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The Complexities of Counting Fish:

Engaging Citizen Scientists in Fish Monitoring

by Karen H. Bieluch, Theodore V. Willis, Jason Smith, and Karen A. Wilson

Abstract

Data gathered by citizen scientists can help ecologists understand long-term trends and can improve the quality and quantity of data about a resource. In Maine and Massachusetts, numerous citizen science programs collect data on river herring, anadromous fish that migrate each spring from the ocean to spawn in rivers and lakes. In collaboration with state and local resource managers and academic institutions, these programs aim to protect and restore river herring, improve local watersheds, and in some cases, support commercial harvesting. To better understand how programs are run and how data are used by managers, we interviewed program coordinators and resource managers. Interviews revealed that resource managers consider citizen science–generated river herring data in decision making, but that their concerns about data quality affect if and how data are used. Although not without challenges, standardizing monitoring approaches could improve data collection and use. We offer six considerations related to standardization for managers.

INTRODUCTION

Each spring millions of sleek, silvery fish called river herring migrate from the ocean to spawn in rivers and lakes along the Eastern Seaboard from Canada to the Carolinas to Florida. In 2015, Maine fisheries biologists estimated that over 4 million river herring migrated to our inland waters (MDMR unpublished data), and harvesters in our local communities brought 1,295,998 pounds of river herring to market, valued at $415,433 (MDMR 2017a). Impressive numbers for a fishery that is local in nature and pursuit. River herring—alewife (*Alosa pseudoharengus*) and, in Maine, the less common blueback herring (*Alosa aestivalis*)—are anadromous, meaning they spawn in freshwater and grow up in salt water, returning every spring to crowd streams and rivers from Kittery to Calais. Their spawning behavior makes them an easily harvested, and thus vulnerable, fishery, but also a spectacle for the public. River herring penetrate well inland, more than 100 miles inland in some places (e.g., Sebasticook Lake) and provide an unprecedented opportunity for the public to interact with a highly migratory marine species. No boat is required to find river herring, just good timing and a keen eye, making them an exception among marine fish. Atlantic salmon are probably the only marine fish that penetrate farther inland, but they are far rarer: 510 salmon migrated to Milford Dam in Milford, Maine, in 2017, compared to 1,256,061 river herring (MDMR 2017b).

Although the fishery appears to be strong and improving, two decades ago the future was not as certain. Starting in the 1970s, landings of river herring saw precipitous declines (NMFS 2013: 48946), and by the 1990s, river herring fisheries in Maine were in dire straits. However, local-level conservation, restoration, and monitoring efforts, grassroots conservation partnerships involving citizen scientists, and aggressive and collaborative actions by resource manager have helped the river herring fishery to rebound. Still, river herring fisheries are spread over a wide area, and understaffed state agencies cannot track all populations.

Natural resource–focused collaborative projects, such as those occurring in Maine's river herring fishery, require that different types of knowledge about a resource be employed in the research process. Successfully combining local ecological knowledge (i.e., harvester knowledge) with scientific knowledge promotes partnerships, builds community consensus, strengthens social learning, and fosters trust (Berkes 2009). Collaborative research may play a critical role in developing sustainable and widely accepted management practices. It not only increases the quality and quantity of data (Johnson and van Densen 2007), but also increases the research collaborative's ability to respond to changing circumstances (Trachtenberg and Focht 2005).

Data generated from citizen scientists can help ecologists understand long-term trends at local and global scales (Miller-Rushing, Primack, and Bonney 2012), and involving citizen scientists in research provides a means for engaging the public in and educating them about scientific research and their environment (Dickinson et al. 2012). We find support for these literature findings in many of the river herring–monitoring programs that incorporate citizen scientists. Citizen scientists help resource managers understand where river herring are migrating and in what numbers, and they encourage other local citizens to become educated about, and stewards of, their local resources. The most successful citizen science programs, such as the Christmas Bird Count, which evolved into eBird hosted out of Cornell University, the Bird Ecology program at the Schoodic Institute at Acadia National Park, and the Maine Brook Trout Survey program led by Maine Department of Inland Fisheries and Wildlife (MDIFW), provide qualitative data that guide state officials in focusing their efforts on more detailed investigations. Predetermined parameters (e.g., count vs presence-absence) and data verification at multiple levels (program or volunteer coordinators followed by resource managers) are hallmarks of successful programs that contribute to natural resource decisions.

In this article, which summarizes interviews with citizen science program managers, citizen scientists, and resource managers, we will discuss how citizen science monitoring contributes to river herring sustainability, the inherent challenges involved with a noncentralized effort, and strategies for standardizing monitoring across diverse programs to improve data collection for decision making.

BACKGROUND

Maine has a long history of collaboration between stakeholders of river herring runs and resource managers. River herring–harvest rights are awarded to municipalities by Maine Department of Marine Resources (MDMR). At the municipal level, management responsibilities fall to fish committees, composed of elected selectpersons, fish wardens, and community volunteers, who guide decisions about which harvester to hire, frequency and magnitude of the harvest, and conservation and maintenance measures for the season (e.g., clearing beaver dams or improvements to the harvest site). Harvest contracts are awarded by the towns, usually by bid, for anywhere from one to five years. To operate and remain open to harvesting, municipalities and the state must collect fishery-dependent and -independent data (ASMFC 2009). Fisheries-dependent data are collected from commercial and recreational fishermen, while independent monitoring programs are typically random samples collected by, for example, state fisheries biologists. Power companies also provide count data from traps in fishways at dams (e.g., MDMR 2013). Citizen scientist–generated data have been used as independent monitoring data to open or requalify harvest sites closed under Amendment 2 (ASMFC 2009). Maine requires towns to report catches and collect fish scales for age determination. Towns submit annual harvest plans to MDMR in collaboration with the harvester, which are approved or returned with recommendations for improvement.

The availability of data can be critical in the management of river herring harvests, and collaborative research is critical for collecting these data. For example, through monitoring the St. Croix River run, a local nongovernmental organization (NGO), the St. Croix Waterway Commission, was able to demonstrate the effects habitat openings and closures had on the river herring population there. The data were used to trigger legislative action, changing how river herring were being managed by the state of Maine (Willis 2009).

Damariscotta Mills is another example of how an NGO collecting independent monitoring data influenced restoration strategies and restoration success. Damariscotta Mills has the longest continuous harvest record of any run in the state. The Newcastle-Nobleboro Fish Committee (in charge of Damariscotta Mills) is large and active, with a strong volunteer pool that helps with activities such as festivals, fundraising, and construction, but not fish counting. A 1989 scientific inquiry by Atlantic States Marine Fisheries Commission (ASMFC) found that the Damariscotta Mills harvest was overfished (Crecco 1999). The fish committee closed the run in 1993 for a period of seven years, choosing a local management action more stringent than state or federal regulations at the time (Spencer 2009). The counting program, which was unique at the time, provided count data paid for by the hydropower dam owner (per provisions in the hydropower license agreement) to trigger the closure. The successful reopening of harvests and changed legislation demonstrates the importance of gathering local data in empowering communities to influence the fate of their resources.

There are also important collaborations for collecting fishery-independent data at smaller, less well-funded runs. In Maine and Massachusetts, numerous citizen science programs are collecting valuable data on river herring and leading river restoration efforts, in close collaboration with local, academic, and state institutions. The River Herring Network ties together river herring runs in the North Shore region of Massachusetts, providing a coordinator of coordinators to work with state agencies and organize training and informational events. In Maine, citizen science–monitoring efforts are assisting individual municipalities and MDMR with assessing the river herring fishery. For example, the citizen science–monitoring program in the town of Pembroke, in collaboration with organizations such as Maine SeaGrant, is collecting data with the hope of reopening their commercial harvest.

Given the diverse and dispersed nature of these programs, Massachusetts Department of Marine Fisheries (MDMF) developed guidelines for collecting high-quality data across years (Nelson 2006). The guide sought to codify a sampling frequency and calculation methods used to generate estimates of river herring passage by comparing methods being used at the time. Although not entirely accessible to a layperson, the recommended basic method provides an estimate of passage with confidence intervals.

To apply the monitoring protocol, citizen scientists typically stand at the top of a fish ladder, or at a passage constriction in the stream, to count fish. The recommendation was to split the day into six segments to cover a twelve-hour migration period. Volunteers conduct one ten-minute count of river herring migrating to their spawning habitat during each segment, and the data are extrapolated to estimate potential passage. Other data, including water or air temperature (if equipment is available), help explain sudden changes in the number of fish passing because water temperature directly affects river herring migration.

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River herring are an ideal marine resource to monitor through citizen science for several reasons. Runs of river herring often occur in streams that flow through people's backyards; one can almost touch the fish as they migrate; and the water in New England, especially Maine, is often clear enough that citizens can count fish with a repeatable level of accuracy (Rootes-Murdy, Kipp, and Drew 2016). Perhaps just as importantly, because these fish return to the lakes and streams in which they were hatched within three to four years, efforts of citizen scientists positively affect *their* fish. Such characteristics squarely establish these as community runs that connect communities to the resource and creates abundant educational opportunities. Still, developing and implementing a statewide standardized program has many challenges. Understanding these challenges and developing strategies for overcoming them is critical to enabling managers to use local data for larger-scale decision making.

METHODS

To better understand how programs are run, why people are engaging in citizen science counts, and what managers are looking for when they consider using the data for management decisions, we conducted a multiyear study in Maine and Massachusetts of volunteer, coordinator, and manager perceptions of the citizen science process and outcomes. We used a mixed-methods study design, including individual interviews with volunteer coordinators of river herring–monitoring programs and state, regional, and federal managers, a survey of citizen scientists involved in monitoring programs in Maine and Massachusetts, and participant observation at multiple runs and at river herring–related meetings (e.g., Maine Fishermen's Forum, River Herring Network annual meeting). Researchers at the University of Southern Maine (authors Smith, Willis, and Wilson) also initiated and continue to coordinate a citizen science–based river herring count at Highland Lake in Windham, Maine.

We conducted individual or small-group interviews in person or over the phone in 2014 and 2015. In total, we interviewed 19 volunteer coordinators of river herring–monitoring programs in Maine and Massachusetts (Bieluch, Smith, and Willis 2015), and nine interviews with fisheries managers (ME—two; MA—three; NH—one; NOAA—two; ASMFC—one) (Smith, Bieluch, and Willis 2015a). We were not aware of any volunteer monitoring coordinators in New Hampshire. With the exception of one interview during which we experienced a technology malfunction, we digitally recorded and transcribed all face-to-face interviews verbatim. We also typed extensive notes during phone interviews.

Interview with volunteer coordinators followed and were informed by 30 interviews with river herring harvesters, municipal officials, managers and scientists, restoration leaders, and board members of the Alewife Harvesters of Maine (AHM). Bieluch in collaboration with AHM conducted the interviews as part of AHM's organizational-visioning process (Bieluch and AHM Board of Directors 2014). In addition, the interviews followed three focus groups conducted in 2013 with citizens and local managers involved in the river herring industry in Maine; the focus groups were coordinated by researchers from the University of New Hampshire and members of the AHM Board (Cournane and Glass 2014).

Project researchers used qualitative data analysis software to analyze interview data. We first looked for information that supported key study themes (e.g., the way in which data are being used in decision making). After sorting the data according to those themes, we reviewed them for additional subthemes (e.g., how individual relationships influence one's trust in the data). After sorting the data according to major themes and subthemes, we analyzed the data again to determine what it told us about citizen science river herring–monitoring programs, the data they collected, and the use of these data in decision making at multiple scales.

In addition, we conducted an online survey of 176 citizen scientists involved in river herring–monitoring programs in Maine and Massachusetts between December 2014 and January 2015 (Smith, Bieluch, and Willis 2015b). Project researchers worked with volunteer coordinators for each site to distribute a survey invitation to their volunteer monitors via email.

FINDINGS

Interviews revealed that whether citizen science–generated river herring data are considered in decision making depends on project scale and the research question(s) being asked. Three state officials mentioned citizen science–generated data is used in regional trend analyses, and two state officials indicated that some volunteer river herring–count data can be considered in coast-wide assessments. Data are also used in concert with other data collected by state biologists; for example, volunteer counts can be combined with counts by state agencies using electronic counters, video-monitoring equipment, or trap counts, and with biological metrics such as scale samples. Interannual data provide feedback to volunteer groups by helping people understand if their restoration efforts are contributing to increasing fish numbers. At the organizational scale, data may be used to measure the effect of restoration efforts (e.g., culvert replacements or fish ladder renovations), and at the local and state scale, count data contribute to determining if a run is sustainable and whether it should be conserved or harvested. Presence-absence assessments of river herring contributes to interwatershed assessments across regions. As stated earlier, regional-scale data may be used as a relative index for comparing between watersheds.

Although data are used for decision making, interviews with managers indicated that the quality of citizen science data can be a concern. State officials tend to base their trust in citizen science data on volunteers' adherence to a specific data-collection protocol, and trust is often assessed on a "case-by-case basis," as one state official stated. Another state official said, "I think that there is value in volunteer data, and there might be some caveats with it, but it can probably be used for something." Officials noted that factors that decrease data quality include inefficacy of the current statistical design backing sample-collection protocols, a lack of adherence to the prescribed protocol, poor data diversity, such as counts not being fully reported, or when programs report skewed counts due to data collection occurring primarily during one segment of the fish run (beginning, middle, or end). Lack of commitment of volunteer monitors to continue consistent long-term counts at a site was another factor that decreased the quality of data. It is difficult to assess the health of a river herring run based on one or two years of data.

Coordinators also expressed some concerns with data quality and usability. For example, participants identified conditions that may affect count accuracy, such as poor weather, high numbers of fish passing at once, volunteers choosing not to count or not taking the count seriously. In addition, coordinators noted that some volunteers needed help distinguishing river herring from other fish. Thus, some coordinators sent comparison pictures out to their volunteer pool to help people accurately identify river herring. Several coordinators also expressed concerns with the robustness of the data for drawing conclusions. One coordinator said that the data quality was low, especially for trend analysis, but that it was better than no data. Another explained that there was not enough data at the run to draw any conclusions about it, and another individual noted concerns with the assumptions made in the Nelson model to estimate run sizes. Concerns with the data were not universal. Some coordinators did not express any concerns with the quality of the data or thought they had a quality dataset. Interestingly, a few coordinators indicated they use, or will use, video-monitoring equipment to complement and check volunteer counts.

Key Challenges to Standardization of Data Collection

The physical attributes of the counting site also influence a program's ability to collect accurate data. The site affects whether a counter can see the fish well enough to count them accurately (that is, counting the correct number and accurately identifying the type of fish). The absence or presence of a dam with a fish ladder strongly affects counting efficacy; without a dam, observers must find or create a constriction to count effectively. Fish tend to swim in schools and may be anywhere in the channel, so they are easy to miss or double count. In contrast, streams with dams concentrate fish through a single, narrow passage point and delay some fish, thinning out schools and making counting easier. Ironically, dams are the premiere limiting factor affecting most anadromous fish populations (Brown et al. 2013). The turbidity, or cloudiness, of the water affects visibility, as does water flow; on high-flow days, turbidity is higher, the water is deeper and faster, and visibility decreases. A white background helps create contrast to increase fish visibility. One program coordinator purchased polarized sunglasses to help volunteers see the fish.

A second challenge is the volunteer pool and its ability to collect consistent data over time. For the data to be useful, managers need it collected consistently across volunteers and comparable among years. Missing data or time slots that go unfilled or uncounted require estimating the number of fish that passed during that period, which introduces error into the final count. If too many count slots or time periods go uncounted, managers had lower confidence in the data. Similarly, confidence is affected if the data-collection methods (e.g., length of the count period per volunteer) used are not consistent between years and similar between sites. Lag time between data collection and use by managers is common because most volunteers hand write their findings on a paper data sheet or in a notebook, which means that program coordinators or resource managers spend time entering data. Finally, participation frequency and skill level of the volunteers establishes the accuracy and thoroughness of the count. Encouragingly, our volunteer survey results show participation frequency per volunteer is more than once per river herring–migration season, which may provide the level of commitment necessary to successfully implement standardized approaches: 81 percent of respondents counted more than once a month, 66 percent participated more than one year, and 91 percent planned to participate the following year.

A third challenge we discovered is that individual monitoring programs vary in their goals, and this variance may affect the quality and consistency of the data. Program goals matter because they influence participants' and program organizers' (dis)incentives for collecting sufficiently detailed data for management and sharing those data with local and state managers. For example, some programs are monitoring to demonstrate run sustainability to continue harvesting. These programs only need to demonstrate that enough fish passed upstream to meet a set escapement, but they have a strong incentive to share those data with managers because the data are required for the run to stay open. Conversely, a watershed organization actively restoring a stream may need to demonstrate impact of funding through increasing run counts (total fish counted) over a number of years, but these organizations may not have an incentive to share those data with the state. More resources may be available to municipally sponsored or harvester programs, whereas watershed organizations may be entirely dependent upon volunteers. Short-term vs long-term funding also affect program duration. For example, community-based grant-funded efforts tend to stop when the funding ends, whereas municipal or harvester efforts tend to be longer term and built into the municipal budget. Although some of these challenges—such as the physical properties of the run—cannot be easily changed, programs can implement some strategies to help standardize data collection and strengthen data quality.

Standardization of Monitoring Methods

Although the goals and volunteer pool of the various river herring–monitoring programs vary, standardization across programs may be beneficial to the fishery as a whole. Standardization would not only ensure that the data collected across runs and among states is consistent enough to be used for regional analyses, but also would provide an opportunity to develop training protocols useful for any group starting a monitoring program. Our interviewees offered several insights on the opportunities and needs for standardization.

One state official said, "Absolutely, a standardized protocol reduces error …[and] the overall confidence you have, if you know that each site is being sampled exactly the same, then it is easier to compare those things." This was echoed by another state official who said that an advantage to standardization is that the "more groups do counts, and they are all doing them the same way, theoretically we should be able to compare those over a larger area." These quotes indicate general support for standardization, but others stressed the need for some flexibility to accommodate site differences and program capacity. For example, a state official noted, "I do not think that a standardized monitoring approach would be superior to a set of guidelines," and "for each of those methods, I think that having standardized protocols would be good." Another state official was generally supportive of method standardization, but argued that there are some caveats to consider, such as the availability of volunteer counters to fill the counts and the site-specific configurations relative to the surrounding environment. There are mixed, if generally positive, feelings towards mandating a standard counting protocol because of the diversity of counting situations.

Steps to Accomplish Standardization

In contrast to the grassroots nature of volunteer river herring monitoring in New England, some officials were of the opinion that standardized monitoring would only occur if the effort came from the regional or federal level. When asked how to implement a standardized protocol along the whole East Coast, one state official

said, "when you go state to state to state, they all have their own way of doing things." Thus, some state officials recognized their limited ability to control other state's monitoring methods. It seems likely that coastwide standardization would require support and supervision from a regional or federal organization. When asked to describe some of the next steps to standardize a protocol, another official stated:

> a lot of them [steps] would have to be coordinated through the technical committee and the technical expert working group. They would identify what are the primary areas of research and management needs [and] the information should be disseminated through the representatives who are on the technical committee for when they go back to their respective states and say this is what needs to be done.

Yet others see working at the site level as the key to consistent, comparable data, but the costs in terms of direct involvement and time would be high. The official stated, "you would have to meet with your volunteer base, and your harvester, and explain to them, ideally all of them would be in the same place, and then show them [how to follow the standardized protocol]." Other officials indicated that a regional strategy for monitoring could only occur after conducting state-by-state comparisons of existing protocols, presumably to determine if there are median methods that touch on any situation.

Strides Towards Standardization

The theme of simplicity came up several times during the interviews with program coordinators, and we mention it here as a tool for improving and standardizing data collection. Coordinators offered several suggestions for creating a simple process for volunteers:

- Keep the counting process *bomb-proof simple* by having a simple protocol, leaving the equipment at a central location (preferably on-site at the count), and by using simple sign-up tools, such as Google Docs.
- Organize the counting site in an accessible location.
- Take structural steps to help simplify counting, such as putting white sandbags or a whiteboard at the counting site to increase the visibility of fish for volunteers.

Further, coordinators discussed the need to train volunteers on the importance of data quality, the factors that affect it, and importantly, that even counts of zero fish are important data points in the dataset.

Technology can assist with counting and monitoring standardization in multiple ways, keeping in mind the goal of one count per counting period as specified in Nelson (2006). Through our experiments with various counting methods at Highland Lake in Windham, we found that a hybrid volunteer-video system worked best. The volunteer pool in Windham has proven insufficient to cover the entire alewife run. We recruited volunteers as usual to make counts, but at the same time, we recorded underwater video of fish passage. At the end of the season, we identified time slots that were skipped and used a paid staffer to observe video to fill in those slots. The video also allowed us to evaluate the accuracy of counts by frequent volunteers; that is, the staffer recounted a small percentage of the periods counted by the frequent volunteers and reported to those volunteers on their accuracy.

> **River herring play a role in Maine's economy and culture.**

These methods were codified in a Quality Assurance Project Plan (QAPP—Appendix 1) in 2017. The QAPP, a document reviewed by the Environmental Protection Agency (EPA) as a requirement of receiving EPA funding, sets out guidelines for count structure, quality-control check of volunteer activities, and disposition of the data. In the case of Highland Lake, the data are released to a local land trust and an EPA-sponsored National Estuary Program, Casco Bay Estuary Partnership, for archiving.

DISCUSSION AND CONCLUSION

River herring play a role in Maine's economy and culture. Tourists visit Maine to see river herring runs, and fishermen use river herring for lobster bait. Eagles, osprey, mink and seals are attracted to river herring runs for feeding, which draw other tourists to the region to view those wildlife. Additionally, river herring are a symbol of healthy lakes and streams (EPA 2012), and they are an upstream connection between the ocean and freshwater ecosystems (Ames and Lichter 2013; Willis, Wilson, and Johnson 2017). Although our interviewees professed a need for standardized counting methods, the nature of river herring significantly complicates standardization efforts. River herring are elusive, evolved to be invisible to predators from above, and tend to travel in numbers difficult to enumerate. Schools of fish arrive at irregular intervals, further complicating counts. Every counting situation is different, even in northern New England where the streams are relatively small, small dams are widespread, the water is relatively clear, and volunteers are widely available. Yet, our research documents steps we can take to strengthen monitoring toward standardization. The following are six considerations for standardizing river herring monitoring in Maine:

- The protocol must be specific enough to be adoptable by any type of community.
- The protocol must be flexible enough to accommodate site-specific and state-specific conditions.
- The protocol must collect information that can be gathered any time a volunteer is on-site, even when fish are not running, to help volunteers stay engaged. This engagement is critical for retention.
- Volunteers and program coordinators need to understand the protocol and how data are being used for decision making to help ensure data accuracy.
- Coordinators and state and regional managers need to communicate with each other at least biannually to discuss the protocol and how it's working and to review data collection and determine how they can be used.
- The protocol must be approved by state managers and regional committees.

It is critical for this type of review that there are program coordinators who would also help implement any standardized strategy or protocol. In general, developing a network and establishing forums in which resource managers, municipal agents, program coordinators, and volunteers can share information and strategies for management of the program may improve consistency among programs and spur innovation. Further, these networks may strengthen relationships, leading to improved trust in the data.

The potential participation of citizen scientists in the development of standardized methods will further deepen citizen involvement in the management of an ecologically and economically significant resource. Having a trained and experienced group of citizen scientists with transferrable scientific skills and familiarity with the processes and requirements of environmental monitoring programs will better equip the management infrastructure to monitor future changes in the environment. Citizen scientists can be an effective extension of professionals, covering areas much larger than a professional staff can at a fraction of the cost and complementing monitoring technology. Effectively deployed citizen scientists are a triage tool that help focus limited resources on the most pressing environmental problems and help engage individuals and communities in resource stewardship and local management. Citizen science programs related to the river herring industry offer a glimpse of both the challenges of statewide standardization and of the possible solutions to these challenges. Further, they demonstrate the importance of collaborative resource management, where citizens, fishermen and fisherwomen, municipal agents, and state and regional managers work together to contribute unique insights and to gather data to inform decision making at multiple scales.

River herring monitoring has a differing policy history in the Northeast, with Maine and Massachusetts in particular using volunteer counts to different degrees and for different purposes. Managers at the national, regional, and state levels recognize the variation in methodology between sites as a limitation to the wide application of volunteer counts, but also recognize that flexibility in methods is necessary to achieve any counts. The local knowledge and stewardship of river herring by citizens, harvesters, and municipal agents is critical for effectively shepherding this resource. Ultimately, managers need a tool that uses the data and knowledge generated by volunteer counts to predict or inform sustainable harvest calculations. The investment in the development of standardized river herring–counting and –monitoring methods is an important step in managing river herring fisheries.

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