

Sea Change: Using Citizen Science to Inform Fisheries Management

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Increasing costs are challenging the capacity for resource management agencies to keep up with mounting needs for robust data about fish populations and their habitats. Furthermore, trust among scientists, government agencies, and the public is fundamental to effective fisheries management, and relations among these three groups are increasingly strained when decisions about fishing limits are made (or are perceived to be made) on the basis of limited information or analysis. In the South Atlantic region of the United States, the South Atlantic Fishery Management Council has begun building a citizen science program to increase the quantity and quality of data used for fisheries management decisions throughout the region and to build trust and foster mutual understanding among those involved in the process. The goal is to build on existing management infrastructure to address key challenges to managing fisheries for long-term sustainability. In the present article, we examine the collaborative process used to establish the program.

Keywords: fisheries management, citizen science, cooperative research, collaborative science, sustainability

Fisheries provide a valuable source of food, income, and recreation to individuals and communities worldwide. Managing fisheries to meet competing needs while ensuring sustainability of fish stocks is challenging. Decisions about fisheries management are expected to be made using sound science and data, and more data are needed for sustainable management of numerous fisheries and fish stocks. In the United States, the Magnuson–Stevens Fishery Conservation and Management Act of 1976 (Magnuson–Stevens Act) requires that federal fisheries management actions (such as determinations of catch limits and protected areas) be based on BSIA (the best scientific information available), and the multiple agencies and organizations involved in federal fisheries management devote considerable time and effort to meeting this mandate. Unfortunately, increasing costs for research and operations are challenging the capacity for resource agencies to keep up with mounting needs for robust data about fish populations and their habitats.

One avenue toward collecting such data is to build on the growing momentum of citizen science, defined as a form of open collaboration in which individuals participate voluntarily in the scientific process (US Congress 2016). Citizen science—if it is carefully designed and thoughtfully implemented—could be an important collaborative approach to filling key data gaps in fisheries science and management. Existing data collection programs could be

supplemented with new projects collaboratively designed and carried out by scientists and volunteers including fisherman (hereafter, *fishers*), potentially filling knowledge gaps with information that could inform fisheries management. Engaging multiple stakeholders in the science that drives management decisions also could enhance the decision-making process, helping to increase trust and transparency among fishers, scientists, and managers.

This vision is on its way to becoming a reality in the South Atlantic region of the United States, where the varied stakeholder groups of the South Atlantic Fishery Management Council (SAFMC) have recently been inspired to build a citizen science program. In the present article, we examine the collaborative process that was created to establish the infrastructure necessary to develop citizen science projects that can increase the quantity and quality of data used for fisheries management decisions throughout the region. This process is significant, because it is the first known case of any group intentionally building a citizen science program framework to guide the development of targeted citizen science projects. In the present article, we also describe products developed by the SAFMC program that can be used by other resource management citizen science efforts. First, however, some background will provide perspective on the challenges facing South Atlantic fisheries managers to place development of the new citizen science program in context.

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Figure 1. South Carolina Department of Natural Resources fisheries biologist conducting creel survey with recreational fisher. Such surveys can provide data useful in assessing catch. Photograph: Phillip Jones, South Carolina Wildlife Magazine.

Fisheries Management 101

In the United States in 2017, saltwater fisheries supported 1.7 million jobs and contributed \$244 billion in sales to the economy (National Marine Fisheries Service 2020a). US policies regulating this vast enterprise, which includes both commercial and recreational fishing, are determined by eight regional fishery management councils created by the aforementioned Magnuson–Stevens Act. The jurisdiction of these councils extends over federal waters, which lie between 3 and 200 nautical miles offshore and cover more than 4 million square miles (except in Texas, western Florida, and Puerto Rico, where federal waters start at 9 nautical miles offshore).

Each council includes the regional administrator for the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries) and multiple stakeholders from each state, usually employees of state resource agencies and members of the fishing community. Advisory panels appointed by the council, including fishers, scientists, members of nongovernmental organizations, and community members with fishery-specific expertise, are official avenues for wider stakeholder input into the policy-setting process.

Developing regulations often begins with a stock assessment to determine the condition of a fish population. The overall goal of an assessment is to provide the best available high-quality scientific information for managers to develop appropriate regulations to ensure sustainable fisheries, healthy ecosystems, and productive coastal communities. The majority of assessments require large amounts of data to accurately portray fishery population size, distribution, and response to fishing activity. Three types of data are commonly used (Lynch et al. 2018).

First is information on catch, the amount of fish removed from a stock by fishing. Because catch data come primarily from fishers, they are considered fishery-dependent data and may be collected by various methods. Commercial catch is estimated primarily from reports filed by fishers and dealers. Additional information may be provided by observers, logbooks, and random surveys of participants. Dockside sampling is often used to obtain detailed information about species composition and the length, weight, and age of landed fish.

For assessing recreational catch, the primary data-collection methods are the Marine Recreational Information Program (MRIP) catch and fishing effort surveys, operated by NOAA Fisheries and largely conducted by the states. This program samples boat- and shore-based recreational and for-hire (charter or headboat) fishing trips for catch information. Other sources of recreational

catch and effort information include supplemental surveys and electronic logbooks submitted by for-hire vessel operators, telephone surveys, trip reporting, creel surveys, and various specialized regional surveys conducted by NOAA Fisheries and some states (figure 1).

The second type of data used in stock assessments is information on a stock's abundance, a measure or relative index of the number or weight of fish in the population. Data on abundance ideally come from surveys for which researchers systematically sample fish at numerous locations within as much of a stock's geographic range as possible. Because scientific surveys collect abundance data independently of either commercial or recreational fishing activities, the resulting data have been called *fishery independent*. Abundance data in the form of catch rates also can be inferred from fishery-dependent sources. These are less desirable, however, because of potential bias from inconsistent fishing methods and the selection of perceived high-catch fishing areas.

The third type of data collection needed for assessments is information on a stock's biology and typically includes measures of fish size, age, movements, genetics for stock identification, and rates of growth, reproduction, and natural mortality. Biological information is collected from a range of fishery-dependent and fishery-independent sources.

In addition to information on catch, abundance, and biology, stock assessments may include information on the environment, climate, or other variables pertinent to current and future stock health. Together, all of this information is incorporated into a population dynamics model that provides the foundation for council management actions and management program evaluations. Councils develop such actions

through fishery management plans and amendments, and the resulting regulations are implemented by NOAA.

This entire process requires reliable data, which are costly to collect across the vast expanse of federal waters. In addition, a recent emphasis on ecosystem-based fisheries management has put a focus on the need to look beyond single species and to examine interactions between target and nontarget species, such as predator–prey relationships. Resources are often insufficient to provide and analyze the large amounts and diverse types of data about population sizes and trends and ecosystem characteristics needed by councils for making recommendations.

Furthermore, the US federal fishery management system can be viewed as an interdependent ecosystem of data collection, stakeholder input, and decision-making processes. Trust among all players—scientists, government agencies, fishers, and the public—is fundamental to effective functioning of this ecosystem. Relations among the stakeholder groups are increasingly strained when decisions about fishing limits are made (or are perceived to be made) on the basis of limited information or analysis.

This all means that basic fisheries management depends on filling multiple known knowledge gaps and building trust, all within the existing management infrastructure. Citizen science offers new opportunities for collaboration that, if carefully designed, can address each of these needs and foster mutual understanding among all those invested in managing fisheries for long-term sustainability.

How can citizen science help?

Resource management increasingly has been informed by citizen science, which can enlist members of the public in collecting data across wide geographic areas and over long periods of time (Bonney et al. 2009). Citizen science data can be used to inform resource management decisions (Sullivan et al. 2017). Citizen science also can involve input and engagement of a variety of stakeholders in identifying resource issues and crafting strategies to address them across a range of environmental fields, with the potential of improving trust among stakeholders (McKinley et al. 2017).

Many ocean-based citizen science projects already are under way. A review by Thiel and colleagues (2014) yielded 227 peer-reviewed publications focused on marine citizen science data covering topics including micro- and macroalgae, seagrasses, coral reefs, and most major taxa of animals, and Hyder and colleagues (2015) provided examples of citizen science projects that produce evidence underpinning key areas of marine policy—that is, managing rare or endangered species and the impacts of pollution and environmental change.

In addition, some US fishers already collect data through cooperative fisheries research programs, which fund research partnerships between scientists and fishers. Some cooperative research may be considered citizen science when fishers voluntarily take on an active role in the research process, for example, informing scientists about where or how to

find fish or taking part in collecting data. In one example, volunteer anglers worked with scientists to locate, capture, and collect genetic samples from rockfish species in Puget Sound, Washington, which were listed on the US federal endangered species list. Results showed that canary rockfish (*Sebastes pinniger*) in Puget Sound were genetically similar to canary rockfish caught on the outer coast of Washington. This new information led to a decision to remove this species from the endangered species list in 2017. In contrast, yelloweye rockfish (*Sebastes ruberrimus*) caught in Puget Sound and the inland waters of British Columbia, Canada, were found to be genetically distinct from their coastal counterparts, which led to a decision to expand the population boundaries for the US Endangered Species Act listed yelloweye rockfish (Andrews et al. 2018).

Despite the many volunteer-based data-collection activities that are under way in the oceans, the full potential for citizen science to inform marine policy (Hyder et al. 2015) and in particular fisheries management (Cigliano et al. 2015) has yet to be realized. Passage of the Crowdsourcing and Citizen Science Act in 2016 (US Congress 2016) offers new opportunities for citizen science in the US because the Act provides broad authority for federal agencies, including NOAA Fisheries, to conduct citizen science projects. Given that NOAA Fisheries is responsible for managing nearly 500 stocks and stock complexes over an area covering 4 million square nautical miles—more than twice the area of the United States—the eyes on the water provided by volunteers have tremendous potential to supplement and enhance existing sources of fisheries data. Fishing vessels also offer increased at-sea platforms for deploying equipment for technology-based data collection. In addition, fishers can be key partners in enhancing the overall science of fisheries management, because they hold extensive knowledge and insights on catch, habitats, and ocean conditions, and can play a significant role in project design.

To illustrate the possibilities of realizing the full potential for citizen science to inform marine policy, especially to aid in stock assessments and management decisions, we next provide some examples of fisheries-focused marine citizen science activities.

Gathering data on abundance, distribution, and habitat preferences.

One method of gathering data about fish distribution patterns and habitat preferences is through tagging programs such as the NOAA Fisheries Cooperative Shark Tagging Program (CSTP). Begun in 1962, CSTP involves thousands of volunteers, including both recreational and commercial fishers, who tag and recover sharks along the Atlantic and gulf coasts of North America and Europe. Mark–recapture data help to provide valuable information on sharks including stock identity, abundance, age and growth, mortality, behavior, and movements and migration, which have been used to support domestic and international stock assessments (single and multispecies) as well as essential fish habitat designations. The program has made enormous

contributions to understanding these often misunderstood species. Between 1962 and 2019, volunteers tagged more than 300,000 sharks of over 50 species and recaptured more than 18,000 sharks of over 30 species. For some species, data from CSTP provide some of the best information on distributions and habitat use currently available (Kohler and Turner 2019; Cami McCandless, NOAA Fisheries, Northeast Fisheries Science Center, Narragansett Lab, Narragansett, RI, USA, personal communication, 25 August 2020).

Another longstanding tagging effort is the American Littoral Society Fish Tagging Program. Begun in 1965 with objectives similar to those of CSTP, this program initially focused on tagging coastal Atlantic sharks. In the 1970s, however, following a decrease in striped bass populations, the program's focus shifted to tagging littoral (nearshore) fish species including striped bass (*Morone saxatilis*), summer flounder (*Paralichthys dentatus*), bluefish (*Pomatomus saltatrix*), tautog (*Tautoga onitis*), and black sea bass (*Centropristis striata*). Today, approximately 1000 volunteers tag between 10,000 to 30,000 fish each year, of which between 4.5% and 5% are recaptured. As of May 2019, more than 600,000 fish had been tagged cumulatively by volunteers (Dement 2015, American Littoral Society 2019). One of these volunteers was former president George H. W. Bush, who caught a tagged striped bass that was later returned by the Secret Service. Every spring, data collected from the program are sent to NOAA's Northeast Fisheries Science Center and the Atlantic States Marine Fisheries Commission. Fish size composition from tagging efforts are used in stock assessments for striped bass, bluefish, black sea bass, tautog, summer flounder, and scup (*Stenotomus chrysops*).

Another example of volunteer-assisted fisheries research is the California Collaborative Fisheries Research Program (CCFRP; Wendt and Starr 2009, Yochum et al. 2011, Starr et al. 2015). In 2007, California designated 29 new marine protected areas (MPAs) covering nearly 20% of California's central coast. The CCFRP was formed to monitor these resource-rich areas and relies on the help of citizen scientists. CCFRP volunteers—more than 1500 to date, many of whom are recreational fishers—work side by side with scientists and managers to conduct fishery-independent surveys of popular nearshore fish species such as blue and canary rockfish.

The project's fishery-independent sampling design was adopted after a series of workshops with fishers, harbor officials, and scientists from agency, academic, and conservation organizations. Fixed sampling locations with known rocky habitat were created and are randomly selected during a survey. Captains use their knowledge to determine the best places to fish at a sampling location. Volunteer anglers do the fishing, whereas scientists measure and tag fishes. The program has now collected rockfish survey data in central California for more than a decade, meaning that NOAA Fisheries can use CCFRP information to determine population trends. In 2017 CCFRP expanded to the entire California coast, which will allow exploration of the

long-term effects of the MPA network along a much wider area.

Supplementing existing catch data. Data collected through mandatory reporting of catch already are widely used in stock assessments. Collecting and using data that are volunteered about harvest (opt-in reporting) is a challenging issue in fisheries management, however. Some scientists perceive a conflict of interest in inviting fishers to report information that can directly affect their livelihoods, and these scientists worry about an incentive for the fishers to report. Nevertheless, research is under way to explore how citizen science techniques can supplement the quality and quantity of fisheries data, because more accurate data will support more accurate assessments and help insure the long-term sustainability of fisheries. Of particular interest is the development and dissemination of mobile applications (apps).

For example, the Snook and Gamefish Foundation, now the Angler Action Foundation, developed the iAngler app so that fishers can submit information about fish caught and released during recreational fishing trips, including fish length, weight, and location, along with photos of fish caught (figure 2; Jiorle et al. 2016). Reports from iAngler, in conjunction with other sources (e.g., angler interviews and logbooks), have been used to provide information on the sizes of recreational fish releases for use in stock assessments (e.g., common snook and red drum) in Florida (Muller and Taylor 2013, Chagaris et al. 2015, Munyandorero et al. 2017, Addis 2018).

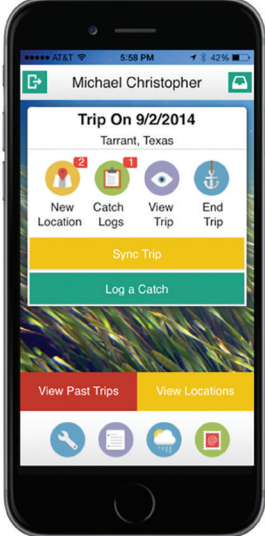
Another example is the Catch Reporter app. As part of a collaborative effort to measure demographics of three species of bass (kelp bass, barred sand bass, and spotted sand bass) off the coast of southern California, Catch Reporter allows fishers to report angler recaptures of tagged bass (e.g., tag number, species, catch location, date and time, vessel type, fish size, fish condition, whether a fish was released) to a central database (www.cooperativedishtagging.org). These data inform analyses of movement patterns, mortality, population abundance, and fishery dynamics for each species in the context of marine protected area functioning. Demographic estimates using Catch Reporter will be provided to the California Department of Fish and Wildlife to be integrated into future stock assessments for these species.

Such integration is challenging, because when fishers voluntarily provide catch information, their efforts fall under the umbrella of opportunistic or nonprobability sampling, which is not considered appropriate for estimating population characteristics (American Association for Public Opinion Research 2013). Therefore, an important next step is to assess the appropriate uses for opt-in data and to determine how they can best be used to supplement rather than replace existing data sources for fisheries management. A key recommendation from a 2017 National Academies of Sciences, Engineering, and Medicine report that reviewed the MRIP, the current program used to provide data on

Create Trips
Create a Trip with to keep the logs of one trip together

Personal Log
Your Trips are saved on the server and can be retrieved at any time

Simple and Easy
It takes about 3 minutes on an average for a new angler to setup the app, create a trip and log their first catch.



Log your Catch
Provide the species, add a picture, record your observation - keep or release it

Favorite Locations
You can mark a location as favorite and keep coming back to log there

Share with Friends
Share your trip summary with friends on social media

Figure 2. The Angler Action Foundation's *iAngler* app provides a method for fishers to record fishing trips, as well as each fish caught. Such data potentially can be useful in stock assessments. Photograph: Angler Action Foundation.

recreational catch and effort for stock assessment purposes, is that “electronic data collection should be further evaluated as an option for the Fishing Effort Survey, including smartphone apps, electronic diaries for prospective data collection” (National Academies of Sciences, Engineering, and Medicine 2017).

Biological data and environmental change. Fishers also can collect important biological and environmental data. On the environmental side, consider eMOLT (the Environmental Monitors on Lobster Traps Program), which was formed in 1995 when a NOAA Fisheries oceanographer, Jim Manning, realized that fishing boats and their gear provided a wealth of platforms and opportunities to sample the ocean environment. The project began by providing volunteer lobstermen around the Gulf of Maine and Southern New England with temperature probes to attach to their traps to collect information on ocean bottom temperatures. Currently, more than 50 lobstermen are participating—most of whom were original participants—and together they have collected more than 20 years of data and over 7 million hourly observations of temperatures on the ocean floor. Recent technological advances are allowing project data to be uploaded to a NOAA server as soon as volunteers pull their gear—which includes traps and trawls—via satellite telemetry without the fishers having to take any extra steps, and all data are carefully archived and served according to NOAA's Integrated Ocean Observing Systems protocols. Data from 2001 to the present are helping to calibrate ocean models and also have been revealing a rise in ocean bottom temperatures of 1 or more degrees Fahrenheit throughout the New England region, allowing fishers to see an unprecedented trend in ocean warming firsthand through data they collected themselves (Manning and Pelletier 2009, Gawarkiewicz et al.

2012, Doliner and Dimoulas 2017, Van Vranken et al. 2020).

On the biological side, consider Australia's Send Us Your Skeletons (SUYS) program. In 2007, a stock assessment found that three species of fish off Australia's west coast—snapper (*Chrysophrys auratus*), Australian dhufish (*Glaucosoma Hebraicum*), and Baldchin groper (*Choerodon rubescens*)—were being overfished. Management measures were put into place to restrict fishing efforts to allow the stocks to recover, and SUYS was established in 2010–2011 to help monitor these stocks. SUYS asks anglers to voluntarily donate fish skeletons from their catch, along with corresponding information on date and capture location, to the Department of Fisheries Western Australia. The skeletons provide biological information on age structures (e.g., how many fish are

of each age), which is an indicator of the health of the stock and an aid in conducting stock assessments (Fairclough et al. 2014).

Considering all of these examples, including the potential that they and similar projects have to inform marine policy, led the SAFMC to begin exploring the idea of developing citizen science to help improve the science used to inform fisheries management throughout the South Atlantic region.

The US South Atlantic

In the US South Atlantic, the region off the coasts of North Carolina, South Carolina, Georgia, and eastern Florida (figure 3), fishing policies are set by the aforementioned SAFMC, which manages 64 species including shrimp, crab, lobster, sargassum seaweed, corals, and 56 species of fish. The majority (50) of the fish species are members of the snapper–grouper complex, which includes some of the most popular species for both commercial and recreational fishing because they are tasty and fun to catch. Like all fishery management councils, the SAFMC faces numerous challenges in obtaining timely data to inform stock assessments and management evaluations required to make well-informed decisions. For example, the SAFMC must deal with high species and ecosystem diversity, a regional science center that serves two other councils, a large recreational fishery sector (which is more difficult to monitor than the commercial sector), and low stakeholder trust in the management process.

In addition, the marine ecosystems that support the biodiversity of this region are highly dynamic and interconnected. They span subtropical to continental shelf-edge ecosystems, and their fauna exhibit markedly different life histories, which complicates data collection and interpretation. Juveniles of some species use specific inshore habitats, such

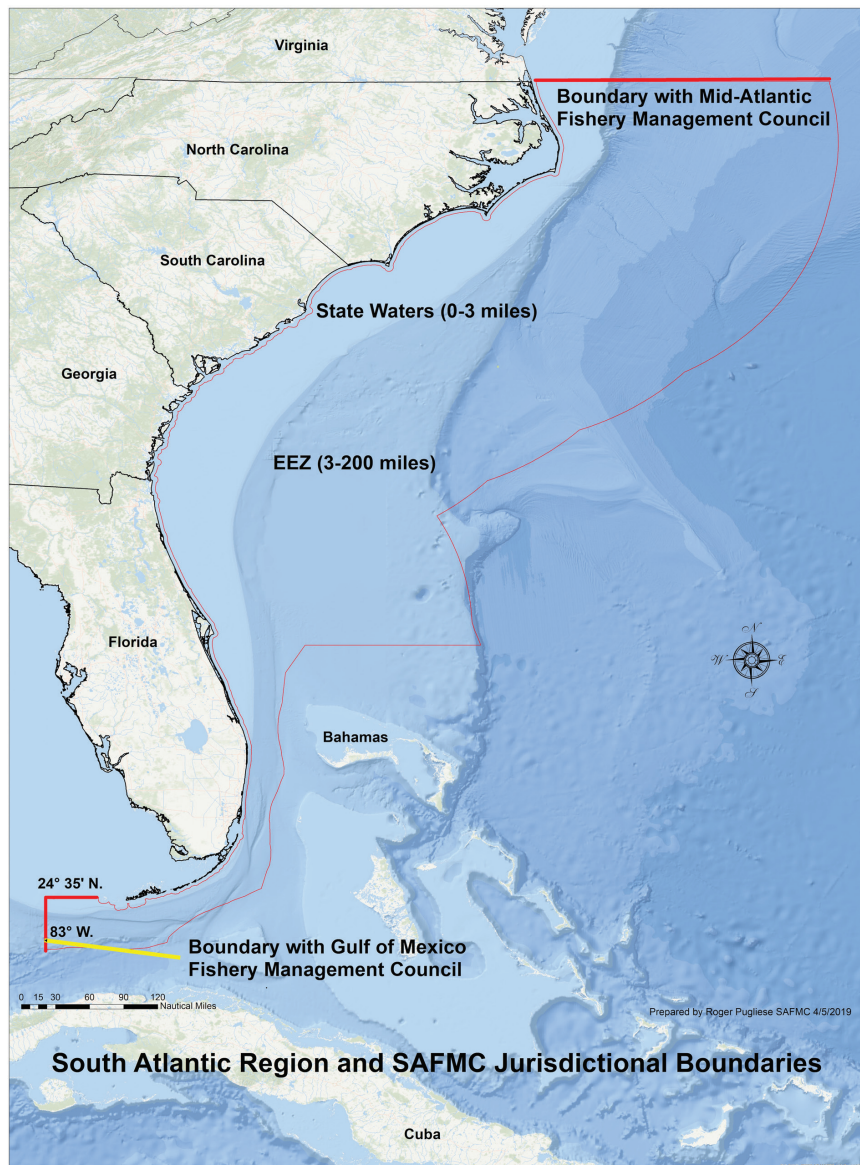


Figure 3. The jurisdiction of the South Atlantic Fisheries Management Council includes federal waters (3–200 miles offshore) off of North Carolina, South Carolina, Georgia, and the east coast of Florida. The council manages 64 species, including several species of fish sought by both commercial and recreational fisheries. Map: Roger Pugliese, South Atlantic Fisheries Management Council.

as seagrass beds and mangrove roots, then move offshore to mature and spawn. Other species spend the majority of their lives near hard structures. Meanwhile, changing oceanographic conditions influence habitat usage and ecosystem connectivity, adding complexity to monitoring and assessing population health.

Despite the serious need for information to inform management, only 50% (8 of 16) of the most economically important fish stocks and stock complexes in the South Atlantic are considered adequately assessed according to NOAA Fisheries (National Marine Fisheries Service 2020b). In addition, the NOAA Fisheries science center responsible

for the broader Southeast region covers three management areas and nationwide management of highly migratory species in the Atlantic (e.g., tuna), which adds to the quantity and diversity of data required to inform management. A larger recreational component for most managed fisheries, along with a diversity of fisheries that are relatively small in scale, together complicate data collection and assessment options relative to other regions. For example, New England and the North Pacific, which are dominated by commercial trawl fisheries that are high volume, tracked via GPS, and subject to strict reporting standards, enjoy a higher degree of data standardization and reliability.

Many of the factors that limit traditional data collection for South Atlantic fishery management can be addressed through the strengths of citizen science. Although a recreational fishery may be hard to monitor owing to few reporting requirements, it is well positioned to participate in citizen science because of the dedication of recreational anglers and fishing groups. Although volunteers can never replace the work of paid fisheries biologists, fishers can significantly augment both the frequency and distribution of data collection opportunities. Beyond increasing the quantity of data, fishers with a lifetime of local expertise regarding species or systems can provide insights into complexity, interconnectivity, and changing systems they encounter on the water.

Considering the numerous possibilities for furthering fisheries management through citizen science, in 2015, the SAFMC decided to pursue citizen science as a means to address gaps in both data and trust. SAFMC members and

staff were well aware, however, that integrating fishers into the data-collection process, analyzing the resultant data, and using the information to make decisions that satisfy multiple stakeholders while also meeting the BSIA standard would be challenging. From exploring best practices in citizen science, they knew that setting expectations for participant engagement, establishing procedures for data use, and facilitating timely project development in response to pressing management needs would require intentional program design, which calls for project planning to articulate project goals at the outset, along with all project activities (e.g., protocols, trainings, data architecture) to meet those

goals (Shirk et al. 2012). Furthermore, they understood the high stakes of building relationships and trust while creating a research collaboration between a group of people who are dependent on access to a resource and another group that is tasked with developing regulations regarding that resource. Therefore, they determined to do something unprecedented: to develop a regional fisheries-based citizen science program, which would include the infrastructure to identify and support intentional design of subsequent projects to address concerns while meeting identified needs of all stakeholders.

Developing program infrastructure

The SAFMC started by creating a citizen science organizing committee that included council staff and members, fishers, federal and state agency employees, nongovernmental organizations, and outside experts. The group spent 1 year reviewing background information and best practices for citizen science and surveying multiple stakeholders to understand their knowledge of and opinions about citizen science. Next, in January 2016, the SAFMC convened more than 60 participants from numerous diverse stakeholder groups for a workshop whose goal was to clearly delineate the components and resources necessary to design and implement a citizen science program.

The workshop clearly revealed the energy and enthusiasm of all stakeholders for the opportunities that citizen science presents to inform management, but also the potential for mistrust in science and management to result if fishers were asked to report information that is not used. With this in mind, the group came up with a vision for the program: to advance science and increase trust, one project at a time. To realize this vision, specific operational and scientific guidelines related to project design, data management, and volunteer engagement would need to be created. The committee determined that establishing programmatic infrastructure at the outset of program development would be critical, because of the high bar for usable data in fisheries management and the high stakes for developing trust among all parties regarding the data and the decisions those data would inform. To test the infrastructure for use in project development, the committee decided to design a pilot project at the same time it began building the program, although it was mindful that years would be required for any project to fully demonstrate proof of concept.

Defining program goals and components

Informed by the workshop and the program's mission—to build and maintain a program that improves information for fisheries management through collaborative science—the committee drafted program goals and a blueprint to identify key program components (South Atlantic Fisheries Management Council 2016). Guided by a framework for citizen science developed through a contract provided to the Cornell Lab of Ornithology by the US Fish and Wildlife Service (Shirk and Bonney 2015), the blueprint outlined recommendations for program administration and oversight

and named five action teams (A-Teams) to develop each of five key components: volunteers, projects and topics management, communication and outreach, data management, and finance and infrastructure. A-Team members were appointed on the basis of their topical areas of expertise and interest, and each contained fishers, scientists, researchers, managers, outreach experts, conservation professionals, and others whom the committee hoped would become participants and partners in projects supported by the program. Teams met multiple times via webinar between July 2017 and October 2018 to develop best practices and recommendations for use in developing new projects. The resulting program and project-level recommendations, which are among the most comprehensive guidelines yet developed for citizen science, are described in table 1 and are available at <http://safmc.net/cit-sci/action-team-table>. These guidelines should be valuable for any group wishing to set up a citizen science project or program, and should save significant time and effort for anyone designing future citizen science endeavors.

The next step was formation of an operations committee, including members representing each of the five A-Teams and regional fishery management partners, to develop the program's standard operating policies and procedures (SOPPs) using the recommendations and best practices identified by the A-Teams. Developing SOPPs is the process followed by other groups within the council system (e.g., advisory panels); therefore, while the A-Team structure was new, it built on existing council infrastructure. The SOPPs were designed as living documents, overseen by the operations committee, which will help to guide development of the program's organizational infrastructure, describe ways that program components and activities will be implemented to support projects, and ensure that the SAFMC's needs to receive citizen science data that can be used to inform stock assessments and fisheries management will be met (<https://safmc.net/citizen-science-program>).

For two specific examples of how the SOPPs provide the foundational infrastructure for developing management-relevant citizen science projects, consider several components of the SOPPs in relationship to the Fisheries Management 101 requirements identified earlier in the present article.

First, recall that fisheries management depends on the "best available high-quality scientific information." Every 2 years, the SAFMC develops a research and monitoring plan that outlines gaps in information for key species, ecosystems, and habitats and the types of data and associated research topics that would help to fill those gaps. As the citizen science program has developed, this research and monitoring plan, as well as input from the 2016 Program Design Workshop and the A-Teams, has helped to guide selection of key research topics that could be addressed using citizen science. In relationship to the data needed for assessing abundance, catch, and biology, appendix C of the SOPPs—SAFMC's Citizen Science Research Priorities—is

Table 1. Best practices, core products, and recommendations for citizen science programs focused on resource management as compiled and developed by the SAFMC action teams.

Action team	Products	Information collected	Additional products
Data management	Data standards template Quality assurance or quality control recommendations Data requirements template	Data management resources by agency	Options for data storage
Volunteers	Basic volunteer orientation best practices Basic volunteer orientation training template	Example approaches for training	Online volunteer interest form, a tool to recruit volunteers
Projects or topics management	Citizen science research priorities Project development plan template	Sources for research needs	Project endorsement program Project review metrics
Finance and infrastructure	Example operational or programmatic budget needs	Active list of project or program funding opportunities	Funding models and sources to pursue Partnerships to pursue
Communication	Project communication plan template	Sample outreach or communication approaches	Samples of approaches for sharing project results

Table 2. SAFMC summarized citizen science research priorities, 2019–2021.

Topic	Data needed	Potential outcome
Age sampling	Otolith collection	Age of catches
Maturity data	Gonad collection	Improved reproductive information
Discard information	Length, depth, number of fish, reason, devices used	Improved discard removal estimates, size composition of discards
Genetic sampling	Fin clips	Stock identification
Fishing infrastructure	Location and type of infrastructure	Document social or economic impacts of regulations over time
Historical fishing photos	Images (electronic)	Length compositions, improved historical information
Fishing oral histories	Fishermen interviews	Improved understanding of the changes in the fishery over time
Oceanographic or environmental conditions	Bottom temperature, weather	Build database on climate and changing conditions
Rare or data limited species observations	Point observations	Baseline for species shift, increased information on data limited species
Diet samples	Stomach collection	Improved diet information
Personal fishing logbooks or diaries	Logbook data (electronic)	Develop relative indices of abundance

a list of citizen science needs and possible projects that have the potential to obtain data for known research priorities (summarized in table 2). Furthermore, appendix B of the SOPPS (the “Process for Identifying SAFMC Citizen Science Program Research Priorities”) outlines ways for this list to be updated biannually in relationship to the council’s cycle for reviewing the larger research and monitoring plan.

As another example of how the SOPPS support development of the program, recall that the fishery management ecosystem also depends on stakeholder-engaged processes to foster trust in the system as well as the data. Appendix D of the SOPPS, the Project Endorsement Program, details

criteria for acceptable projects including the need for the project to meet program goals and to address a research priority, as well as the necessity to have a data management plan, a volunteer training plan, and a communications plan. Significantly, the criteria include a strong recommendation that any proposed project have a multiple-stakeholder design team including fishers, scientists, outreach specialists, data managers, and others with relevant expertise. Standards for implementing the endorsement program also stipulate that all reviews of proposed projects be conducted by a multiple-stakeholder team.

After developing the SOPPS, the operations committee developed objectives in support of the program goals. In

Box 1. SAFMC Citizen Science Program goals and objectives.

Goal 1. Design, implement, and sustain a program framework to guide the development of projects that support fishery management decision-making.

- **Objective 1.1.** Establish organizational infrastructure to provide program administration and oversight.
- **Objective 1.2.** Develop program procedures, policies, and tools.
- **Objective 1.3.** Create a funding strategy that is adaptable to changing circumstances and needs.

Goal 2. Facilitate development of individual projects to address specific research priorities.

- **Objective 2.1.** Publish and broadly disseminate the SAFMC's citizen science research priorities.
- **Objective 2.2.** Implement the SAFMC's Citizen Science Project Endorsement Program.
- **Objective 2.3.** Provide project support resources (best practices, templates, etc.) and project development guidance.
- **Objective 2.4.** Encourage collaboration by diverse teams of stakeholders (scientists, fishermen, managers, etc.) to develop projects.

Goal 3. Ensure that data collected by projects are accessible, robust, and fit for purpose.

- **Objective 3.1.** Implement program guidelines that address data management, standards, quality, and accessibility.
- **Objective 3.2.** Review project results to determine if data meet project or program needs.
- **Objective 3.3.** Document the contribution of citizen science projects and data to specific SAFMC research priorities and science and management decision-making.

Goal 4. Foster mutual learning, collaboration, and program engagement.

- **Objective 4.1.** Promote opportunities for learning among diverse constituents.
- **Objective 4.2.** Foster existing partnerships and develop new partnerships to support both program and project goals.
- **Objective 4.3.** Strive to enhance trust among scientists, managers, and fishermen.
- **Objective 4.4.** Engage new categories of stakeholders that are not typically involved in the council process.
- **Objective 4.5.** Develop citizen science program volunteer engagement (recruitment, training, retention) strategies, products, and activities using best practices outlined by the citizen science action teams.

doing so, the committee decided to further refine the goals to better articulate the vision of the program. The updated goals and associated objectives, which not only are guiding the program but also are being used to design a multiyear program evaluation, are shown in box 1.

Launching the program: Choosing and designing a pilot project

With the programmatic infrastructure near completion, the council proceeded to design a pilot project that would test the utility of the infrastructure and eventually the viability of citizen science to meet the goals of the program. Careful selection of the program's first pilot project was critical. It needed to support collection of information on a known data gap; capture the interest of fishers, scientists, and managers; and test the feasibility of using a citizen science approach. One research topic identified as a research priority and meaningful for fishers was improving discard information (e.g., information

on released fish) on many of the region's snapper-grouper species.

In the spring of 2018, the program selected a small-scale pilot to collect discard information on scamp grouper, a species that will be undergoing a stock assessment starting in 2020. The program is working with volunteer fishers from all sectors of the fishery (commercial, recreational, and for hire) to test the use of a mobile app to provide length of released scamp grouper and other supplemental data that can be collected during regular fishing activities (figure 4). Best practices, recommendations, and products from all the A-Teams are being used to guide this project, and the data collected so far are showing promise. Although they are not yet sufficient for use in the assessment, they are useful for interpreting trends found in other data sources. As more trips are reported and sample size increases, additional analyses will check for potential biases in the data including spatial distribution of releases, angler avidity, and representation of fishing sectors.



Figure 4. SAFMC Citizen Science Program staff training a fisher to use the SAFMC Release app. Photograph: Bryan Fluech.

The team drew from members of each of the A-Teams including fishers. They kept at the forefront the goal that project data should contribute to the forthcoming stock assessment. This goal is intended to account not only for the scientific utility of the data, but also for the trust that fishers are placing in the project as a worthwhile investment of their time. Fishers also were critical to the design of the app, contributing insights such as the fact that geolocation features run down data and batteries, that the app must be operational one handed, and that it would be critical for the app to be useful once back at the dock.

The design team also gave feedback on the data requirements document that was in development for the SOPPs and made sure that the app focused on data fields needed for the assessment. Through the lens of designing the pilot project, they were able to identify needs, for example, for data infrastructure to accommodate the potential for multiple submissions of the same data (for example by two charters from the same boat). This process gave both the project and the program a chance to encounter challenges to usability, data quality, and trust during the planning stages, rather than after investment in and launch of a project.

One unexpected outcome of the scamp release pilot project has been interest in the project's mobile app expressed by numerous state and federal agencies. Many regions face similar management challenges with discarded fish, and many are interested in adapting the app for use in their fisheries. This interest has opened the door for new partnerships and has led to other agencies adapting the application for use in other citizen science projects.

A second pilot with a different approach

In May 2020 the council launched a second pilot project, FISHstory, which takes a different approach to citizen science.

FISHstory uses historic fishing photos to gather data about species and length of fish caught in the charter and headboat fisheries prior to the 1970s when dedicated catch monitoring began (figure 5). Knowing the species, number, and size of fish caught over time is critical in understanding the health of a fish population, and



Figure 5. Historic photo of a fishing trip on the Miss Juanita in June 1956, which has been analyzed for data for the FISHstory project. Photos for FISHstory were provided by retired captain Rusty Hudson. Photograph: Rusty Hudson and the Hudson, Stone, and Timmons families.

In addition, the process of developing the project as a product of the program already has shown results. To design the project the council established a design team to consider every project aspect, including research protocols, app features, volunteer recruitment, and data management plans.

historic photos can help to fill important data gaps in for-hire South Atlantic fisheries.

The FISHstory project is collaborating with Rusty Hudson, a retired fisher, who has provided more than 1300 historic dock photos from his family's headboat fleet in Daytona Beach, Florida, from the 1940s to the 1970s. Using Zooniverse, an online crowdsourcing platform, volunteers learn to identify and count the fish and anglers in the photos. A validation team, including fishers and scientists, is verifying species identifications and counts when volunteers disagree. In addition, the FISHstory team will develop a method to estimate fish lengths from the historic photos. If the FISHstory pilot project is successful, the team hopes to expand it to collect photos from other fishers and stakeholders across the South Atlantic.

Conclusions

Citizen science could be an important collaborative approach to filling key data gaps in fisheries science and management. Critical to its success will be the shared understanding among all stakeholders that it will not replace existing science programs. Rather, citizen science is intended to be an adaptive tool to supplement existing data sources. It also may build trust among stakeholders who often hold different perspectives, which is critical when recalling the program's vision, "To advance science and increase trust, one project at a time." By including fishers in all aspects of building the program and its first two projects, starting from the program's inception, the council has laid the groundwork for building trust, an effort whose success will be measured over time.

The SAFMC's approach of developing an overarching program to support projects that will fill data gaps and meet the council's research needs is a first in the system of US regional fishery management councils. Results of the program that already have been achieved—the SOPPS that underpin the program, diverse stakeholder commitment to program development, documentation of the program's evolution and utility, and the ability of the program to design and implement future projects—can guide how citizen science may be used by other councils around the country.

Results from the SAFMC program also may contribute to a larger exploration of the potential for citizen science to inform natural resource science and management or, indeed, any setting in which broader participation could help to answer pressing questions. In an environment of shrinking budgets and growing needs for reliable information with which to make decisions, citizen science presents an excellent opportunity for federal and state science agencies to advance scientific knowledge and solve real-world problems. Building programmatic infrastructure in advance of launching projects is a new means of supporting strategic project development and takes a long view on investing in intentional design for comprehensive and durable outcomes.

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