply about data, so the CMC could consider investing in improving their resources and outreach efforts that contribute directly towards helping stakeholders collect higher-quality data, efficiently manage and share their data, and easily access other groups' data. Previous research shows that environmental monitoring collaborations can be more productive when stakeholders work together to explore questions of mutual interest and accomplish shared goals (Buytaert et al., 2014). Furthermore, Verbrugge et al. (2017) noted that when participants and program organizers have differing driving motivations, taking the time to align stakeholders' expectations and wishes can provide a foundation for sustained participation. Therefore, the CMC might also benefit from strategically communicating their priorities to members in a way that highlights goal alignment between stakeholder groups and also shows that the CMC is providing services that are highly valued by its members. Our results suggest that if the CMC frames itself as an organization that prioritizes improving environmental conditions throughout the Chesapeake Bay watershed, this message would resonate with their entire environmentally-motivated audience.

The shared goal of improving environmental conditions also presents an opportunity for CMC to increase organizational focus and outreach on areas where underrepresented communities are living with higher levels of environmental pollution. Indeed, a future priority for the CMC should be to target outreach efforts towards underrepresented communities, to both better understand their environmental priorities and to engage them in monitoring. Within the context of volunteer monitoring, participation is often concentrated among more privileged communities in areas of lower environmental justice concern (Burgess et al., 2017; Pandya 2012), which has implications for data quality and environmental justice (Blake et al., 2020). Improving the accessibility of volunteer science programs is not only an important step along the path of increasing diversity, equity, inclusion, and accessibility within the broader environmental research and management community, but it also leads to improvements in the quality of science and decision making due to more representative sampling and synergies between stakeholders with different values and skill sets (Blake et al., 2020; Hermoso et al., 2021). Misalignment between community priorities and research objectives is one factor that can contribute to a lack of diverse participation in volunteer science efforts (Pandya, 2012). For example, focusing primarily on improving environmental conditions for the sake of wildlife would not align well with a community seeking to reduce the human health impacts of pollution in their backyard. CMC has an opportunity to develop the shared goal of improving environmental conditions throughout Chesapeake Bay to include working with regional partners to reach out to new and underrepresented audiences and align their engagement strategies and research objectives so that they promote environmental justice throughout the region.

Finally, the CMC can use knowledge of specific stakeholder groups' unique monitoring goals to coordinate targeted outreach efforts and showcase how their services can support stakeholders in addressing their particular priorities. Previous research suggests that understanding and acknowledging stakeholders' specific goals can improve volunteer recruitment and retention (Alender, 2016); thus, targeted outreach could help the CMC to attract volunteers, coordinators, scientists, and managers into the Cooperative and then retain them as long-term members.

Community-driven boundary spanners help build social capital

Although our survey uncovered many similarities and differences in how each of the five stakeholder groups prioritized the goal categories, the only statistically significant difference was that service providers rated goals within the Community category higher than other stakeholder groups. This result highlights service providers' focus on building community across the CMC, which is especially fitting considering this group's boundary-spanning role within the Chesapeake environmental monitoring community. Boundary-spanning organizations are institutions that link communities together by creating a more neutral, hybrid space for knowledge co-production and sharing (Guston, 2001; Jensen-Ryan & German, 2019). Bednarek et al. (2018) defines this practice of boundary spanning as "work to enable exchange between the production and use of knowledge to support evidence-informed decision making". Boundary organizations, such as the CMC, create bridges between science and policy, environmental research and management, and scientists and nonscientists by building social relationships, facilitating communication, mediating among stakeholders' varying interests, and negotiating power differentials (Crona & Parker, 2012).

The CMC is poised to play a crucial role in the Chesapeake Bay environmental research and management community because the organization joins together previously-disconnected stakeholders to create an extended peer community that can exchange knowledge and collaboratively address complex problems. Our study found that service providers, uniquely among other stakeholder groups, placed high emphasis on individual monitoring priorities relating to building community and uniquely rated two community-oriented objectives within the organization's top five priorities. While other stakeholder groups prioritized monitoring goals and organizational objectives related to collecting and exchanging high-quality data, service providers embraced the broader opportunity to deliberately shape the Chesapeake environmental monitoring community and create a space for connection and communication.

This focus on community and social capital is essential for expanding the CMC and helping its constituents achieve their goals. Social capital has been conceptualized in many ways across the literature; however, broadly it refers to people's ability to work together (Coleman, 1988), to trust each other and share a sense of common purpose (Quddus, 2000), and to draw benefits from their social network of relationships, if needed (Snijders, 1999). Communities with more social capital are more likely to achieve their goals (Krishna, 2002), and this result has also specifically been observed amongst watershed groups (Floress et al., 2011). For example, Overdevest et al. (2004) found that participation in a volunteer stream monitoring project increased feelings of community connectedness, personal networks, and political participation among volunteers, suggesting that volunteer monitoring can enhance local adaptive management and social capital. CMC stakeholders will likely experience similar benefits as a result of the organization's leadership focusing on engaging groups and building ties between members. Furthermore, although CMC stakeholders appeared to value the CMC primarily for its more traditional services such as providing data storage, promoting increased data quantity and quality, and offering hands-on training and other support, stakeholders specifically acknowledged the role that the CMC has played in building community partnerships throughout the watershed, and expressed interest in increased levels of communication and outreach from the CMC in the future.

Stakeholders' priorities could shift with continued participation

Having a clear understanding of stakeholders' current monitoring goals can certainly help an organization like the CMC better serve and communicate with its members; however, stakeholders' priorities and motivations are dynamic and may change over time. For example, Rotman et al. (2012) found that volunteers' motivations stemmed from personal curiosity at the beginning of their involvement in a project, but then other factors influenced whether or not they continued to participate, such as feeling like part of a community and receiving feedback and acknowledgement for their contributions. Larson et al. (2020) reported that while volunteers report a wide diversity of motivations, those that are conservation-oriented are most likely to grow with continued participation. Still, in their synthesis of peer-reviewed journal articles about participatory environmental monitoring, Stepenuck & Green (2015) identified that while many studies confirm that participants' attitudes and behaviors change as a result of their volunteer work, there is a persistent lack of understanding of the nature and extent of that change over time.

As CMC stakeholders participate in the Cooperative and achieve their goals over time, resulting changes in individual attitudes, as well as environmental conditions, management strategies, community dynamics, environmental literacy, and the volume of available data might cause a shift in the way stakeholders prioritize goals relating to Environment, Management, Community, Knowledge, and Data, respectively. Indeed, Dengah (2013) reminds us that cognition is not static, and our cultural consensus analysis and ranking analysis provide only a snapshot in time of stakeholders' underlying cultural understanding of environmental monitoring priorities. Therefore, as the CMC network continues to grow, it will be essential to continue conversations with stakeholders in order to understand and effectively respond to their changing goals and motivations. Follow-up research to characterize CMC stakeholders' changing needs and priorities would answer the call for more data-rich assessments of environmental monitoring communities' engagement over time (Stepenuck & Green, 2015).

Furthermore, there are such a high number of potential reasons why stakeholders might participate in environmental monitoring, that it is likely impossible to capture them all in a single survey. For example, we know from our respondents' free-response survey answers that CMC stakeholders are also monitoring in hopes to enhance the reputation of their watershed organization, motivate local governments to take ownership over addressing environmental concerns, and enjoy various intrinsic benefits, such as increased personal wellness from spending time outdoors. Additional research could explore how CMC stakeholders prioritize these and other goals that were not included in this study, and assess how the CMC community's priorities compare with other studies of stakeholder goals and motivations (e.g., Robinson et al., 2020; Wright et al., 2015).

Conclusion

The present study shows that while individual stakeholder groups within the Chesapeake environmental monitoring community have their own specific monitoring goals, all CMC stakeholders share an underlying system of cultural knowledge that provides a foundation for collaboration. Furthermore, there are compelling similarities and differences in how stakeholder groups prioritize certain monitoring goals over others and in what objectives they perceive to be the most important for the CMC, as an organization. At the end of the day, CMC stakeholders are united by their shared motivation to collect useful, high-quality data that can be used to inform environmental assessments and decision making and ultimately improve the environment. With this new fine-scale knowledge of stakeholders' goals, the CMC is better positioned to highlight shared goals while also reconciling and balancing varying priorities. Thus, the CMC is poised to truly live up to its name: by integrating volunteer data into traditional datastreams and fostering a more cooperative mentality throughout the environmental monitoring community, the CMC can make volunteer monitoring even more impactful for Chesapeake science and management.

Although this research represents a case study of the CMC community, we suspect that our methodology and resulting recommendations can be broadly applied in a variety of volunteer monitoring contexts in order to help ascertain how to best serve multiple stakeholder groups and build successful and enduring partnerships. "The CMC family has created the engine to keep evolving and growing," said one of its members. "The sky's the limit for this strong group to grow its powerhouse presence in the region, the nation, and as a global model for such work."

Acknowledgements and funding information

We would like to thank the volunteers, coordinators, scientists, managers, and service providers who participated in this research. We also want to acknowledge Natalie Spitzer for her statistical assistance. We are grateful to CMC leadership for helping to refine and distribute the survey, and to Andrea Grover, Astrid Caldas, and Judy O'Neil for providing comments and suggestions on the study and survey design. We also thank the Chesapeake Bay Program and the NOAA Technology Partnerships Office for their support.

Funding for this research was provided by the Integration and Application Network at the University of Maryland Center for Environmental Science. Additionally, this manuscript was prepared by Suzanne Webster, in part, using

Federal funds under award NA21OAR4170062 from National Oceanic and Atmospheric Administration's National Sea Grant College Program, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Sea Grant College Program or the U.S. Department of Commerce. These federal funding sources had no involvement in designing the study; collecting, analyzing, and interpreting the data; writing the manuscript, or deciding to submit the manuscript for publication.

Author contributions

Suzanne E. Webster: Conceptualization (lead), Project administration, Methodology (lead), Investigation (lead), Formal analysis (lead), Visualization (lead), Writing - Original draft (lead), Writing- Reviewing and Editing (lead). **E. Caroline Donovan:** Writing - Original draft (supporting), Visualization (supporting), Reviewing and Editing (supporting). **Elizabeth Chudoba:** Writing - Original draft (supporting), Investigation (supporting). **Christine D. Miller Hesed:** Methodology (supporting), Formal analysis (supporting), Writing- Reviewing and Editing (supporting). **Michael Paolisso:** Conceptualization (supporting), Methodology (supporting), Writing- Reviewing and Editing (supporting). **William C. Dennison:** Writing- Reviewing and Editing (supporting), Funding acquisition (lead)

Part III: Co-creating and evaluating a citizen science program for monitoring submerged aquatic vegetation in Chesapeake Bay

Reprinted from: Webster, S. E., Landry, J. B., Laumann, K. M., Swanson, S., & Dennison, W. C. (2021). Co-creating and evaluating a citizen science program for monitoring submerged aquatic vegetation in Chesapeake Bay. *Regional Studies in Marine Science*, 46, 101906. doi.org/10.1016/j.rsma.2021.101906.

Abstract

Research on submerged aquatic vegetation (SAV) directly informs policy and management decisions in Chesapeake Bay; however, limitations to data collection capabilities of professional scientists have left knowledge gaps that hinder scientific research and management efforts. Experts have called upon volunteers to help collect the local-scale data that are necessary for understanding SAV growth and species distribution within one of the world's largest estuaries. We collaborated with various environmental stakeholders, including SAV experts, volunteer monitoring coordinators, and citizen scientists, to design a multi-tiered monitoring protocol and training program for citizen scientists monitoring SAV in Chesapeake Bay. We employed a sequence of research approaches, which included online surveys, literature review, a pilot study, participant observation with volunteers in the field, and a protocol-testing workshop. From these approaches, we were able to better understand the stakeholders' various needs and requirements for the Chesapeake Bay SAV Watchers program. Evaluative interviews helped us collect feedback on the process of developing the program, as well as on the program itself. We learned that the collaborative process of co-creating the monitoring program led to positive

outcomes for the stakeholders involved, as well as for the perceived scientific rigor of the program. Furthermore, our use of science communication and user-centered design increased the program's functionality and credibility. Finally, our interview results suggested that continuing to incorporate participants' motivations into the program's management will improve volunteer retention and therefore increase the program's impact and longevity. This research will inform the creation of other collaboratively-developed participatory research programs, as well as citizen science programs that simultaneously prioritize engagement, education, and collection of high-quality data.

Introduction

Submerged aquatic vegetation (SAV), or underwater grasses, play a critical ecological role in coastal regions throughout the temperate and tropical oceans, providing many diverse ecosystem services that other species depend on (Orth et al., 2010). For example, SAV serves as a nursery for juvenile fish and shellfish (Beck et al., 2001), and as a key source of food and habitat for wildlife (Lubbers et al.1990), such as blue crabs and migratory waterfowl. SAV also contributes to improved water clarity by trapping suspended sediments (Ward et al., 1984) and absorbing excess nutrients (Kemp et al., 2005; McGlathery et al., 2007), and hydrodynamic damping in SAV beds protects nearby shorelines from erosion (Fonseca et al., 1982; Lacy & Wyllie-Echeverria 2011). Furthermore, SAV increases dissolved oxygen levels while removing carbon dioxide from the water during photosynthesis, serving as a sink for anthropogenic carbon (Duarte et al., 2013) and alleviating coastal acidification (Su et al., 2020). Beyond their ecological value, SAV beds can be understood as a coupled system because the ecological services that SAV provides directly support the well-being of society (Cullen-Unsworth et al., 2014). For example, because SAV is crucial to the survival of many culturally and economically important fisheries, SAV plays a role in increasing food security, providing economic livelihood, and protecting the Bay's rich cultural heritage.

SAV have been described as sentinel species due to their role as both defenders of ecosystem services and crucial habitat, as well as indicators of environmental health (Orth et al., 2017). SAV has high minimum light requirements, therefore light availability is often the most important constraint to the growth of underwater grasses (Dennison, 1987; Gurbisz & Kemp 2014). Largely as a result of this sensitivity to low light conditions and turbidity, underwater grasses are some of the first organisms to be impacted by anthropogenic stressors such as nutrient pollution and sea level rise. Consequently, SAV often serves as a "coastal canary," or an indicator for environmental change and overall ecosystem health (Dennison et al., 1993). Since 1980, global SAV losses have been documented (Orth et al., 2006; Waycott et al., 2009) at a rate of net SAV loss of 0.9% per year. Because underwater grasses provide so many ecosystem services, SAV loss is catastrophic for ecosystems worldwide.

Chesapeake Bay is one of many estuaries globally that has historically suffered major SAV losses. SAV once covered between 200,000 and 600,000 acres of Chesapeake Bay and its tributaries, but dramatic declines of SAV have been observed in Chesapeake Bay since the late 1960s. In 1972, Tropical Storm Agnes decimated over 50% of existing SAV in the Bay (Orth & Moore, 1983), leading to further environmental degradation and economic losses due to the disruption of ecosystem services (Kahn & Kemp, 1985). Due to the decline in Bay health, the Chesapeake Bay Program was formed in 1983. Since its inception, the Chesapeake Bay Program has guided the restoration and protection of the Bay by setting restoration goals, developing management strategies, and monitoring progress. Since 1984, nitrogen in Chesapeake Bay has been reduced by 23% and phosphorus has been reduced by 8% (Lefcheck et al., 2018). Paired with modest restoration efforts, nutrient reductions have allowed for the recovery of over 40,000 acres of SAV, indicating that science-based management actions have been successful (Lefcheck et al., 2018). Today, over twenty species of SAV are commonly observed throughout the Bay and its tributaries, with high species diversity linked to enhanced SAV recovery (Lefcheck et al., 2018).

Though SAV acreage has increased in recent years in some areas of the Bay, thanks to sustained research and management efforts, continued recovery remains a priority for managers and policy makers (Dennison et al., 1993). In 2014, an updated Chesapeake Bay Watershed Agreement established a goal of increasing SAV in the Bay to 185,000 acres, with an interim goal of 130,000 acres by 2025. Additional monitoring and implementation of protective measures will be essential for continued SAV recovery and eventual restoration goal attainment. SAV recovery has thus far been tracked through a long-term, Bay-wide annual aerial SAV monitoring program that is carried out by the Virginia Institute of Marine Science (VIMS) (Orth et al., 2019). This survey (vims.edu/sav), which began in 1984, is one of the most successful long-term SAV habitat monitoring programs in the world, and has repeatedly been used to assess overall Bay health and inform environmental policy. The imagery collected and maps derived provide acreage and density data and are useful for quantifying habitat distribution and density throughout the Bay and its tributaries, and for tracking progress towards the Bay-wide and tributary-specific SAV restoration goals. However, the Bay-wide aerial survey does not provide important species composition data or any other more detailed local-scale information that can help Bay scientists and managers accurately assess the need for targeted conservation and restoration efforts or predict resistance or resilience to the litany of stressors that SAV is subjected to in the constantly evolving Bay environment.

Driven by this need for more detailed and targeted SAV data, members of a coordinated workgroup of researchers, managers, and volunteer monitoring coordinators have taken steps towards adopting a three-tiered hierarchical monitoring framework for SAV in Chesapeake Bay. Tiered, hierarchical habitat monitoring has previously been shown to be effective for understanding and managing SAV conditions at multiple scales (Neckles et al., 2012) and has been implemented by various organizations nationally. Each tier of the Chesapeake Bay hierarchical approach (Figure 19) has its strengths and limitations, but together they maximize the ability to predict local and system-wide responses to environmental stressors and climate change impacts. The annual aerial survey is the first tier in this framework, and it allows Bay scientists and managers to track progress towards restoration targets by quantifying broad-scale SAV habitat distribution and density. The third tier, conversely, provides extensive finer-scale data on SAV and other environmental variables using underwater monitoring methodologies at a limited number of sentinel sites (approximately 20), which are positioned throughout the Bay in locations chosen by SAV experts and environmental managers. The primary purpose of the Chesapeake Bay Sentinel Site Program for SAV is to identify causal relationships by intensively monitoring drivers of change, ecosystem responses, and ecological processes. The middle, second, tier in the overall Chesapeake Bay SAV monitoring effort is the Chesapeake Bay SAV Watchers Program, which is the focus of this manuscript. The SAV Watchers program surveys a diverse amount of habitat characteristics at a large number of locations throughout the Bay, which is useful for broad-scale condition assessments and for identifying and quantifying driver and response relationships.

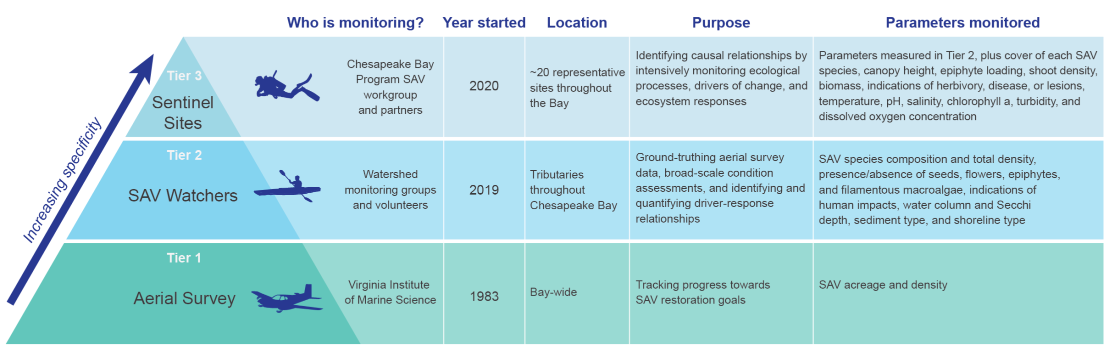

Figure 19. The SAV Watchers program is situated within a three-tiered hierarchical framework for monitoring Chesapeake Bay grasses.

The SAV Watchers program is powered by citizen scientists, or volunteer monitors, who make it possible to generate a large amount of data at a widespread geographical scale. Citizen science is a way to increase public participation in the creation and use of scientific data and knowledge, allowing scientists and volunteers to collaborate on research projects in order to address specific problems (Bäckstrand, 2003; Wiggins & Crowston, 2011). Citizen science is known by many other terms, including community science (Carr, 2004; Wilderman et al., 2004), volunteer biological monitoring (Lawrence, 2006), and public participation in scientific research (Shirk et al., 2012). Regardless of the label, the movement to include volunteers in scientific research, and even more specifically, in environmental monitoring, has expanded around the world over the last three decades (Conrad & Hilchey, 2011; Whitelaw et al., 2003,), in part due to increasing public concern about human impacts on ecosystems (Whitelaw et al., 2003) and government-led environmental monitoring (Conrad & Hilchey, 2011; Pollock & Whitelaw, 2005).

Although citizen science offers many lasting benefits to society, volunteers, and local ecosystems (Conrad & Hilchey, 2011; Dickinson et al., 2010, McKinley et al., 2017; Pocock et al., 2019), it has been increasingly embraced by the environmental science and management community largely due to its ability to increase data collection capacity at minimal additional cost to researchers. The increase in data enables much-needed monitoring at finer-scale resolutions, and thereby expands the scope of research projects beyond what would have otherwise been feasible (Barreto et al., 2003; Cohn, 2008; Fröde & Masara, 2007). In the context of coastal resource conservation, data collected through citizen science programs have been used to increase understanding and inform management of these systems (Cigliano et al., 2015; Lehtiniemi et al., 2020; Marshall et al., 2012; Pattengill-Semmens & Semmens, 2003). In recent years, citizen scientists have helped to fill local and global data gaps (Jones et al., 2018; Waycott et al., 2009) and influence conservation policy and adaptive management for SAV (Unsworth et al., 2020). For example, volunteer-collected data from the Seagrass-Watch program has increased scientific understanding of the seagrasses in various locations, including Torres Straits, Moreton Bay, and the Great Barrier Reef (Finn et al., 2010; McKenzie et al., 2012; Mellors et al., 2008), and has also assisted decision makers and communities in assessing and managing coastal resources and fisheries habitats. Volunteer monitoring of SAV in Chesapeake Bay similarly has the potential to increase knowledge of this important natural resource and inform local and regional environmental decision making and policy.

In Chesapeake Bay, sporadic, localized, or small-scale volunteer SAV monitoring efforts have been patched together in an attempt to meet the data needs of Bay scientists and managers and to ground-truth the annual Bay-wide survey. A coordinated Bay-wide effort was not attempted until a SAV Workgroup survey design workshop identified the need for an integrated and coordinated Bay-wide ground survey conducted by Riverkeepers, watershed organizations, and citizen volunteers and scientists. In 2017, the Chesapeake Bay Program's SAV Workgroup began working with Riverkeepers and watershed organizations to conduct a one-year pilot study that assessed the feasibility of incorporating trained volunteers into the Chesapeake Bay SAV monitoring effort. This study is described in detail in the following sections of this paper. Based on the results of the pilot study, the SAV Workgroup decided to formalize the initiative by developing and implementing a full-scale, Bay-wide, volunteer SAV monitoring program. Although other volunteer SAV monitoring programs exist around the world, one tailored specifically to Chesapeake Bay seemed necessary for many reasons, including the importance of producing data that integrates well with data from ongoing research efforts (Wiggins et al., 2013). Another consideration was that the monitoring protocol for the Bay needed to be flexible enough to facilitate data collection across a large estuary, where water clarity, sampling conditions, and SAV communities are all extremely variable. Furthermore, a new sampling methodology for Chesapeake Bay needed to acknowledge the fact that snorkeling or scuba diving are not always feasible or popular in the Bay's brackish waters, as opposed to other coastal and marine systems where SAV volunteer monitoring relies on volunteers conducting surveys at least partially submerged in clearer waters or wading in intertidal waters (e.g., Seagrass-Watch, SeagrassNet, Community Seagrass Initiative). Finally, the new volunteer monitoring program also needed to be engaging, simple, and useful enough to entice monitoring groups that, in large part, do not necessarily receive allocated funding or other incentives for SAV monitoring.

Our team's objective, therefore, was to develop a monitoring program that generates high quality and actionable scientific data while also providing an engaging and valuable opportunity for participating volunteers and watershed organizations. In order to create a program that simultaneously meets the needs of data collectors and data users, it was important to involve these stakeholders in the process of developing the program. In this paper, we describe the process of collaboratively developing the Chesapeake Bay SAV Watchers monitoring program. We start by sharing the ways in which our team solicited and then synthesized extensive input from volunteer monitoring coordinators, citizen scientists, environmental managers, and scientific experts in order to create and review a protocol for monitoring SAV in Chesapeake Bay. We then describe the elements of the finalized monitoring program and share lessons learned from our evaluative interviews with stakeholders who provided feedback on their experience developing the program, as well as on the final program itself. Finally, we conclude with several helpful recommendations for other scientific teams that are looking to develop or expand environmental monitoring programs in their area.

Methods

Study site

Geography and ecology

Chesapeake Bay is one of the largest and most intensively managed estuaries in the world, and is home to one of the most expansive known resurgences of SAV. The Bay is a highly complex system with a range of habitat conditions, from the near-open waters of the higher salinity southern Bay to the freshwater shallow creeks diverging from dozens of rivers. SAV can be found throughout the Bay's tributaries and is especially prevalent in the Susquehanna Flats. Elements of this study took place at various locations around the Bay (Figure 20).

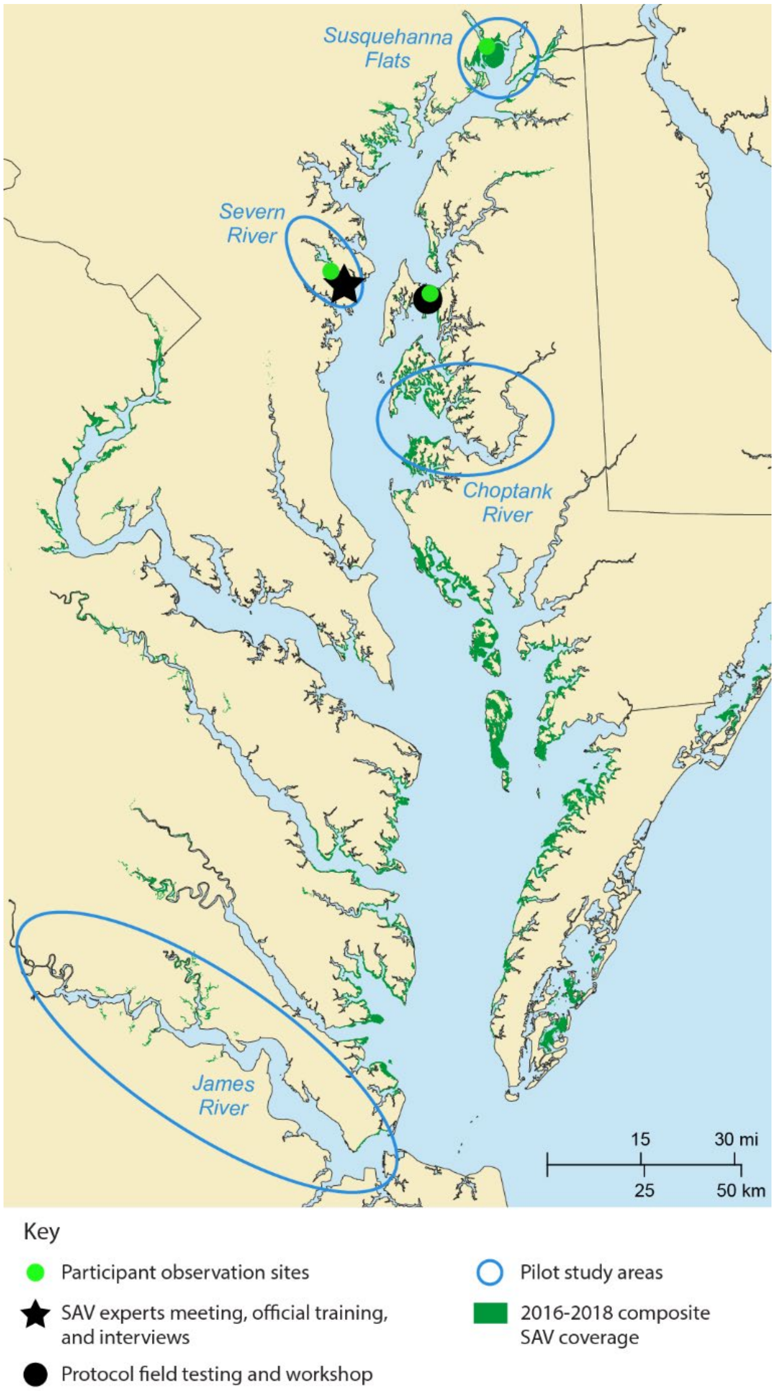

Figure 20. Elements of this study took place across the entire salinity spectrum of tidal portions of Chesapeake Bay.

Culture and politics

In the Chesapeake region, SAV research and monitoring regularly informs environmental policy and management. For example, maps of SAV beds inform decisions on several environmental bills discussed by the Maryland General Assembly. Furthermore, because SAV is widely recognized as a key indicator of Bay-wide health, several regional environmental assessments use SAV acreage as a metric for researching how the health of the Bay is changing over time.

As grasses continue to rebound throughout the Bay, SAV has increasingly attracted the attention of a more general audience; however, the public reaction to SAV resurgence is not always positive. For instance, while many people celebrate the return of SAV to locations where they have been absent for decades, other people lament the increase of "nuisance grasses" that make boating near their docks more difficult. Thus, there is a push to educate the public on the benefits of SAV and shift public perception of SAV resurgence to be more positive and scientifically informed. For example, the 2017 Chesapeake Bay Report Card credited the resurgence of Bay grasses as being a driving factor of the first statistically significant improvement of Bay-wide health in over 30 years. This message was widely circulated in printed and online media, reaching an audience of over 58 million people (GreenSmith Public Relations, personal communication).

As SAV has become part a core part of the public conversation about the Bay's health and its resources, volunteer monitoring groups have expressed interest in expanding beyond collecting water quality data to start monitoring SAV in their local tributaries. The revitalization of SAV in the Bay itself and in the public's interest is an opportunity to create meaningful engagement opportunities for volunteers.

Volunteer engagement has the potential to increase our collective scientific understanding of SAV distribution and to empower knowledgeable environmental stewards.

Pilot study

The SAV Watchers monitoring program was developed and initiated over the course of two and a half years, beginning with a pilot study in 2017 (Table 6). The pilot study was conducted to determine the feasibility of engaging volunteers in SAV monitoring throughout the Bay. The three main objectives of the pilot study were to provide essential SAV data to local, state, federal, and academic institutions in the Chesapeake Bay watershed, foster a relationship between multiple watershed groups and Chesapeake Bay Program partners, and encourage watershed groups to meet their own local conservation, restoration, and outreach objectives.

Table 6. Components of the process of developing the citizen science program took place over the course of two and a half years.

Project milestone	**Date**
Pilot study	Summer 2017
Literature review	June 2018
Participant observation	June and July 2018
SAV Workgroup survey and workshop	June 2018
Protocol field-testing workshop	August 2018
Program resources published	April 2019

First certification training	September 2019
Evaluative interviews	Fall 2019

This project was funded by the Chesapeake Bay Program Goal Implementation Team Project Initiative to advance outcomes identified in the Chesapeake Bay Watershed Agreement. The project was intended to provide seed funding to purchase the materials and equipment necessary to initiate and maintain local volunteer SAV monitoring programs. In addition to funding, SAV Workgroup members provided SAV species identification training for staff and volunteers, and throughout the summer accompanied them in the field to observe volunteer capacity, discuss logistics, and provide additional training when necessary.

Study participants included one umbrella organization, two Riverkeeper organizations, and two watershed groups. The umbrella organization, Waterkeepers Chesapeake, oversaw the logistical components of this project, including contracts, disbursement of funds, and report submission. The organizations involved with SAV data collection included the James River Association, the Severn River Association, the Havre de Grace Maritime Museum Environmental Center, and the Choptank Riverkeeper, which is now part of a larger coalition of eastern shore Riverkeepers called ShoreRivers. These groups monitored SAV in the James River in Virginia, the Severn River on the western shore of Maryland, the Susquehanna Flats at the northern tip of the Bay in Maryland, and the Choptank River on the eastern shore of Maryland, respectively. In total, approximately 60 volunteers participated in the 2017 pilot study and over 700 SAV observations were recorded. All observations and data points were shared with VIMS to ground-truth their aerial survey data.

Because significant ecological differences exist between the participating tributaries, including SAV community types, data collection procedures varied between each monitoring program to best fit the organization's specific location and needs. These initial protocols were established in coordination with the SAV Workgroup, but extensive flexibility was allowed to accommodate for the learning curve of each group and their volunteer capacity. Transect surveys, systematic random sampling, and shoreline surveys were all employed. To accommodate volunteers who did not want to be as rigorously involved in the SAV survey effort, the Water Reporter smartphone app, developed by Chesapeake Commons, was adapted to use for SAV monitoring so that volunteers could report SAV whenever they happened upon it while recreating or fishing.

To learn more about the experiences of volunteer groups, we also surveyed the leadership of the four monitoring groups that participated in the pilot study. Respondents were asked to provide feedback on aspects of their monitoring experience that they found to be enjoyable and useful, as well as aspects that were unwieldy, unsuccessful, or otherwise in need of improvement.

Review of monitoring materials and academic literature

Our team did an extensive review of other SAV monitoring protocol documents, data sheets, and reference materials. We reviewed the materials from other volunteer monitoring programs that focus on SAV, including Seagrass-Watch, Seagrass Spotter, and the Community Seagrass Monitoring Project. We also reviewed the data collection methodologies of several local water quality volunteer monitoring programs, as well as SAV monitoring efforts conducted by professional scientists (e.g., Kirkman 1996; Phillips & McRoy, 1990; Short et al., 2006; Walker, 1988). We consulted several SAV species identification keys, including multiple that are specific to Chesapeake Bay grasses. Finally, we reviewed several published studies on volunteer monitoring of SAV (e.g., Finn et al., 2010; McKenzie et al., 2000; Mellors et al., 2008) and other biodiversity data in coastal regions. Our goal in consulting all of these resources was to learn from the successes and recommendations of other programs and determine what materials and data collection methods we could adopt vs. what would need to be customized for our program based on environmental and sociocultural differences.

Participant observation

During the summer of 2018, we joined volunteers on three separate training days that were held on boats in various locations around the Bay (Figure 21a). During these training sessions, volunteers collected SAV specimens and then practiced identifying different species as a group with the help of a SAV biologist. Our team participated in these activities to learn more about SAV monitoring first-hand. During the training activities, we talked individually with trainees to better understand what volunteers hoped to gain from participating in SAV monitoring, what aspects of data collection they found most difficult or enjoyable, and what kinds of tools might increase their confidence in their own ability to collect scientifically accurate data.

Figure 21. Photos of study participants throughout the process of developing the monitoring program. (a) Participant observation with volunteers at a species identification training in Susquehanna Flats, (b) field testing the monitoring protocol within our team and (c) with the input of workshop participants, and (d) testing volunteer coordinators' SAV species identification abilities during the first certification training.

Feedback from the science and management community

We also needed to determine what type of SAV data would be most desirable and useful from a research and management perspective. In June 2018 we sent a 15-minute online survey to Chesapeake scientists and environmental managers who were members of an interdisciplinary Chesapeake Bay SAV Workgroup and received 21 responses. We then led a one-hour in-person discussion to answer questions that emerged from our survey results and to reach consensus on topics that showed lower levels of agreement on the survey. We also asked the Workgroup how they would prefer to access volunteer-collected data on the existing SAV data platform that is hosted on the VIMS website. A total of 36 SAV experts, riverkeepers, and other environmental professionals in the SAV community attended this session. Our team left the workshop with a short list of high-priority data parameters and recommended data collection methodologies for each chosen data parameter.

Protocol field-testing and refinement

Using data from our surveys, field observations with volunteers, and the expert workgroup meeting, we outlined a tiered monitoring protocol. To discuss and test the protocol, we hosted a two-day in-person workshop in August 2018. On the first day, core project members engaged in detailed discussions about each section of the protocol and field-tested parts of the monitoring protocol (Figure 21b). This resulted in numerous proposed changes to the protocol and datasheets, which we incorporated before the second day of the workshop. On the second day, our team provided an overview of the monitoring program and protocol for 12 volunteers and volunteer coordinators in attendance. The entire group then spent time going through each section of the protocol off a dock adjacent to a SAV bed (Figure 21c). This fieldwork functioned both as training for participants, as well as an opportunity to provide input on the proposed methodology. We received feedback on not only the monitoring protocol, but also on the datasheets, Pocket Sampling Guide prototypes, and monitoring app.

Following the workshop, we integrated the volunteers' feedback into the protocol and consulted with scientific experts to answer questions about specific data parameters. We also discussed data management priorities, data visualization capabilities, and data-related concerns with a VIMS scientist, and collaborated with the developers of the Water Reporter app to improve the app's functionality in the field and better integrate the monitoring protocol into the app's user interface. Once the protocol was completed, it was reviewed by several environmental professionals who were not otherwise directly involved in developing the protocol, and we incorporated their feedback into the final version. All materials for the program were published in April 2019. The first formal certification training was held in September 2019 and six volunteer coordinators from four monitoring groups were certified to train volunteers to collect data in upcoming sampling seasons (Figure 21d). Additional certification training sessions scheduled for June 2020 were postponed due to COVID-19 restrictions.

Evaluative interviews with project partners

Following the training session, we conducted semi-structured interviews with individuals who were involved in the process of developing and launching the program. Two overlapping series of 11 ordered questions guided the interviews; one series was used to interview volunteers or volunteer coordinators, and the other series was for scientific experts (Bernard, 2017). During the interviews, participants were asked to describe their background and motivations for SAV monitoring, reflect on their participation in the process of developing the program, and share their thoughts on the final program and the degree to which it met their needs. We used interview probes throughout the interviews to clarify participants' statements and further explore certain topics. Interviews were conducted in person or using video conferencing software (Zoom.us) over the course of two months in the Fall of 2019. All interviews were audio-recorded and then transcribed with the assistance of an AI-powered transcription app (Otter.ai). A total of 28 interviews were conducted, varying in length from 15 minutes to one hour.

We interviewed 16 volunteer coordinators and 5 volunteers (10 females and 11 males) with a broad range of experience in SAV monitoring. These individuals had varying degrees of involvement in the program's development, from attending a single SAV species training session to participating in multiple feedback opportunities. Interviewees represented a total of 8 volunteer monitoring organizations from watersheds located in Maryland and Virginia. We also interviewed 7 scientific experts (4 females and 3 males) from 4 institutions. These individuals have expertise in a variety of subjects, including SAV biology and monitoring, as well as Chesapeake Bay habitat management and restoration. The scientific experts also had a range of experience working with volunteer monitors or volunteer-collected data.

All interviews were analyzed using MAXQDA, a qualitative data analysis software (Kuckartz & Rädiker, 2019). We used the questions from our semi-structured interviews to create codes for participants' motivations for monitoring SAV, core themes about the process of developing the program, and positive and negative feedback on aspects of the final monitoring program. Text from the interview transcripts was then highlighted and tagged with descriptive phrases representing major themes and sub-themes. We used the resulting list of text fragments to pinpoint the ideas that were repeated by many individuals, or ideas that were of particular interest to this study.

Results

Motivations for participating in the SAV monitoring program development process

It was important for our team to understand the motivations of volunteers, volunteer coordinators, and scientific experts who elected to contribute to the development of this monitoring program because this helped us assess whether the program was delivering the expected benefits and make future changes to improve the program for all users. From our interviews, we identified four major motivations.

First, many interviewees said that they were eager to help develop a more organized monitoring program because the resulting data would benefit their groups directly. Participants recognized that SAV health is an effective indicator of the overall health of local environments; therefore, many volunteer groups were eager to include fine-scale and localized SAV data in their local ecosystem health assessments and environmental report cards. Participants also hoped to use the SAV data to accomplish many local-level goals, such as researching high-priority local questions, tracking restoration progress, and informing policy and decisions that drive the management of the Bay. Second, improving education around the issue of SAV was another driving motivation. Several people participated in this study in order to increase their own knowledge of SAV, and many others expressed interest in improving their ability to help others in their community understand how beneficial SAV is for the Bay as a whole.

Third, while some scientific experts said that they were motivated to participate in this project because of a specific interest in SAV itself, most interviewees indicated that they choose to be involved in SAV research primarily because of the important ecological role that SAV plays in improving the Bay as a whole. One study participant recognized this common interest among study participants, saying they felt a sense of camaraderie with other participants because "Everyone seems to have a collective goal of supporting the health of the Chesapeake Bay." Lastly, participants became involved in this study because they recognized the opportunity to build partnerships across the Chesapeake Bay environmental community. Many interviewees viewed the other program participants as resources and expressed eagerness to learn from each other and strengthen ties between different volunteer monitoring organizations and between monitoring organizations and scientific experts.

Pilot study key results

Overall, the pilot study provided evidence that a formalized volunteer SAV monitoring program would be welcomed, feasible, and impactful in the Bay. The participating monitoring organizations reported that their volunteers were enthusiastic about the opportunity to monitor SAV, and most groups indicated that they would most likely continue to monitor SAV in their locations. All participants agreed that trained volunteers were reliable, dedicated, and able to properly identify SAV species. However, participants expressed a desire for increased rigor and organization from a future volunteer SAV monitoring program and it became evident that dedicated staff time would be necessary to collect and provide SAV data where spatial gaps exist.

The pilot study also had lasting positive impacts. With the funding provided, each of the four participating groups purchased equipment necessary for monitoring SAV that will last for years to come. The data that was collected during this pilot study was valuable for Bay scientists and managers and had a high rate of accuracy. Importantly, the groups involved in this pilot study all anticipated using their own SAV data. Most groups also said that the pilot study provided networking opportunities for the participating volunteers and organizations. Furthermore, participants acknowledged that involvement in the pilot project helped promote environmental stewardship, awareness of water quality issues, connection to the river itself, and both knowledge and appreciation of SAV among their volunteers.

Overall, this study justified providing further support for developing a standardized monitoring protocol and training program. The pilot monitoring program also identified several potential obstacles, including an unwillingness by some volunteers to enter the water or to use the Water Reporter smartphone app while in the field, as well as a need for waterproof species identification guides. We used this constructive feedback when developing the official SAV Watchers protocol and resources.

Lessons learned from the literature review

Reviewing materials from other seagrass monitoring programs helped us gather information about specific content and design options. We used other methods manuals to develop a comprehensive list of potential data collection methodologies and key parameters, including SAV-specific parameters like canopy height and shoot density, as well as other environmental parameters such as water clarity and salinity. We also noted sections of text outside of the monitoring protocol that would be helpful to include in a methods manual, such as an explanation of why SAV monitoring is important and directions for how to take an effective photograph. In our review of SAV species identification keys, we identified a list of categories that are often used to describe each species. While reviewing these materials, our team encountered several styles of presenting information, which helped us brainstorm techniques for communicating our program's content in a way that would be clear and visually compelling.

Our review of published studies on SAV and other biodiversity volunteer monitoring produced several key insights on best practices of volunteer monitoring. For example, we learned that existing marine and coastal volunteer environmental monitoring programs support a wide diversity of conservation-related outcomes, including policy, education, research, community capacity building, and species management (Cigliano et al., 2015). These outcomes aligned closely with our stakeholders' motivations for developing the SAV Watchers program. Our literature review confirmed that in order to achieve these outcomes, it was essential that our group adapt to volunteers' expectations, interests, and skills (Roy et al., 2012) and secure the trust and support of the scientific community (Cigliano et al., 2015) by involving all of these stakeholders throughout the program's development (Pocock et al., 2015). Furthermore, we learned that although citizen science can serve as a reliable source of SAV data (Finn et al., 2010), it is important to remember that training and data verification are essential in assuring the collection of high-quality data. Our group elected to follow the example of many other citizen science biodiversity monitoring projects by requiring participants to attend an in-person training and to submit photographs of observed species alongside quantitative data in order to provide a means for others to verify species identifications (Chandler et al., 2017).

Insights from participant observations of training sessions

Our participant observation studies yielded insights about volunteers' monitoring expectations, needs, and preferences for a SAV monitoring program. Volunteers and monitoring coordinators viewed the training sessions as opportunities to practice SAV species identification and to ask questions that had arisen during their monitoring activities. Training participants expressed that attending multiple training opportunities throughout a single sampling season was an effective way to improve both their ability and their confidence to collect high-quality SAV diversity data. Participant observation also allowed us to establish more realistic expectations for what types of data could feasibly be collected in Chesapeake Bay. For example, we learned that several data collection methodologies used in other SAV monitoring programs would not be appropriate in the Bay's brackish waters, where placing a quadrat and counting stems is difficult, especially considering that many volunteers are unwilling to enter the water while monitoring. The protocol therefore needed to be feasible from small single-person vessels like kayaks, as well as higher-standing boats such as pontoons. It was also clear that some volunteers preferred to record data using their smartphones, while others preferred to use paper datasheets, therefore the protocol needed to accommodate volunteers with variable preferences and abilities.

Finally, our participant observation studies highlighted the necessity and widespread desire for a standardized monitoring protocol with an accompanying set of supporting reference materials. Volunteers and coordinators shared that the members of their monitoring groups have varied perspectives on how best to select sampling sites and how frequently to monitor, and they asked that the new protocol provide specific recommendations and justifications to address these methodological questions. Training attendees shared a need for a standardized list of species with all accepted names included, and expressed frustration with the existing SAV species identification guides, describing them as overly detailed, impractical for use in the field, out of date, or lacking in high-quality pictures that show distinguishing characteristics. Participants admired a personalized and "pocket-sized" species guide that one of the attendees had made for herself, so our team resolved to design a similar resource.

Prioritizing data parameters and selecting appropriate sampling methodologies

The survey of SAV experts and environmental managers clarified the conditions under which the scientific community would be most eager and able to use volunteer-collected data in their own work. An encouraging 14 of 17 respondents indicated that they were interested in increasing their use of volunteer-collected SAV data. Respondents identified specific data parameters that would be most useful for research and management purposes, ultimately prioritizing SAV species data but also expressing high levels of interest in a number of other parameters, such as SAV density and sediment type.

While the survey highlighted several areas of consensus among SAV experts and managers, it also indicated areas of disagreement. During the in-person workshop, our team was able to identify consensus views and address questions left unanswered by the survey. Workshop attendees discussed the addition and removal of several data parameters, and offered recommendations for what sampling methodologies would be most suitable for volunteers and desirable from a data user point of view. For example, workshop attendees confirmed SAV density data would be valuable, and eventually agreed that volunteers should record density observations using a 4-point scale, rather than other methods commonly used in other SAV volunteer monitoring efforts, because they felt that this scale is less likely to result in measurement inaccuracies and has the added benefit of being able to serve as a direct comparison for ground-truthing VIMS aerial density records. Finally, workshop attendees also offered feedback on the process of selecting and defining sampling locations, as well as the overall structure of the tiered monitoring protocol and certification program.

Protocol field-testing and refinement

The first day of the workshop resulted in multiple adjustments to the protocol and datasheet, which were completed overnight so that participants could discuss the most updated versions on the second day. One notable change was simplifying the original protocol into a more streamlined two-tiered design. The field testing and group discussions on the second day of the workshop prompted additional modifications. For example, volunteers appreciated the visual formatting of the datasheet, but requested that additional reference information be provided on each page for easy access, as well as instructional prompts to guide observers while in the field. Participants also offered feedback on the prototype pocket guide, providing a list of features that would make the final product more user-friendly, such as a mixture of photographs and scientific illustrations, a monitoring equipment checklist, and species pages that are easily sortable or removable based on the individual observers' monitoring regions. Finally, workshop attendees provided input on the app that SAV Watchers participants use to collect certain types of data, requesting several additional features that would make the app more user friendly.

Our team used the feedback that we received during the workshop to improve the content and design of the monitoring protocol and other program resources. Consulting with several scientific experts helped us determine the best ways for volunteers to collect useful high-quality data for the parameters that presented a challenge during the protocol field test, including shoreline type and sediment type. Collaborating with the Water Reporter team also yielded successful results, including a customized fillable form that streamlines volunteers' data collection process.

Feedback on the process of developing the program

During our interviews, participants expressed high levels of satisfaction regarding the participatory nature of the program development process. Overall, participants felt that they were offered an appropriate quantity and diversity of opportunities to contribute to the extent that they were able and willing to get involved. Interviewees also commended the collaborative process for creating a space where individuals with such a wide variety of expertise could contribute their perspectives. Many participants especially appreciated the high degree of influence that volunteers and volunteer coordinators were able to have throughout the process, such as sharing ideas about whether or not aspects of the protocol were reasonable requests for volunteers. Multiple people commented that they felt valued throughout the duration of the project, and that they enjoyed feelings of shared ownership for the program after witnessing their contributions being used to make improvements. One volunteer said “It was cool that we got to see changes be made after we suggested certain things.”

Beyond offering feedback on the process of developing the program, participants also commented that their involvement offered direct and immediate personal benefits. Several people expressed that after having participated, they felt more comfortable identifying SAV species and confident about the prospect of teaching the new protocol to members of their own monitoring groups.

Importantly, one final theme that emerged from the interviews was that participants were already thinking about the effects that continued collaboration could have for the long-term success of the program. Several interviewees expressed a hope that the program would evolve over time to best serve program participants. A volunteer summarized this widely-shared sentiment effectively, saying “Every year you need to keep working on it because it can always get better. So I think it's important to keep that attitude and make changes as you hear feedback from the field.”

Monitoring program structure and resources

Tiered monitoring protocol

We created a two-tiered monitoring program structure in order to make this program to be as inclusive as possible for participants with diverse skill sets, time commitments, and technological expertise. The introductory monitoring program (Tier 1) is geared towards individuals who are not members of organized monitoring groups. Site selection and sampling timing is opportunistic, and Tier 1 participants are not required to receive formal training or certification. Tier 1 volunteers record observed SAV species in order of abundance and submit their data to SAV Watchers using the Water Reporter app. The advanced monitoring program (Tier 2), in contrast, is targeted towards volunteers who are members of organized monitoring groups. Site selection and sampling timing is determined by the individual monitoring groups, and Tier 2 volunteers are required to complete a training and certification process. Volunteers collect data on various aspects of the SAV itself, as well as other information that provides further context to the SAV data. These parameters include SAV species composition and total density, presence or absence of seeds, flowers, epiphytes, and filamentous macroalgae, water column and Secchi depth, sediment and shoreline type, and indications of marine debris, shoreline erosion, or other human impacts. Tier 2 volunteers record data on printed datasheets and submit paper sheets to their monitoring group coordinators, who then digitize the data and submit an excel sheet to the SAV Watchers program coordinator. For both Tier 1 and Tier 2, volunteers are required to submit photos to accompany any observations of SAV species, which provide a means to verify the accuracy of all species identification data, if desired. Scientists at VIMS incorporate the data from both Tier 1 and Tier 2 programs into their SAV database and map.

Training and certification model

The SAV Watchers advanced monitoring program follows a ‘train the trainer’ model, under which individuals become certified to take a leadership role in training other people to take part in the monitoring program. The certification process involves attending a structured one- or two-day training session that is hosted by the program coordinator. The training session itself consists of both field and classroom modules, during which attendees, typically volunteer coordinators or riverkeepers, are taught and then quizzed on SAV biology and species identification, field protocols, and data management practices. After completing the training, attendees receive certificates confirming their status as certified SAV Watchers Trainers, along with access to digital copies of all of the training materials and invitations to refresher courses in subsequent years. Certified Trainers are encouraged to attend refresher training sessions as needed and provide an annual training opportunity for their volunteers at the start of each monitoring season.

Resources for program participants

We produced a variety of resources that support certified trainers and volunteers (Figure 22). The methods manual is the core document associated with the advanced monitoring program. This manual contains a step-by-step protocol detailing Tier 2 data collection methodology, as well as several other resources including a SAV species identification guide, information on SAV in Chesapeake Bay, various data collection best practices, and other helpful materials. We also created a series of short instructional videos that accompany the manual and walk viewers through the protocol for each data parameter, as well as several informational videos about topics such as SAV biology, monitoring, and recovery in Chesapeake Bay.

Figure 22. Resources developed to support SAV Watchers participants included a methods manual, introductory monitoring program guide, instructional video series, data sheet, certificates, and a pocket-sized field guide. These materials can be downloaded at www.chesapeakebaysavwatchers.com.

To support volunteers' fieldwork, we created a pocket-sized field guide that contains a condensed SAV species identification guide and other key information such as a field gear packing list. Individual users can customize which SAV species pages are included in their guide based on which plants are most often found in the salinity regime where they monitor. Additionally, we developed a printable data sheet with fill-in data fields arranged in a visually accessible layout and key data collection reference materials printed in the margins. To accompany the paper data sheets, we also developed a data digitization template to assist volunteer coordinators in converting observations from paper to a digital table format. Finally, we developed an agenda for the certification training session, along with printable certificates for certified trainers and volunteers.

To facilitate data collection for the introductory monitoring program, we created a guide that contains instructions on how to submit SAV species observations on the Water Reporter app. We also designed a fillable form that integrates into the Water Report app, which prompts volunteers to provide specified types of observations in a standardized format when submitting data.

Feedback on the monitoring program

When asked about the strengths of the SAV Watchers monitoring program, many participants shared appreciation for the comprehensiveness and clarity of the materials, describing all of the resources as "a complete package." One environmental professional said "You get the manual, but you also get the pocket guide and the data sheet. Everything is really clearly laid out and easy to understand." Volunteers described the data sheet as self-explanatory, the methods manual as approachable and clean, and the training video series as helpful for answering questions and reviewing protocols. Several volunteers and coordinators mentioned that the detailed species identification reference materials and hands-on species identification training sessions have increased their confidence in their own SAV monitoring capabilities.

Interviewees also voiced confidence in the program's ability to engage new and broader audiences. According to participants, the program's tiered approach and built-in flexibility increased its inclusivity and made it possible to engage volunteers with "different levels of interest or engagement or training." For example, multiple people commended the program's ability to "reach audiences where they're most comfortable" by offering options that allow volunteers to collect data using either an app or paper datasheets. Volunteer coordinators were excited at the prospect of using this program to grow their volunteer monitoring programs and further their organizations' missions. Scientists, managers, and volunteers alike shared their hopes that increased public understanding and appreciation for SAV could encourage more people to be more vocal about environmental protection and feel more empowered to speak up against activities that are detrimental to the Bay. Finally, participants felt that volunteers are more likely to become engaged because the program integrates with a broader effort to monitor Bay grasses and overall health. One volunteer coordinator explained, as if speaking to a potential volunteer, "'I would like to enlist you to join this study with us, and the data will also be useful to the Chesapeake Bay Program.' I think that is a useful thing to be able to say to people, so that it's not just local interests, but it's Bay-wide interests, too. I think people really like to see that bigger connection to the Chesapeake Bay."

In addition to offering feedback on perceived strengths of the program, interviewees also shared ideas for how the program could continue to improve. One major theme was the importance of building and maintaining a strong sense of community and enduring support for the partnership. Interviewees proposed that the program would benefit from increased resources invested into building relationships between program participants through social events, social media, or periodic newsletters. A volunteer said "If I'm going to participate... I'm a very small nib in a big tapestry and it would be nice to feel more connected." Specifically, participants expressed interest in receiving updates on the geographical spread of program participation, the quantity and species diversity of SAV in various sections of the Bay, and examples of how the data are being used by scientists or managers for research or policy-making purposes. Additionally, reflecting on other now-extinct SAV volunteer monitoring efforts in Chesapeake Bay, several participants stressed the importance of securing sustained funding to host social events and training sessions, carry out data management activities, and provide ongoing support for volunteers.

Other suggestions for how to improve and expand the monitoring program were centered around the need to further refine the processes of submitting, accessing, and interpreting data. Participants suggested that incorporating the use of existing apps like iNaturalist or Seek into the SAV Watchers protocol could make species diversity data collection more convenient and accurate. Several interviewees also shared that they would eventually like to see a more streamlined process for uploading observations and downloading data of interest, and suggested either integrating with an existing regional environmental database or, more ideally, building a new user-friendly database. A final recommendation on the subject of data management was to be mindful of how the new program fits within the larger and longer-term context of SAV volunteer monitoring. Specifically, one interviewee said "Having seen different programs come and go, it makes me aware that it's important to figure out how they're all going to fit together" and suggested that the SAV Watchers program invest time in digitizing data from previous volunteer efforts to create a single long-term dataset, and furthermore, consider how to clean and store the new incoming data in a way that makes it easy to use as the program continues to evolve over time.

Participants expressed high levels of confidence in the SAV Watchers program's potential to generate valuable data. The quality and variety of training materials, as well as the requirement to receive certification before collecting data, provided interviewees with reassurance that the data are trustworthy. Other interviewees attributed their confidence in the data's value to the collaborative process of creating the program, specifying that "extensive input from the actual volunteers" gave them confidence that the data collection protocol was reasonable and the data was credible. Finally, many participants shared that the connections that the program had with respected organizations playing key roles within the broader context of Chesapeake Bay environmental research and management, such as the University of Maryland Center for Environmental Science, the Maryland Department of Natural Resources, and the Chesapeake Bay Program, made them view the data as more defensible and likely to be accepted and impactful outside of volunteer monitoring organizations.

Several people shared examples of how they were already using volunteer-collected SAV monitoring data and were hoping to expand their use in the future as more data are made available. For example, one organization produced an interactive exhibit about SAV and local species diversity in a museum gallery and another monitoring group used their data to develop a social marketing campaign that informed boaters in their community about the benefits of SAV. Additionally, many local environmental organizations have already incorporated SAV data into their environmental report cards and assessments. One volunteer coordinator shared that their group plans to create a map of SAV species and density for their monitoring region, which they believe will serve as a compelling tool for public education and outreach purposes, as well as an internal reference for helping their group prioritize future management actions and monitoring efforts. Several scientists also shared that they have already started to incorporate volunteer stories into their research and plan to increase their use of volunteer-collected SAV data as they become more available.

Many interviewees also expressed confidence that the data could be used to inform policy changes and management decisions. A volunteer coordinator explained that they were optimistic that the data could and would be used in an actionable way, saying “I don't want to say it’s like ‘ammo,’ but that data was what we needed to go to the Departments and say, ‘We have an issue with xyz policy and here's the data we have to back us up’… I think the data is collected in a way that's very easily understood by policymakers and regulators.” Finally, an environmental manager explained that the program was also helping to inform management activities by promoting dialogue and partnerships: “Just by having watershed organizations involved in the program, we're interacting with them more…We're already using their input and feedback for locating restoration projects, and it's already helping… as more data becomes available, I think we'll be paying a lot more attention to it.”

Despite widespread eagerness to incorporate SAV Watchers data into their work, interviewees also expressed various concerns about the usability of the data. For example, several scientists explained that they expect the quantity of available data, rather than the quality, will determine whether or not they use the data in their future work. Several scientists expressed hope that over time, the program participants would generate a robust and geographically-dispersed dataset, with a critical mass of observations enough to counter any potential errors in data reporting. Other interviewees emphasized the impact that building trust in the program and establishing credibility for the data over time will have on the extent to which the data are ultimately used. Participants voiced cautious optimism for eventually using SAV Watchers data but indicated that this level of confidence would take additional time and effort on the part of the SAV Watchers program. One scientist explained that “often it's just perception of data quality as much as the quality of the data” that is a barrier for people deciding whether or not to use volunteer-collected data.

Discussion

This collaborative process that we have described in detail does not necessarily outline a fixed sequence of activities that we believe others should follow when establishing a monitoring program. Instead, our process and the evaluative interviews reveal a number of important insights about both the collaborative development process and the resulting monitoring program. In this section, we share three specific recommendations with other researchers who wish to develop a volunteer monitoring program or improve upon an existing citizen science effort:

1. Co-creation leads to diverse positive outcomes for science and society
2. Science communication and user-centered design increase program functionality and credibility
3. Incorporating participants' motivations into program management will improve volunteer retention

Co-creation leads to diverse positive outcomes for science and society

The overarching objective of the SAV Watchers program is to generate data that are valuable to scientific communities because of its ability to enhance our knowledge of the Bay's underwater grasses, but also valuable to environmental managers, watershed groups, and individual environmental advocates because of its ability to affect changes in environmental policy and management. The program, therefore, was designed to integrate aspects of two distinct approaches to citizen science— volunteers share their data with experts for the purpose of advancing scientific research, but they also collaborate with scientific partners in order to co-produce new knowledge that addresses concerns of local communities and drives specific policy goals (Bowser & Shanley, 2013; Eitzel et al., 2017; Irwin, 1995). Achieving both of these outcomes necessitates balancing the needs of potential data users with the interests and capabilities of participating data collectors. To create a monitoring program that more successfully meets the diverse needs of Chesapeake Bay SAV experts, environmental managers, volunteer coordinators, and citizen scientists, we adopted an integrative and collaborative approach towards the program's development from the very beginning of the process. For this reason, this program can be regarded on the spectrum of citizen science projects as an example of "co-created public participation in scientific research" (Bonney et al., 2009a; Shirk et al., 2012), also known as "extreme citizen science" (Haklay, 2013), "collaborative monitoring with local data interpretation," (Danielsen et al., 2009), and "participatory action research" (Cooper et al., 2007), among other names. This distinction means that program participants and scientific experts not only collaborate, but share authority and decision-making power throughout all phases of the research, including deciding which scientific questions to address, designing data collection methodologies, collecting samples, interpreting data, and sharing results.

The benefits to adopting this type of participatory approach are significant for individuals, science, and socio-ecological systems (Shirk et al., 2012). For example, projects that involve full collaboration between volunteers and scientific experts earn the highest public confidence ratings of any type of investigation across the citizen science spectrum (Lewandowski et al., 2017). Furthermore, Carney et al. (2009)

found that participatory approaches increase buy-in and participation for collaborative research. Through our interviews and direct observations, we found that participants developed a sense of ownership for the program as they witnessed their own contributions being integrated into the program. Also, because SAV Watchers participants contributed to the creation of the program and have the ongoing ability to develop central research questions and monitoring strategies that address local concerns, research suggests that the volunteer-collected data can be immediately applied towards solving real-world environmental problems of local importance (Bonney et al., 2009a), and has high potential to lead to environmental outcomes like best management practices and restoration projects (Wilderman et al., 2004). Co-created projects also have a high potential for increasing participants' capacities for understanding scientific concepts (Bonney et al., 2009a), interpreting data, presenting results, and contributing to environmental advocacy and decision making (Wilderman et al., 2004). Knowledge produced as part of such a collaborative and transparent process is also more likely to be used by project partners and external data users due to enhanced feelings of ownership for the scientific data and understanding of the knowledge production process (Meadow et al., 2015). Finally, the process of co-creating a citizen science program has been shown to increase trust among stakeholders (Fernandez-Gimenez et al., 2008) and participants' knowledge of community structure (Bonney et al., 2009a), meaning that stakeholders stand to benefit from an enhanced network of individuals with local knowledge and expertise. Our team found evidence of this throughout our interviews-- for example, several volunteer coordinators and environmental managers expressed a desire to continue learning from members of the other group as this program continues.

Despite its benefits, this model of co-creation is less common than other approaches to designing and maintaining citizen science projects, in which volunteer involvement is less intensive or reserved for particular research tasks. This relative rarity is due to the fact that co-creation is often a slower process (Wilderman et al., 2004) that requires more time and money resources from stakeholders not only upfront during the program's development, but also throughout the program's entire existence. Still, our results suggest that this model of integrating stakeholder perspectives throughout the development and duration of the program is particularly effective when attempting to create a program that produces science that meets diverse user needs. This conclusion was also highlighted by Jones et al. (2018), who recommends that seagrass citizen science projects use co-creation to integrate community values into targeted conservation efforts.

The SAV Watchers program answers a broader call for academic scientists to participate in research collaborations with non-academic partners in order to create actionable new science that more directly benefits society and solves real-world problems (Lang et al., 2012; Mauser et al., 2013; Whitehead et al., 2020). Collaborative research that engages non-academic partners can help to close the "the science-action gap" (Reyers et al., 2010), bridging the divide between academic research and real-world implementation in environmental policy and management by facilitating the discovery of socially-relevant and impactful scientific knowledge that can be used to inform science-based decisions. We argue that environmental researchers and managers should consider adopting a similar collaborative approach to creating volunteer monitoring programs in order to increase the likelihood that the programs will enhance scientific understanding of the environment while also empowering watershed groups to affect changes that benefit both communities and the natural environment.

Science communication and user-centered design increase program functionality and credibility

Our goal in developing the program resources was to produce training and reference materials that offer ample support to volunteers and coordinators throughout both the certification process and subsequent monitoring activities. Our interview results suggest that we were successful, as many participants offered positive feedback on the polished appearance, clarity of information, and functional utility of the finalized set of program resources. To do this, we employed various science communication techniques to make scientific concepts and methodologies more approachable and engaging for participants with limited formal scientific training. Burns et al. (2003) defines science communication as the use of skills, media, activities, and dialogue to produce various personal responses to scientific information, such as increased understanding and willingness to engage with science. For example, our practice of integrating visual elements with scientific prose helps to connect with audiences and increase their understanding of scientific content (Frankel & DePace, 2012; Trumbo, 1999). Furthermore, we made a concerted effort to present multiple representations of our key scientific content, which has been shown to be an effective way of meeting the needs of individuals with different learning preferences and diverse backgrounds interacting with science (Burns et al., 2003; Sankey et al., 2010). Specifically, the use of videos, such as our short training videos that accompany written sampling protocols, have been shown to enhance learning experiences and outcomes (Sankey et al., 2010; Swan, 1996) and can potentially increase the quality of volunteer-collected data, especially when paired with in-person training opportunities (Newman et al., 2010; Ratnieks et al., 2016; Starr et al., 2014).

Our work also answers previous calls for science communicators to integrate practices from the discipline of design to enhance the effectiveness of science communication (Davis 2010, Frankel & DePace, 2012, Rodríguez Estrada & Davis, 2015). Science communicators should adopt a user-centered design approach, which involves prioritizing the needs and perspectives of members of the target audience throughout the process of creating communication materials, in order to develop a customized product (Rodríguez Estrada & Davis, 2015). Employing principles of user-centered design, including evaluating prototypes and incrementally refining the product can improve the functionality of products and users' willingness to engage with them (Randall et al., 2005). The extensive input that we received from project participants allowed us to design project resources with the users not only in mind, but involved. Our interviews show that the products ultimately matched well with user preferences, as evidenced by comments about the functionality and approachability of the datasheet and pocket field guide. Additionally, the consistent use of several graphic design elements across our suite of resources, including a thematic blue-green color scheme and a project logo, allowed our team to establish a distinct brand for the monitoring program. Research in the fields of business and marketing has shown that brands can establish an overall personality for an organization or product, signify quality and distinctiveness, and generally strengthen the degree to which stakeholders value the product (Deagon, 2002; Gardner & Levy 1955; Nandon, 2005). Importantly, our results indicated that after being involved in the process of developing the monitoring program and seeing the final resources, participants expressed high levels of confidence in the credibility of the monitoring protocol and the quality of the SAV data that trained volunteers will collect, as well as an eagerness to continue using the monitoring protocol and the resulting data in their future scientific endeavors. The observed positive reaction to the appearance of the program resources further supports the theory that the way that a product is visually presented can influence the perceptions of customers, or in our case, monitoring program participants and potential data users.

Incorporating participants' motivations into program management will improve volunteer retention

Now that the SAV Watchers program is established, complete with a monitoring protocol and an assortment of reference materials and other resources that account for stakeholders' needs, our team needs to focus more of our attention towards building the longevity of the program. Moving forward, a key consideration for maintaining the program's initial momentum will be to take steps to ensure that volunteers remain motivated to participate. Understanding what motivates volunteers to participate in the program will help our team to manage the program in a way that improves both volunteer retention and recruitment (Alender, 2016; Bonney et al., 2009a, West & Pateman, 2016). This is because reconciling the different research goals of citizen scientists, professional researchers, and other stakeholders can be difficult and when not done effectively, these differences in motivations can have significant impacts on volunteer involvement and data outcomes (Jollymore et al., 2017). Through our interviews, we identified many discreet motivations for participating in this study, and in SAV monitoring more broadly, which included making a positive impact on an environment that holds personal significance, enjoying a sense of comradery working towards a shared goal, and using the data to learn more about local SAV habitats. The specific motivations of our participants are consistent with other published studies (e.g., Alender, 2016; McCauley, 2017).

Rotman et al. (2012) found that establishing consistent channels of communication between participants, scientists, and other data users can help to encourage continued volunteer involvement. Our team could use these channels of communication to promote strong identification and sense of place with Chesapeake Bay (Newman et al., 2017), increase feelings of connectedness between participants, and communicate how the volunteer-collected data are being used and what scientific information has been gleaned as a result of volunteer efforts (Alender, 2016; Singh et al., 2014; Van Den Berg et al., 2009). Like our study participants, West and Pateman (2016) suggest sharing the impacts of volunteers' efforts through a newsletter or social media, which can also be an effective tool for recruiting new volunteers and securing additional funding. Additionally, regular newsletters and social media can be useful for establishing a sense of community (Bell et al., 2008) and offering opportunities for participants to interact with each other, which have been shown to be important motivating factors for sustained participation (Locke et al., 2003, West & Pateman, 2016). Furthermore, when volunteers feel undervalued, they are more likely to stop participating in scientific research (Locke et al., 2003; Ryan et al., 2001), therefore, we should take steps to thank volunteers for their contributions, share volunteer experiences, and publicly celebrate accomplishments (West & Pateman, 2016; Wolcott et al., 2008). A newsletter could also prove useful for this purpose, through guest-authored columns that invite volunteers to write a section of the newsletter about one of their own recent monitoring experiences (Lynch, 2000) and publicly awarding service badges to long-term volunteers (O'Brien et al., 2010).

It is also important to remember that volunteer motivations change over time (Rotman et al., 2012), so program organizers should continue to communicate regularly with volunteers to understand their changing needs and goals (West & Pateman, 2016). The SAV Watchers monitoring program should be managed so that it evolves over time in recognition of participants' changing motivations. Regular communication between program managers and volunteers also presents opportunities to continue asking for participant feedback on the program and input into program decisions. Providing program participants with opportunities to contribute to the group decisions and evolving organizational structure increases feelings of connection to the group (Lynch, 2000) and enhances volunteer retention (Garner & Garner, 2011). During our interviews, many SAV Watchers participants indicated that they would be interested in continuing to be involved in programmatic decisions and expect that the program will change over time so that it continues to meet the needs of its stakeholders. Finally, if the program continues to offer volunteers opportunities to have meaningful experiences and develop skills, this will increase not only volunteers' willingness to engage in the monitoring program, but also increase the participants' levels of environmental engagement, more broadly (Dean et al., 2018), providing additional incentive to continue volunteering.

Future work for the SAV Watchers program

At the time of publication, only a limited quantity of data have been collected using official SAV Watchers protocols. Therefore, it is too early to answer questions about the scientific, societal, and ecological impacts of the monitoring program. In future years, we would like to conduct further research into the ways in which SAV Watchers data are used by scientists, managers, local watershed organizations, policy makers, and others to make positive environmental impacts. Our team is also interested in learning more about social impacts of the monitoring program, such as how the program contributes to the way citizens and communities in the Chesapeake Bay region understand and value SAV or the Bay environment, more broadly. Finally, we would like to understand how volunteer SAV monitoring and its impacts on both the scientific community and society might influence the trajectory of SAV distribution and biodiversity in Chesapeake Bay over time.

Beyond exploring the impacts of the monitoring program as it currently stands, we also want to continue collaborating with partners and participants to make improvements to the program. The focus of the program development thus far has been to first confirm the feasibility of volunteer SAV monitoring and then create a protocol and reference materials to support a training and certification program. Next steps should include revisiting data management procedures with a user-centered design approach in order to improve data user's experience of entering and accessing observations, as well as securing long-term funding to support a program coordinator who can recruit and train additional volunteer monitoring coordinators and work with them to maintain high data quality and volunteer interest.

Conclusions

Developing the Chesapeake Bay SAV Watchers monitoring program using a collaborative and iterative approach yielded several positive results. Through a pilot study, literature review, a survey, participant observation, and several workshops, our team was able to integrate perspectives and feedback from stakeholders in order to produce a program that satisfied the needs of people who are collecting SAV data, as well as those who use the data in various contexts. Interviews with volunteers, coordinators, SAV experts, and environmental managers revealed that stakeholders were motivated to contribute to the SAV Watchers program for a diversity of reasons, but primarily people recognized the ecological importance of SAV and wanted to use

SAV data to learn more about the health of local environments and Chesapeake Bay as a whole.

The volunteer monitoring program was designed so that it integrated with a larger framework for monitoring SAV in the Bay and generated high-quality, verifiable data that can be used to inform environmental management decisions. The two-tiered monitoring program offers a wealth of multimedia training resources for participants and relies on a 'train the trainer' approach for certifying volunteers. Stakeholders generally had high levels of confidence in the usability of the volunteer-collected data— in fact, the data have already been used for multiple projects, and stakeholders expressed increased interest in incorporating the data into their work as more data become available and the program becomes more established over time.

Feedback from stakeholders who participated in the collaborative process of developing this program taught us that the process itself helped participants build partnerships across the Chesapeake Bay environmental community, and increased their confidence in the program's scientific rigor and ability to generate actionable, high-quality data that can be used to accomplish local and regional management goals. We also learned that our deliberate use of science communication principles and user-centered design when developing the program resources increased the program's functionality and credibility, while making the program more engaging for participants. Finally, our interviews highlighted the importance of incorporating participants' changing needs and motivations into the program's management in order to build a strong sense of community and ultimately retain volunteers over time. Our team is confident that these results can help inform the creation of other collaboratively-developed volunteer monitoring programs. We have learned a great deal through creating this program and we are optimistic that SAV Watchers will improve and expand through continued collaboration.

Acknowledgements

We would like to thank the volunteers, volunteer coordinators, Riverkeepers, watershed groups, and SAV experts who participated in this study. We also want to acknowledge Chesapeake Commons for their work developing the app used in the SAV Watchers protocol. We are grateful to Emily Nastase, Dylan Taillie, Jamie Currey, and Jason Howard for providing science communication assistance on the monitoring program reference materials. We also want to thank Michael Paolisso, Andrea Wiggins, Astrid Caldas, and Judy O'Neil for providing comments and suggestions on the interview process, as well as Drew Webster for his comments on the draft manuscript. Funding to develop the SAV Watchers program was provided by the Chesapeake Bay Program Goal Implementation Team Project Support Initiative via the Chesapeake Bay Trust [grant numbers 14571, CB96341401]. Funding for conducting interviews and producing this manuscript was provided by the Integration and Application Network at the University of Maryland Center for Environmental Science.

Author contributions

Suzanne E. Webster: Conceptualization (supporting), Methodology (lead), Investigation (lead), Formal analysis, Visualization (equal), Project administration, Writing - Original draft (lead), Writing - Reviewing and Editing (lead). **J. Brooke Landry:** Conceptualization (lead), Supervision (equal), Investigation (supporting), Funding acquisition (equal), Writing - Original draft (supporting), Writing - Reviewing and Editing (supporting). **Sky Swanson:** Methodology (supporting), Visualization (equal), Writing - Original Draft (supporting). **Katie May Laumann:** Methodology (supporting), Writing - Original Draft (supporting). **William C. Dennison:** Conceptualization (supporting), Supervision (equal), Funding acquisition (equal), Writing - Original draft (supporting), Writing- Reviewing and Editing (supporting).

Discussion

Summary and synthesis

This dissertation involved three distinct research studies that explored stakeholders' perceptions and experiences concerning public engagement in scientific research and environmental management. Part I investigated stakeholders' perceptions of how power is distributed across the socio-political landscape of Chesapeake Bay environmental science and management. This research provided evidence that the Chesapeake Bay environmental community, on the whole, has a high level of familiarity with Chesapeake Bay science, management, and citizen science, and a distinct awareness of some of the conceptual and functional overlap between these domains. Stakeholders also agreed that diverse stakeholder concerns should be more prominent in management decisions, and there was evidence of shared feelings of disempowerment across the Chesapeake environmental community. Furthermore, this research showed that stakeholders largely agreed that science should play a central role in informing environmental policy, but had more variable perspectives on the degree to which citizen science should ideally be able to influence management decisions. Stakeholder patterned survey responses suggested a potential bias against citizen science or volunteers who take part in participatory research, but many respondents recognized that citizen scientists could potentially play important roles in protecting Chesapeake Bay. The results of this study further support the case for expanded stakeholder engagement in Chesapeake scientific research and environmental decision making, and suggest that the Chesapeake environmental community could further explore transdisciplinary citizen science as a means of empowering non-scientists to participate in scientific knowledge creation and actively contribute to environmental discourse.

Part II explored the extent to which cultural knowledge about environmental monitoring was shared between stakeholders within a network of volunteer monitoring organizations, and pinpointed key similarities and differences in how key stakeholder groups prioritized various environmental monitoring goals. This research showed that members of the Chesapeake Monitoring Cooperative (CMC) drew from a shared system of cultural knowledge surrounding environmental monitoring, which provides a foundation for collaboration amongst stakeholders with different priorities. This study also found that stakeholders prioritized goals related to collecting actionable data and improving environmental conditions, and revealed compelling similarities and differences in how stakeholder groups prioritized increasing knowledge and building a sense of community. Furthermore, stakeholders perceived that the CMC, as an organization, prioritized increasing the quality, quantity, and accessibility of volunteer-collected data, and especially valued the CMC's resources associated with these priorities. The results of this study provide insight into stakeholders' goals and needs, which can inform the CMC's organizational priorities and strategic outreach and ultimately increase the impact that volunteer monitoring has on Chesapeake science and management. These results and the methodological approach can also inform the design and coordination of other large-scale volunteer monitoring efforts, and help citizen science programs more effectively serve as boundary spanning organizations that foster a more cooperative mentality among stakeholders and facilitate monitoring partnerships that accomplish diverse goals.

Part III described the process of collaboratively developing a multi-tiered volunteer monitoring protocol and training program with the input of submerged aquatic vegetation (SAV) experts, environmental managers, and stakeholders within the volunteer monitoring community. Additionally, the study synthesized stakeholders' feedback on their experience engaging in the program development process, as well their perceptions of the final SAV Watchers program. The results reveal that engaging stakeholders in establishing broader program goals and methodologies can lead to positive outcomes for the stakeholders and citizen science efforts. More specifically, using a transdisciplinary approach to citizen science increased stakeholders' feelings of engagement. This research also found that employing principles of user-centered design and science communication in the creation of program resources improved stakeholders' perceptions of the SAV Watchers program's overall functionality and credibility. Furthermore, this research offered support for the hypothesis that continuing to incorporate participants' motivations into the program's management will improve volunteer retention and therefore increase the program's overall likelihood of impacting management decisions and environmental health. The results of this study can inform the creation and expansion of other collaboratively developed participatory research programs, especially those that simultaneously prioritize engagement, education, and the collection of high-quality data.

This dissertation shows that citizen science has clear potential to increase stakeholder engagement and improve adaptive management of Chesapeake Bay; however, there are some disadvantages or challenges that must be kept in mind. First, effective citizen science programs are large investments and sometimes securing and sustaining adequate funding and people power is an insurmountable challenge (McKinley et al., 2017). In fact, resource constraints, such as lack of attention from an organizer, are one of the main reasons that citizen science projects fail to achieve their desired outcomes (Wiggins et al., 2018). Success of citizen science programs is enhanced if citizen science projects are interwoven into existing institutional structures and have transparent local benefits (Buytaert et al., 2014), therefore efforts should be made to collaborate and coordinate among stakeholders whenever possible and clearly communicate project goals and expected outcomes to potential funders and participants. Another challenge for citizen science is measuring management outcomes. Because management outcomes are influenced by the interaction of sociological and ecological processes, citizen science should ideally measure ecological and social outcomes (Cooper et al., 2007). Though some tools exist to support the evaluation of citizen science projects with respect to science productivity (e.g., Wiggins et al., 2018), measuring outcomes remains a challenge because citizen science projects have diverse goals and it can be difficult to quantify social change.

Another consideration is that co-created and transdisciplinary citizen science, specifically, is not a panacea and in some cases, is ethically inappropriate. Transdisciplinary citizen science certainly has advantages for engaging stakeholders in producing knowledge and shaping environmental discourse, but the transdisciplinary approach requires significant time and resources (Liu et al., 2008), and presents challenges associated with evaluating research impact (Stokols et al., 2003). This more resource-intensive approach might not be the most appropriate in all cases (DeLorme et al., 2016). For example, citizen science efforts that require extended involvement and more intensive engagement can be overwhelming or prohibitively burdensome for participants, resulting in unintentionally exclusionary research (Belcher et al., 2016). It is important to engage people across the spectrum of citizen science formats and allow participants to choose their own level of participation without making assumptions about their level of interest (Hecker et al., 2018). Offering diverse opportunities for engagement will welcome a higher diversity of participants and will allow everyone involved to reap the benefits and balance the challenges associated with all participation models. It is also important to remember that stakeholders, most notably volunteers, should benefit from the research in a way that is proportional to any amount of risk and burden that they take on (Resnik et al., 2015). Transdisciplinary citizen science projects must adequately address community needs and ensure that a) the community benefits from the research, b) clear communication occurs throughout the project, and c) researchers are implementing community recommendations (del Campo et al., 2013).

It is certainly worth noting that citizen science, whether transdisciplinary or not, could be criticized as an overly restrictive approach to knowledge integration because it often prioritizes the production of scientific knowledge over many other outcomes (Mueller et al., 2012). Furthermore, Pettibone et al. (2018) note that "integrating lay knowledges into dominant scientific frames threatens the plurality of epistemic approaches to knowledge production" and suggest that researchers involved in both citizen science and transdisciplinary research approaches should be more sensitive to the power dynamics of knowledge integration. At its core, transdisciplinary citizen science is a process that strives to integrate multiple types of knowledge using an approach that prioritizes scientific outcomes and draws heavily on scientific discourse; therefore, it runs the risk of not adequately incorporating other types of non-scientific knowledge and environmentalisms. McCarthy (2000) noted that in a truly transdisciplinary and post-normal decision-making context, Chesapeake Bay science would be "another form of knowledge or perspective to complement other equally important viewpoints within an 'extended peer community' decision-making body" (p. 172). He also suggested that developing egalitarian decision-making and governance processes "represents a shift of paradigmatic proportions and thus represents a more normative, long-term socio-political goal" (McCarthy, 2000, p. 172). No matter the approach, knowledge integration is inherently complex and there is no single optimum strategy (Raymond et al., 2010). Therefore, in the absence of a perfect approach, transdisciplinary citizen science could certainly serve as a starting point for broader stakeholder engagement in environmental discourse and decision making, especially in contexts like Chesapeake Bay, where science already has a strong presence in environmental governance.

This dissertation shows that research partnerships between citizens and scientists can lead to a wide variety of beneficial outcomes. To maximize the positive impacts of these collaborations, it is important that all stakeholders involved are able to directly benefit from their participation in these partnerships. Intentional and strategic citizen science efforts can bridge existing gaps between scientific researchers and non-academic partners, and produce synergistic research that would not have been possible in the absence of collaboration. Together, participants can collaboratively prioritize environmental questions and conduct environmental research that accomplishes a diversity of goals. Through their research efforts, stakeholders can co-produce new scientific knowledge that is more valuable for holistically managing socio-environmental systems and solving high-priority environmental problems. Importantly, citizen science projects have the potential to provide opportunities for stakeholders to come together and contribute to the formation of a new, more inclusive, environmentalism that reflects the interests and values of a broader range of stakeholders (Berkes, 2009).

Citizen science can serve as an avenue into the realm of environmental policy for members of the public who are directly affected by political decisions but often have little power to voice their opinions and influence decision-making processes (Bäckstrand, 2003; McKinley et al., 2017). One way that citizen science connects people to environmental policy is by creating opportunities for citizens to co-create scientific knowledge that informs policy decisions (Hecker et al., 2018). In the case of transdisciplinary citizen science efforts, the linkages to policy are perhaps even more direct and empowering. Transdisciplinary citizen science creates the space for environmental stakeholders to collaboratively define research priorities and collect data that will help decision makers address issues of immediate and local concern. Still, there are challenges associated with building effective partnerships between decision makers and citizen scientists (Hecker et al., 2018). This research identifies some of the challenges present in Chesapeake Bay, such as bias against citizen science and perceived misalignment of monitoring goals, and offers evidence-based recommendations for how to overcome these challenges. Once these challenges are addressed, Chesapeake Bay environmental stakeholders will be able to more fully make use of the full potential of transdisciplinary citizen science. Taking additional steps towards effectively integrating community knowledge and value systems into science discourse will increase stakeholder buy-in and heighten the sense of shared governance and stewardship amongst environmental stakeholders. Instead of allowing scientific knowledge and scientific environmentalism to completely dominate environmental discourse, knowledge integration and distributed decision-making authority builds trust and bridges communication gaps within the broader community of stakeholders (Bidwell, 2009; McKinley et al., 2017). In this way, citizen science has the ability to shift authority structures by decentralizing power and enabling more cooperative and democratized management of resources (Freitag & Pfeffer, 2013).

Although this dissertation research represents a case study of the Chesapeake Bay environmental community, the methodology and resulting recommendations can be broadly useful in a variety of contexts. The Chesapeake region has a history of providing original research in estuarine and eutrophication science, and developing integrated monitoring and management programs that are widely emulated, and this original research on citizen science partnerships can also be reproduced or applied elsewhere. This research provides justification for increased public engagement in science, broadly. The case studies each provide recommendations for how to improve citizen science and transdisciplinary citizen science efforts. Results of this dissertation also add to existing literature on how to maximize the benefits of citizen science and build successful and enduring partnerships that serve multiple stakeholder groups. Specifically, the analysis of stakeholders' monitoring goals and evaluation of the process of co-developing a monitoring program could also encourage more scientists to consider collaborating with citizen scientists during earlier stages of projects, including conceptualization and design phases.

Further reflections and future directions

Looking back on the research comprising this dissertation, there are several lessons learned that might benefit other scholars looking to conduct transdisciplinary research involving mixed methodologies, multiple epistemological approaches, and long-term collaborative partnerships. First, qualitative research provides rich details about people's perspectives, experiences, and cultures. This dissertation research would not have been possible without extensive qualitative research approaches and methodologies. It is important to bear in mind that collecting and interpreting qualitative data can be a complex because it reflects a messy reality. Collecting perceptions data, specifically, is time-intensive and requires interpersonal skills that are not necessarily essential when conducting research that is grounded in the natural sciences and relies on quantitative data. Collecting perceptions data involves building trust and rapport with research participants, and the information must be earned by the researcher. Researchers should invest time and energy into building relationships, networking, and connecting with people who are well connected themselves and willing to help recruit other participants. It can also be advantageous to work in a location or community where there is pre-established interest in the research and a certain level of partnership infrastructure and coordination already in place.

Another consideration associated with conducting qualitative research is that researchers must build in additional time to secure institutional approval before beginning to conduct qualitative research involving human subjects. This is ethically-essential, but also potentially challenging process in that it requires researchers to carefully plan how they will recruit participants and obtain their consent, what steps they will take to protect participants from potential harm, and what data they will collect, among other details. It can be difficult to plan to this level of detail in advance because research questions in qualitative research studies often evolve continuously and require investigators to be adaptive throughout the course of a study (Darlington & Scott, 2020). Researchers should start this ethics review process early and build flexibility into their plan wherever possible and appropriate.

Another lesson learned is that interdisciplinary and transdisciplinary research is challenging because there are so many moving pieces. This type of research necessarily draws from several academic disciplines, so it is likely that a researcher will need to review a comparably larger number of studies than what might be typical for a more traditional research effort. During the literature review process, it can be helpful to keep an organized folder of literature, take notes in the form of an annotated bibliography, and be continuously mindful of maintaining a suitable balance between depth and breadth. Furthermore, it is important to note that transdisciplinary research requires and develops different skills than traditional research (Roux et al., 2012). Even while "drowning in information," transdisciplinary researchers must embrace their role as synthesizers and, as E. O. Wilson suggests, be able to "put together the right information at the right time, think critically about it, and make important choices wisely" (Wilson, 1999). Transdisciplinary (and "undisciplinary") scholars should develop the skills of methodological groundedness and epistemological agility, which allow them to effectively navigate and synthesize aspects of multiple disciplines (Haider et al., 2017). It is also essential that transdisciplinary researchers strategically select an interdisciplinary team of mentors who can help them develop these skills and also draw from their own specific expertise to ensure that the researcher is, in fact, considering the "right information at the right time". Additionally, transdisciplinary research is case-specific, highly integrative, and fraught with both anticipated and unforeseen challenges. In cases when researchers are faced with many potential options, there is often not one single correct approach or decision, and almost as often, mentors and partners are not going to be in complete agreement with each other about which option is best. Transdisciplinary researchers need to be team players and authentic listeners, but at the same time, they must be bold and maintain enough independence and self-confidence to feel empowered to make and defend their own decisions.

An additional lesson is directed towards researchers who span the research-practitioner divide in various ways, by collaborating with practitioners, conducting research based on ongoing projects, or simultaneously playing both roles, themselves. It can be difficult for a researcher to juggle the responsibilities of completing project work, meeting real-world needs, and conducting original research that contributes to academic literature. In the case of this dissertation, the work was partially funded and inspired by two distinct grants designed to advance citizen science in Chesapeake Bay. This presented an incredible opportunity to conduct research that was immediately actionable; however, it also presented various challenges. For example, both the CMC project and the SAV Watchers project had their own deliverables and grant schedules, which were both interwoven and yet also distinct from the investigative and evaluative research components of this dissertation. When conducting research that also involves producing project deliverables and informing ongoing decision-making processes, it is important to work closely and communicate clearly with partners to ensure that there is a shared understanding of critical dates, information needs, and overall objectives (Karrer et al., 2011; Nagle et al., 2016). Taking care to closely link data collection to relevant practitioner goals and outcomes can help to further bridge the researcher-practitioner divide (Rasmussen et al., 2017). It might also be necessary for a researcher to be flexible with their approach in order to meet evolving project and partner needs while also maintaining a manageable workload and realistic scope for their own research. Finally, researchers coordinating efforts that bridge the research-practitioner divide should work hard to maintain a bird's-eye view of the effort in its entirety, and be proactive in ensuring that all the moving pieces are balanced and synergistic.

It is also important to consider some of the common concerns or potential "pitfalls" associated with conducting research that is focused on stakeholder perspectives or embedded in stakeholder communities. First, when conducting a study to better understand differences between groups of people, researchers should clearly acknowledge the complexity within individuals and the variation within stakeholder groups. Doing this will help researchers to avoid the structuralist tendency of falsely homogenizing viewpoints or cultural perspectives (Cohen, 1992; Forsynth, 2004). Researchers must also take care to be perceptive and truthful when representing research participants and translating or integrating local knowledge. Participants should be able to recognize themselves in the final research (Cohen, 1992). When researchers neglect to speak responsibly and accurately about a group of people or on behalf of a community, even if done unintentionally, they can generify cultures and silence local perspectives (West, 2005). Ideally, researchers should empower communities to speak for themselves in order to maximize the benefits of research for the community of interest (Milton, 1993). Using direct quotes and including participants as reviewers or coauthors of final research products are just two of many ways of addressing power discrepancies between researchers and participants.

One additional consideration is that researchers who study communities or conduct collaborative research with communities need to reflect on their own positionality as insiders and outsiders of the communities in question (Merton, 1972). A researcher's self-identity and perceived status can affect their research process, partnerships, and outcomes (Wallerstein & Duran, 2008). For example, researchers who are perceived as insiders can sometimes gain a community's trust more easily and draw from their shared experiences to collect richer data and more fully understand community perspectives (Dwyer & Buckle, 2009); however they might also struggle to answer questions about potential bias in their research, and their ability to legitimately analyze "that of which they are a part" might be called into question (Kerstetter, 2012). In contrast, researchers perceived as community outsiders are often valued for their objectivity and emotional distance but could be required to work harder for access to data, and to defend their ability to understand a perspective or situation even without having experienced it directly (Kerstetter, 2012).

Researchers can take several actions to navigate the challenges and enjoy the benefits associated with each of these positions. For example, it is beneficial to develop partnerships and trust with communities over time, and to work on diverse teams that include a mixture of insider and outsider researchers (Kerstetter, 2012). Collaborating on teams composed of a mixture of insider and outsider investigators has been shown to offer advantages for projects that involve integrating diverse perspectives (Louis & Bartunek, 1992). Finally, researchers should understand that the insider/outsider dichotomy is overly simplistic (Breen, 2007; Dwyer & Buckle, 2009), and that in actuality, most researchers will occupy different roles depending on changing contexts. This was certainly the case for this dissertation. The responsibility, therefore, falls on researchers to be self-reflexive about how their positionality could impact their research at any given time (Serrant-Green, 2002).

I would like to acknowledge my own positionality as a researcher and offer a reflexive perspective of how my role and positionality potentially influenced this research. I am a 30-year-old white woman with a middle-class upbringing, a resident of the Chesapeake Bay watershed throughout my time conducting this research, and a member of the Chesapeake Bay environmental community. Specifically, I am a scientist with a background in ecology, cultural anthropology, and science communication, and a student within the interdisciplinary Marine Estuarine and

Environmental Sciences Graduate Program at UMCES. While I am not an active participant in any Chesapeake Bay citizen science efforts, I value public science and research that offers immediate benefits to society beyond contributions to academic research. My individual characteristics and values make me demographically similar to many of the participants who contributed to this research, including other members of the Chesapeake environmental community and people affiliated with the CMC and the SAV Watchers programs.

I consider my positionality as a researcher to be advantageous for understanding the perspectives and experiences of the stakeholders involved in my research for several reasons. First, I believe that I benefitted from an increased level of trust and familiarity on the part of my research participants, particularly for Parts II and III of this dissertation. For example, my professional and personal relationships with CMC leaders and SAV Watchers participants greatly improved my access to data and capacity for co-production with stakeholders. As a colleague and a fellow environmentalist, I had the opportunity to converse with participants who were perhaps more open and honest in sharing their perspectives with me than they would have been with an unknown and socially distant researcher. Second, my personal interests in applied and public science have resulted in high levels of genuine enthusiasm for this work, which has increased my commitment to conducting research that is both 1) responsive to the needs of the Chesapeake Bay citizen science community, as well as 2) scientifically rigorous and trusted by environmental professionals and academics. These dual commitments have incentivized me to be as objective as possible in my research, and be inquisitive of assumptions, appropriately critical of community practices, and inclusive of diverse participants and perspectives.

Future researchers could build upon several aspects of this dissertation, both in Chesapeake Bay and more broadly. To expand on this work in Chesapeake Bay, future researchers could use this dissertation as a baseline dataset for longitudinal studies on stakeholder perceptions. For example, it would be interesting to learn how CMC stakeholders' monitoring goals evolve as the Cooperative continues to mature, or how environmental stakeholders' perceptions of citizen science and stakeholder engagement in Chesapeake management change over time. It is also worthwhile to note that 2025 is a milestone year for the Chesapeake Bay science and management community. Any best management practices that are needed to achieve the water quality standards established by the 2010 Total Maximum Daily Load (TMDL) are supposed to be implemented by 2025. To achieve this goal, scientists and managers will need to accelerate progress over the next four years by collaborating with stakeholders to address pressing science needs and inform management decisions (Hyer & Phillips, 2021). After 2025, Bay stakeholders will need to revisit management and restoration goals and reassess how they can best work together going forward. This dissertation could provide insight into how to expand stakeholder engagement in future Chesapeake Bay science and management. Future researchers could build upon this work and conduct evaluative research that more directly investigates the impacts that Chesapeake citizen science efforts have on environmental conditions or management outcomes. For example, studies could be designed to determine whether the SAV Watchers effort results in environmental policies that more aggressively protect vulnerable habitats, or whether the CMC contributes to improved water quality or increased use of volunteer monitoring data in environmental decision-making contexts. Evaluating environmental, political, and educational outcomes will help improve individual citizen science efforts and advance the broader field of citizen science (Hecker et al., 2018). Additionally, future initiatives could also investigate how large-scale citizen science efforts like the CMC could most effectively be incorporated into existing Chesapeake environmental science and education programs. Environmental literacy and education programs form the foundation of the CBP's goal of having an "informed and active citizenry" (O'Neil et al., 2020), and engaging in citizen science efforts could enhance connections between students and the natural world, especially in urban environments. Finally, this dissertation offers yet another example of how social science contributes rich information to enhance Bay environmental science and management efforts. Future researchers should continue to conduct social science research, and the Chesapeake environmental management community should expand the role that social science research has in Bay management. Specifically, empowered stakeholders should draw more heavily from social science contributions and integrate social scientists into collaborative learning and decision-making processes.

Outside of the context of Chesapeake Bay, this research could be replicated across different socio-ecological systems. For instance, disseminating a broader survey to measure environmental stakeholders' feelings of empowerment or attitudes towards citizen science in other contexts could further inform best practices for stakeholder engagement in environmental management. Similarly, future researchers could employ the approaches presented in Part II of this dissertation to conduct more in-depth analyses of stakeholders' motivations and goals for participating in environmental monitoring programs. Up until now, most research has explored the motivations of volunteers while largely overlooking the perspectives of data consumers; however, a more detailed understanding of all stakeholders' goals could help monitoring programs more strategically align resources to meet diverse needs. This research would likely produce significantly different results in other socio-environmental systems, especially in communities with more diverse citizen science participation (socio-economic status, race, age, etc.), geographic locations where residents are not as culturally connected to the landscape, and management contexts in which decision-making processes are not historically as coupled with environmental research. Beyond replicating portions of this research in other locations and communities, future work could also expand on this research through the development and evaluation of other co-created citizen science projects.

Co-created and transdisciplinary citizen science programs are less common than other types of volunteer monitoring programs, but recently, citizen science scholars suggested that more co-design with participants could enhance citizen science progress at the science-society-policy interface (Hecker et al., 2018). Future research could evaluate projects like SAV Watchers to "provide evidence that co-designing projects is worth the effort" (Hecker et al., 2018). Finally, increasing diversity, equity, inclusion, and accessibility within the broader environmental research and management community has implications for data quality and environmental justice (Blake et al., 2020). Further research that provides insight into how citizen science programs could better engage and empower underrepresented communities would advance Chesapeake Bay citizen science and also benefit the broader movement towards more participatory, actionable environmental research.

Conclusion

This dissertation provides evidence that further efforts to enhance stakeholder engagement in Chesapeake Bay research and management would be welcomed by stakeholders and would likely lead to beneficial science and policy outcomes. Specifically, this research shows that benefits arise from designing citizen science programs collaboratively with direct input from stakeholders and with stakeholders' diverse monitoring goals in mind. Citizen science responds to recent calls for local-scale monitoring data and science-based models that are more representative of the needs of stakeholders (e.g., Hood et al., 2021; Zhang et al., 2018). Citizen science programs can also function as boundary spanning organizations that build partnerships within the environmental stakeholder community and empower non-scientists to participate in scientific knowledge creation. Additionally, this research shows that citizen science also increases feelings of inclusion among stakeholders, increases confidence in data quality, and produces actionable data that stakeholders can use to accomplish their diverse goals.

In his recently-published book, titled The Future Chesapeake, Schubel (2021) urged the environmental management community to shift away from pushing to restore the Bay back to a former state, and instead pull together to collaboratively shape the future Bay using forward-looking, currently-underutilized tools. Citizen science is one such underutilized tool that has proven potential. With enhanced stakeholder engagement in environmental research and management, Chesapeake Bay stakeholders can co-create a more holistic environmentalism that empowers all stakeholders to contribute to the shared goal of adaptively managing the Bay. Citizen science is a promising new frontier that could help navigate Chesapeake science and management forward along its present trajectory towards increasingly transdisciplinary adaptive management that serves the Chesapeake Bay socio-ecological system in its entirety.

Appendices

Appendix 1. List of the organizations represented among the survey respondents.

Respondents were asked to provide the name of the organization that they were primarily affiliated with in their role as an environmental stakeholder.

1. Alan J. Anderson Foundation
2. Alexandria Renew Enterprises
3. Allegheny Mountain Chapter of Trout Unlimited
4. Alliance for the Chesapeake Bay
5. Anacostia Riverkeeper
6. Anne Arundel Community College Environmental Center
7. Anne Arundel County Public Schools
8. Anne Arundel Watershed Stewards Academy
9. Antietam-Conococheague Watershed Alliance
10. Arundel Rivers Federation
11. Audubon Naturalist Society
12. Baltimore County Department of Environmental Protection & Sustainability
13. BayLand Consultants & Designers, Inc.
14. Berkeley County Farmland Protection Board
15. Blue Water Baltimore
16. Bradford County Conservation District
17. Cambridge South Dorchester High School
18. Capital Stand up Paddleboarding
19. Charles County Government
20. Chesapeake Bay Commission
21. Chesapeake Bay Environmental Center
22. Chesapeake Bay Foundation
23. Chesapeake Bay Magazine
24. Chesapeake Bay National Estuarine Research Reserve, Maryland
25. Chesapeake Bay National Estuarine Research Reserve, Virginia
26. Chesapeake Bay Program
27. Chesapeake Bay Trust
28. Chesapeake Conservancy
29. Chesapeake Conservation Landscaping Council
30. Chesapeake Legal Alliance
31. Chesapeake Research Consortium
32. Citizens Advisory Committee
33. City of Annapolis, Maryland
34. City of Gaithersburg, Maryland
35. City of York, Pennsylvania
36. Colonial Soil and Water Conservation District
37. Columbia County Conservation District
38. Delaware Division of Parks and Recreation
39. Dewberry Engineers
40. District of Columbia Department of Energy and Environment
41. District of Columbia Government
42. Eastern Shore Land Conservancy
43. Eastern Shore Maryland local government
44. EcoLatinos, Inc.

45. EcoLogix Group, Inc.
46. Environmental Finance Center
47. Fairfax County Government
48. Four Mile Run Conservatory Foundation
49. Friends of Herring Run Parks
50. Friends of the Rappahannock
51. Geosyntec Consultants, Inc.
52. Glen Echo Park Aquarium
53. Great Bay Work
54. Gunpowder Valley Conservancy
55. Hampton Roads Planning District Commission
56. Harford County Watershed Stewards Academy
57. Havre de Grace Maritime Museum, Inc. & Environmental Center
58. Headwaters, LLC
59. Howard County Office of Sustainability
60. Interfaith Partners for the Chesapeake
61. Interstate Commission on the Potomac River Basin
62. Izaak Walton League of America
63. James River Association
64. Johns Hopkins University
65. Lancaster Clean Water Partners
66. Lancaster County Conservation District
67. Lancaster Farmland Trust
68. Little Falls Watershed Alliance
69. Local Government Advisory Committee to the Chesapeake Executive Council
70. Lord Fairfax Soil and Water Conservation District
71. Magothy River Association
72. Maryland Agricultural Education Foundation
73. Maryland Association for Environmental and Outdoor Education
74. Maryland Campaign for Environmental Human Rights
75. Maryland Department of Agriculture
76. Maryland Department of Natural Resources
77. Maryland Department of Planning
78. Maryland Department of the Environment
79. Maryland Department of Transportation
80. Maryland Environmental Service
81. Maryland Environmental Trust
82. Maryland Farm Bureau
83. Maryland Forest Service
84. Maryland General Assembly
85. Maryland House of Delegates
86. Maryland League of Conservation Voters
87. Maryland Master Naturalists
88. Maryland Park Service
89. Maryland Sea Grant
90. Mathews County Land Conservancy
91. Mid-Atlantic 4R Nutrient Stewardship Association
92. Mitchell Enterprises, Inc.
93. Montgomery College
94. Montgomery County Department of Environmental Protection
95. Morgan State University
96. National Aquarium
97. National Fish and Wildlife Foundation
98. National Marine Fisheries Service

99. National Oceanic and Atmospheric Administration
100. National Park Service Chesapeake Bay Office
101. Natural Resources Conservation Service
102. OpinionWorks, LLC
103. Oyster Recovery Partnership
104. Patapsco Heritage Greenway
105. Patuxent Riverkeeper
106. Paxton Creek Watershed & Education Association
107. Peninsula Master Naturalist
108. Penn State Communication, Science, and Society Initiative
109. Penn State Master Watershed Stewards
110. Penn State University
111. Pennsylvania Association of Conservation Districts
112. Pennsylvania Department of Conservation and Natural Resources
113. Pennsylvania Department of Environmental Protection
114. Pennsylvania Forest Stewards
115. Pennsylvania House of Representatives
116. Pennsylvania No Till Alliance
117. Pennsylvania Organization for Watersheds and Rivers
118. Pennsylvania Townships Association
119. Petro Design Build
120. Pickering Creek Audubon Center
121. Piedmont Environmental Council
122. Plisko Sustainable Solutions, LLC
123. Potomac River Fisheries Commission
124. Potomac Riverkeeper Network
125. Prince William Soil and Water Conservation District
126. Red Lion Municipal Authority
127. Reed Smith, LLP
128. Renfrew Institute for Cultural & Environmental Studies
129. Rivanna Conservation Alliance
130. River Network
131. Robinson Nature Center
132. Safe Skies Maryland
133. Sassafras Environmental Education Center
134. Scientific and Technical Advisory Committee
135. Severn River Association
136. Severn Riverkeeper Program
137. Shore Rivers
138. Smithfield Foods
139. Smithsonian Environmental Research Center
140. Smithsonian Institution
141. Spa Creek Conservancy
142. St. Mary's College of Maryland
143. St. Mary's County Commission on the Environment
144. St. Mary’s County Government
145. Stroud Water Resource Center
146. Susquehanna River Basin Commission
147. Tetra Tech, Inc.
148. The Conservation Fund's Freshwater Institute
149. The Downstream Project
150. The Foundation for Pennsylvania Watersheds
151. The Minimalist Garden
152. The Nature Conservancy

153. Trout Unlimited
154. U.S. Department of Agriculture Natural Resources Conservation Service
155. U.S. Department of Defense
156. U.S. Environmental Protection Agency
157. U.S. Fish and Wildlife Service
158. U.S. Geological Survey
159. University of Baltimore
160. University of Maryland Center for Environmental Science
161. University of Maryland College Park
162. University of Maryland Environmental Finance Center
163. University of Maryland Extension
164. University of Maryland Sea Grant Extension
165. University of Virginia Institute for Engagement & Negotiation
166. University System of Maryland
167. Upper Susquehanna Coalition
168. Verna Harrison Associates, LLC
169. Versar Natural Resources Team Columbia
170. Virginia Coastal Zone Management Program
171. Virginia Conservation Network
172. Virginia Department of Conservation and Recreation
173. Virginia Department of Environmental Quality
174. Virginia Department of Wildlife Resources
175. Virginia Institute for Marine Science
176. Virginia Master Naturalist program
177. Virginia Sea Grant
178. Virginia Wildlife Magazine
179. Washington College
180. Waterford, Inc.
181. Watershed Alliance of Adams County
182. Watershed Alliance of York, Inc.
183. Watershed Stewards Academy
184. West Virginia Conservation Agency
185. West Virginia Department of Agriculture
186. West Virginia Department of Environmental Protection
187. West Virginia Rivers Coalition
188. Wildlife Leadership Academy
189. York County Conservation District
190. York County Extension

Appendix 2. Monitoring goals of CMC stakeholders (N=75), ranked in order of average respondent rating.

Monitoring goal	**Goal category**	**Overall rank**	**Modeled response**	**Average rating**	**Standard deviation**
Collect data that is useful for watershed managers and decision-makers	Data	1	7	6.51	0.96

Contribute credible data to environmental assessments and reports	Data	2	7	6.43	1.02
Learn more about the health of a local waterway	Knowledge	3	7	6.37	1.05
Improve water quality or waterway habitats	Environment	4	7	6.31	1.08
Collect long-term data on waterways	Data	5	7	6.2	1.01
Track year-to-year changes in watershed condition	Data	6	7	6.07	1.14
Make environmental conditions better for future generations	Environment	7	7	6.07	1.21
Provide a baseline status of our stream health	Data	8	7	6.04	1.43
Show where water quality is poor	Environment	9	7	5.97	1.33
Raise public awareness of environmental issues	Knowledge	10	7	5.87	1.45
Protect the resources that local waterways provide for communities	Community	11	7	5.83	1.42
Evaluate the suitability of certain sections of the waterway for aquatic life	Environment	12	7	5.72	1.42
Inspire people to become stewards of their local waterways	Community	13	7	5.69	1.5
Determine which areas need protection or restoration	Environment	14	7	5.69	1.43
Work towards restoring my local waterway to a healthy state	Environment	15	7	5.68	1.66
Provide data for scientific models and research	Data	16	7	5.65	1.56
Build community connection to the greater watershed	Community	17	7	5.53	1.66
Promote community understanding of their local streams	Knowledge	18	7	5.47	1.68

Encourage citizen volunteer involvement in environmental issues	Community	19	7	5.45	1.59
Evaluate the effectiveness of restoration measures or best management practices	Manage	20	7	5.39	1.7
Generate new knowledge on a waterway that is currently not understood	Knowledge	21	7	5.36	1.63
Build collaborative partnerships between citizens and environmental agencies working on water quality issues	Community	22	7	5.32	1.57
Increase my understanding of environmental issues	Knowledge	23	7	5.24	1.73
Encourage neighbors to implement best management practices on their property	Community	24	6	5.23	1.52
Respond to public concern for the health of a particular waterway	Environment	25	7	5.21	1.76
Assess the environmental condition of an area that I am worried about	Environment	26	7	5.15	1.73
Assess whether or not public policies and other management tools adequately protect the environment	Manage	27	7	5.09	1.78
Assess the health of places of public recreational interest (swimming and fishing areas, drinking reservoirs, etc.)	Manage	28	7	5	1.76
Assess the impact of a specific change in land use on air quality, water quality, or living resources (*e.g.,* development, logging, gas shale development, dam removal)	Manage	29	7	4.97	1.64
Enhance government accountability	Manage	30	7	4.96	1.87
Influence new land use and resource management policy	Manage	31	6	4.95	1.48

Help people understand what they can do to help save the Bay	Knowledge	32	7	4.91	1.56
Monitor possible locations of point source pollution (*e.g.,* acid mine drainage site, sewage treatment plant, storm water pipe, industry discharge site)	Manage	33	7	4.83	1.87
Provide opportunities for people to engage with other people in their community	Community	34	7	4.81	1.82
Satisfy my scientific curiosity	Knowledge	35	7	4.81	1.8
Provide environmental education opportunities	Knowledge	36	7	4.73	1.96
Answer a specific research question on a particular location, species, or environmental threat of interest	Knowledge	37	4	4.73	1.58
Assess species distribution and abundance	Environment	38	7	4.72	2.08
Monitor for waterborne pathogens (*e.g.,* E. coli, enterococcus, fecal coliform)	Manage	39	7	4.72	2.16
Report possible violations if an area is not in compliance (does not meet designated use, exceeds total maximum daily load, etc.)	Manage	40	7	4.71	1.9
Collect data as part of an agreement with county, state, or federal agencies	Data	41	7	4.67	2.02
Offer fun, sustainable initiatives for members of the public	Community	42	6	4.47	1.84
Recruit people for stream advocacy	Community	43	7	4.28	1.88
Collect the first data on a new parameter in a particular area	Data	44	4	3.76	2.03

Appendix 3: Goal categories, ranked in order of average respondent rating (N=75). A Kruskal-Wallis test ($p=0.001$) performed on the average ratings indicated that the average ratings across all CMC stakeholders in aggregate were non-identical across the five goal categories. A significant adjusted p-value from Dunn's multiple comparisons test indicated a significant difference in how CMC stakeholders rated goals across two specified categories. Asterisks indicate level of significance, with (*) meaning $p \leq 0.05$ and (**) meaning $p \leq 0.01$. Stakeholders rated the Management category significantly lower than both the Data and Environment categories.

Goal category	**Overall rank**	**Average rating**	**Standard deviation**	**Bonferroni-adjusted p-values**
Data	1	5.67	0.81	D - E: p=1.000 D - K: p=0.418 D - C: p=0.221 D - M: p=0.002 (**)
Environment	2	5.61	0.93	E - K: p=0.871 E - C: p=0.495 E - M: p=0.008 (**)
Knowledge	3	5.28	1.10	K - C: p=1.000 K - M: p=0.972
Community	4	5.18	1.24	C - M: p=1.000
Management	5	4.96	1.23	

Appendix 4. The five highest-priority monitoring goals for each stakeholder group, based on respondents' mean survey responses. Asterisks indicate that the goal was not included among the five highest-rated monitoring goals CMC stakeholders in aggregate.

Monitoring goal	**Goal category**	**Rank by group**	**Average rating**	**Standard deviation**
Scientists (N=9)				
Contribute credible data to environmental assessments and reports	Data	1	6.78	0.44
Collect data that is useful for watershed managers and decision-makers	Data	2	6.56	0.73
Collect data as part of an agreement with county, state, or federal agencies	Data	*3	6.44	0.73
Show where water quality is poor	Environment	*4	6.22	0.83
Make environmental conditions better for future generations	Environment	*5	6.11	1.17
Managers (N=9)				
Collect data that is useful for watershed managers and decision-makers	Data	1	6.78	0.44
Collect long-term data on waterways	Data	2	6.33	1.00
Assess the impact of a specific change in land use on air quality, water quality, or living resources	Management	*3	6.22	0.97
Contribute credible data to environmental assessments and reports	Data	4	6.11	0.93
Make environmental conditions better for future generations	Environment	*5	6.00	0.93
Volunteers (N=27)				
Collect data that is useful for watershed managers and decision-makers	Data	1	6.52	0.75
Provide a baseline status of our stream health	Data	*2	6.50	0.71
Learn more about the health of a local waterway	Knowledge	3	6.44	0.80
Contribute credible data to environmental assessments and reports	Data	4	6.44	0.93
Improve water quality or waterway habitats	Environment	5	6.30	1.07
Coordinators (N=15)				
Improve water quality or waterway habitats	Environment	1	6.80	0.41
Raise public awareness of environmental issues	Knowledge	*2	6.67	0.62
Learn more about the health of a local waterway	Knowledge	3	6.60	1.12
Make environmental conditions better for future generations	Environment	*4	6.50	0.76
Collect long-term data on waterways	Data	5	6.47	0.74
Service providers (N=8)				
Learn more about the health of a local waterway	Knowledge	1	7.00	0.00

Inspire people to become stewards of their local waterways	Community	*2	6.88	0.35
Collect data that is useful for watershed managers and decision-makers	Data	3	6.75	0.46
Raise public awareness of environmental issues	Knowledge	*4	6.63	0.74
Protect the resources that local waterways provide for communities	Community	*5	6.50	0.53

Appendix 5. Dunn's multiple comparisons test was performed on Scientists' mean responses for each of the goal categories, following a significant Kruskal-Wallis test (Figure 15). Dunn's test indicated that Scientists rated the Data category statistically higher than the Community category (p=0.018). Asterisks indicate level of significance, with (*) meaning p≤ 0.05 and (**) meaning p≤ 0.01. The category that received the highest average rating is listed first for each comparison in the first column.

Categories compared	**Unadjusted p-values**	**Bonferroni-adjusted p-values**
Data - Community	0.002 (**)	0.018 (*)
Environment - Community	0.032 (*)	0.319
Data - Knowledge	0.044 (*)	0.443
Data - Management	0.049 (*)	0.492
Management - Community	0.247	1.000
Knowledge - Community	0.265	1.000
Environment - Knowledge	0.301	1.000
Environment - Management	0.323	1.000
Data - Environment	0.328	1.000
Management - Knowledge	0.964	1.000

Appendix 6. Dunn's multiple comparisons test was performed on stakeholders' ratings of the Community category, following a significant Kruskal-Wallis test

(Figure 15). Dunn's test indicated that service providers rated the Community category statistically higher than both Scientists (0.004) and Managers (p=0.039). Asterisks indicate level of significance, with (*) meaning p≤ 0.05 and (**) meaning p≤ 0.01. The group that gave the highest average rating is listed first for each comparison in the first column.

Groups compared	**Unadjusted p-values**	**Bonferroni-adjusted p-values**
Service providers - Scientists	3.897e-4 (***)	0.004 (**)
Service providers - Managers	0.004 (**)	0.039 (*)
Coordinators - Scientists	0.006 (**)	0.056
Service providers - Volunteers	0.011 (*)	0.111
Coordinators - Managers	0.044 (*)	0.444
Volunteers - Scientists	0.068	0.682
Coordinators - Volunteers	0.148	1.000
Service providers - Coordinators	0.203	1.000
Volunteers - Managers	0.322	1.000
Managers - Scientists	0.496	1.000

Appendix 7. Respondents who indicated having either a medium or high level of familiarity with the CMC and answered the second set of questions, which pertained to CMC objectives (N=60).

Stakeholder group	**Frequency**	**Percentage**
Coordinators	14	23.3
Volunteers	17	28.3
Service providers	7	11.7
Scientists	9	15.0
Managers	7	11.7
Other	6	10.0
Total	60	100.0

Appendix 8. Objectives of the CMC, according to all stakeholders who indicated having either a medium or high level of familiarity with the CMC (N=60). CMC organizational objectives are ranked in order of stakeholders' mean response.

Question text	**Overall rank**	**Average rating**	**Standard deviation**
Increase the amount of monitoring data that is available across the watershed	1	6.65	0.58
Increase the overall quality of volunteer-collected monitoring data	2	6.40	1.08
Provide technical and logistical support to volunteer monitoring groups	3	6.37	1.07
Standardize data collection methodologies across non-traditional monitoring groups	4	6.33	1.16
Provide scientists and agencies increased access to credible data for their work	5	6.32	1.11
Increase and promote the use of volunteer-collected data in Bay scientific studies and management decisions	6	6.17	1.05
Manage and store all volunteer-collected data in the Chesapeake Bay watershed	7	6.08	1.45
Create a watershed-wide baseline dataset	8	6.07	1.25
Encourage citizen volunteer engagement in environmental issues	9	5.85	1.31
Build community connection to the greater watershed	10	5.80	1.22
Provide a platform to view data for the purpose of protecting public health and safety	11	5.80	1.33
Increase environmental stewardship	12	5.72	1.56
Empower communities to analyze and interpret their own monitoring data	13	5.72	1.47
Create collaborations between citizens and natural resource agencies	14	5.68	1.59
Improve water quality and stream health throughout the Chesapeake Bay watershed	15	5.65	1.62
Promote community understanding of local streams	16	5.53	1.56
Increase the public's environmental literacy and scientific knowledge of the Bay	17	5.52	1.30
Help the Chesapeake Bay Program answer specific research questions	18	5.52	1.44
Encourage the formation of new non-traditional monitoring groups	19	5.45	1.41

Provide tools for public outreach	20	5.25	1.58
Identify impaired waters	21	5.10	1.90
Help people understand what they can do to help save the Bay	22	4.98	1.69
Recruit people for stream advocacy	23	4.83	1.70
Verify the effectiveness and progress of management actions	24	4.58	1.85
Influence new land use and resource management policy	25	4.45	1.85

Appendix 9. The five objectives that each stakeholder group perceived were the highest priorities for the CMC as an organization, based on respondents' mean survey responses. Asterisks indicate that the objective was not included among the five highest-rated organizational objectives for CMC stakeholders in aggregate.

Organizational objective	**Rank by group**	**Average rating**	**Standard deviation**
Scientists (N=9)			
Increase the overall quality of volunteer-collected monitoring data	1	6.89	0.33
Standardize data collection methodologies across non-traditional monitoring groups	2	6.56	0.53
Provide technical and logistical support to volunteer monitoring groups	3	6.56	1.01
Increase the amount of monitoring data that is available across the watershed	4	6.56	0.53
Increase and promote the use of non-traditionally-collected data in Bay scientific studies and management decisions	*5	6.44	0.73
Managers (N=7)			
Increase the amount of monitoring data that is available across the watershed	1	6.43	0.98
Increase and promote the use of non-traditionally-collected data in Bay scientific studies and management decisions	*2	6.29	1.11
Provide a platform to view data for the purpose of protecting public health and safety	*3	6.14	1.21
Provide scientists and agencies increased access to credible data for their work	4	6.14	1.21
Provide technical and logistical support to volunteer monitoring groups	5	6.14	1.21

Volunteers (N=17)			
Increase the amount of monitoring data that is available across the watershed	1	6.76	0.44
Create a watershed-wide baseline dataset	*2	6.71	0.59
Manage and store all volunteer-collected data in the Chesapeake Bay watershed	*3	6.59	0.80
Standardize data collection methodologies across non-traditional monitoring groups	4	6.47	1.01
Increase the overall quality of volunteer-collected monitoring data	5	6.41	0.87
Coordinators (N=14)			
Provide scientists and agencies increased access to credible data for their work	1	6.71	0.47
Increase the amount of monitoring data that is available across the watershed	2	6.71	0.47
Manage and store all volunteer-collected data in the Chesapeake Bay watershed	*3	6.64	1.08
Increase the overall quality of volunteer-collected monitoring data	4	6.57	0.76
Standardize data collection methodologies across non-traditional monitoring groups	5	6.50	0.76
Service providers (N=7)			
Increase and promote the use of non-traditionally-collected data in Bay scientific studies and management decisions	*1	7.00	0.00
Provide technical and logistical support to volunteer monitoring groups	2	7.00	0.00
Increase the amount of monitoring data that is available across the watershed	3	7.00	0.00
Empower communities to analyze and interpret their own monitoring data	*4	6.43	0.53
Build community connection to the greater watershed	*5	6.29	1.25

Appendix 10. Respondents represented CMC stakeholders with distinct roles and interests within the organization (n=75).

Selected Characteristic	**Frequency**	**Percentage**
Role within the CMC		
Coordinators	15	20.0
Volunteers	27	36.0
Service providers	8	10.7

Scientists	9	12.0
Managers	9	12.0
Other	7	9.3
Level of familiarity with the CMC		
Very familiar	32	42.7
Familiar to some extent	32	42.7
Not familiar	11	14.7
Tier(s) of data used and/or collected		
Tier 1	38	50.7
Tier 2	39	52.0
Tier 3	24	32.0
I do not collect or use CMC data	7	9.3
Type(s) of data used and/or collected		
Benthic macroinvertebrates	25	33.3
Non-tidal water quality	52	69.3
Tidal water quality	36	48.0
State of primary affiliation		
Delaware	1	1.3
District of Columbia	1	1.3
Maryland	28	37.3
Pennsylvania	6	8.0
Virginia	28	37.3
West Virginia	2	2.7
No primary state-level affiliation	9	12.0
Age		
21 - 35	18	24.0
36 - 50	14	18.7
51 - 65	22	29.3
> 65	14	18.7
Not specified	7	—
Sex		
Woman	38	50.7
Man	34	45.3
Not specified	2	—

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