BAMS Article

Backyard Hydroclimatology:

Citizen Scientists Contribute to Drought Detection and Monitoring

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ABSTRACT: The Community Collaborative Rain, Hail and Snow (CoCoRaHS) network is a well-regarded, trusted source of precipitation data. The network's volunteers also provide weather and climate observations through daily comments, significant weather reports, and condition monitoring reports. Designed to meet a need for local information about drought events and their impacts, "condition monitoring" was initiated as a pilot project in North Carolina and South Carolina in 2013 and launched nationally in October 2016. Volunteers regularly report on how precipitation, or a lack thereof, affects their local environment and community by ranking current conditions on a seven-point scale ranging from severely dry to severely wet and sharing observations through written narratives. This study assesses the usefulness of these reports for drought monitoring and decision-making, drawing from the >7,100 reports submitted in the Carolinas between October 2016 and June 2020. This period encompasses the Carolinas' climate patterns and extreme events such as droughts, wildfires, and hurricanes ("drought busters"). Three aspects of usefulness were evaluated in the reports: the extent to which volunteers' assessments of dry-to-wet conditions correspond to objective drought indicators (EDDI, SPI, SPEI) typically employed for monitoring drought; how volunteers' qualitative observations depict changing conditions, focusing on two flash droughts in 2019; and actual use of the reports by National Weather Service offices, State Climate Offices, U.S. Drought Monitor authors, and drought response committees. Although report content can vary widely, findings show that volunteers' assessments reflect meteorological conditions and provide on-the-ground details that are being incorporated into existing drought monitoring processes.

KEYWORDS: Drought; Communications/decision-making; Decision support; Local effects; Societal impacts; Community

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Drought affects all geographies, but the key physical drivers, as well as specific impacts, of individual events can vary considerably between different climate and water use contexts (Mishra and Singh 2010). As a climate hazard, drought is typically understood as a lack of water compared to normal conditions and measured in terms of meteorological, soil moisture, evapotranspiration, and hydrological anomalies (Svoboda and Fuchs 2016; Van Loon et al. 2016). However, assessments focused only on physical variables and processes fail to capture why drought matters, in other words, how social, economic, and ecological systems are affected (i.e., impacts) (Redmond 2002; Van Loon et al. 2016; Wilhite and Glantz 1985).

Documenting and understanding the full scope of impacts is critical for developing meaningful indicators, tracking and responding to drought events, designing effective community-level mitigation strategies, and communicating to the public (Ferguson et al. 2016; Purdy et al. 2019; Steinemann 2014; Van Loon et al. 2016). Despite the importance of drought impacts data, the extent to which the various entities responsible for drought management systematically collect, maintain, and apply this information is not well documented. Previous studies nonetheless point to challenges and gaps associated with the real-time monitoring and use of impacts information. For example, while some drought-related datasets are readily accessible (e.g., crop yields, insurance claims, water use restrictions, wildfire occurrence, vegetation stress), many assessments are conducted post-event, thereby limiting their operational use (Bachmair et al. 2016). For extended events, longer-term nonmarket (e.g., habitat loss, psychological stress) and nonstructural (e.g., deterioration of water quality, loss of recreation or tourism opportunities) effects can be difficult to evaluate and attribute directly to drought (Ding et al. 2011). Other research suggests that states employ disparate and informal efforts to monitor impacts during drought events, with many relying on organizational and personal networks (e.g., through extension programs) to ascertain the impacts experienced within their jurisdictions (Fontaine et al. 2014; Smith et al. 2021; Steinemann 2014).

The Drought Impact Reporter (DIR; https://droughtreporter.unl.edu) and Arizona DroughtWatch, two efforts to collect near-real-time impacts information, reveal additional considerations regarding the design and implementation of reporting systems. Launched by the National Drought Mitigation Center (NDMC) in 2005, the DIR is an archive of drought impacts reported by the media, government agencies, individual submissions, and volunteer observers enrolled in the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network. The DIR provides a resource that can expand understanding of drought's many effects on communities, business sectors, and the environment and inform drought-related planning and research at multiple scales (Smith et al. 2014). Limitations to its use as an operational monitoring tool center on how the mostly event-driven reports (i.e., those submitted during severe or extreme drought conditions) can lack additional context about both the local climate and the management decisions that may be creating or exacerbating adverse effects. Another concern is that desire for financial assistance for the agricultural sector drives many of the volunteered submissions (Smith et al. 2021). Arizona DroughtWatch, launched in 2009, was designed to collect Arizona-specific information about local drought impacts, help monitor changing conditions over time, and inform local- and state-level response and mitigation strategies. Although developed with much user engagement, the online tool had very limited participation due to a combination of factors. Challenges included an overreliance on volunteers, a lack of clarity about how the submitted information was used, difficulties in understanding what constitutes a drought impact, and usability of the website (Meadow et al. 2013).

With this article we review a drought impacts monitoring initiative that aims to address some of the challenges identified by previous efforts. Led by the Carolinas Integrated Sciences and Assessments (CISA), the motivation came from drought stakeholders in North Carolina and South Carolina. They articulated needs for timely, on-the-ground impacts information that would reveal drought onset, intensification, and recovery and could inform and be integrated into existing state- and local-level monitoring activities (Brennan et al. 2012). The "condition monitoring" pilot launched in September 2013, as part of the National Integrated Drought Information System (NIDIS) Drought Early Warning System for the Carolinas region. In collaboration with CoCoRaHS, we asked their volunteer network to report how precipitation, or the lack of precipitation, affects their local environments and communities. Overall positive feedback from CoCoRaHS, their volunteers, and decision-makers during the pilot phase (phase 1; Lackstrom et al. 2017) allowed us to secure additional funding to expand the project to the full network of CoCoRaHS observers in October 2016 and further evaluate the approach in the Carolinas through June 2020 (phases 2 and 3).

Here we share results from our efforts to assess 1) the feasibility of condition monitoring as an approach to drought impacts reporting and 2) whether and how the information provided by CoCoRaHS volunteers might be used in established drought monitoring and decision-making processes. First, we present an overview of the project's design and evolution, building on Lackstrom et al. (2017). Second, we provide findings from our examination of the effectiveness of the condition monitoring approach and use of reports to inform drought monitoring in the Carolinas. We draw from analyses of the reports submitted from October 2016 and June 2020 and feedback we obtained from agencies responsible for drought monitoring (e.g., state climate offices, NWS offices). Results indicated that condition monitoring reports are valued and augment existing drought monitoring efforts in the Carolinas. We conclude by reflecting on broader implications, the opportunities as well as limitations, of using volunteered impacts information for drought-related decisions and monitoring.

The Carolinas Condition Monitoring Project

Project design and evolution. The underlying premise behind condition monitoring is that regular reporting of local-scale observations can help decision-makers identify, monitor, and understand changes occurring during unseasonal dry or wet weather. This approach contrasts with other drought impact assessment efforts that tend to occur post-event or when drought has reached a severe level (Bachmair et al. 2016; Lackstrom et al. 2013). In designing the project, we were very cognizant of drought impact reporting challenges, such as maintaining volunteer interest, particularly in the absence of drought conditions (Meadow et al. 2013), understanding the different incentives that motivate volunteered reports (Smith et al. 2021), and a lack of clarity about the operational use of impacts reports (Bachmair et al. 2016). Accordingly, we looked to best practices for designing citizen science projects (e.g., Bonney et al. 2009; Shirk et al. 2012) and employed three key, interconnected strategies as we initiated and subsequently continued the project: leverage partnerships, evaluate the various project components, and conduct regular outreach with volunteers.

First, we leveraged existing partnerships and trusted networks. At the project's outset, stakeholders recommended we partner with CoCoRaHS (http://www.cocorahs.org/), a well-regarded nonprofit, community-based network of volunteer precipitation reporters (Reges et al. 2016). Since the network's introduction in 1998, thousands of volunteers have contributed measurements which are used for climate monitoring, model and forecast verification, and post-event assessments (e.g., Goble et al. 2020; Lin et al. 2018; Menne et al. 2012; Shepherd et al. 2011; Story 2018). CoCoRaHS started as a precipitation (rain, hail, and snow) measuring network but over time has given motivated and interested volunteers opportunities to report on other aspects of the water cycle (e.g., evapotranspiration, soil moisture, and drought) (Reges et al. 2016). Beginning in 2010, CoCoRaHS provided a drought impact report form to observers; their submissions were then ingested by the DIR (Smith et al. 2014). During phase 1 of this project (2013–15), volunteers in the Carolinas used this existing form to submit their condition monitoring reports.

Additionally, we drew on relationships with the State Climate Offices (SCO) and NWS forecast offices in the region. NWS and SCO personnel serve as state and regional CoCoRaHS coordinators, and they helped us to connect and communicate with local volunteers. As these offices also participate in state-level drought committees and/or provide input to the U.S. Drought Monitor (USDM) process, they gave invaluable feedback on the usability and use of the condition monitoring reports.

Second, we integrated evaluation into the project to gather volunteers' and report users' feedback on developed products and resources, perspectives on condition monitoring, and overall experience with the project. Specific methods included online surveys, telephone interviews, and small group discussions (primarily via webinar). We applied these methods in an iterative manner to monitor the effort, stay connected to volunteers and decision-makers, and enhance products and informational materials as the project progressed (Fig. 1).

The major change occurred after phase 1 feedback signaled a need for improved access to condition monitoring reports, and the original "Drought Impact Form" was modified and renamed the "Condition Monitoring Report Form." The key addition to the form, the "Condition Scale Bar," allows observers to rank local conditions on a seven-point scale from severely dry to severely wet. Selections correspond to the symbology on the concurrently launched, interactive web map (Fig. 2; Lackstrom et al. 2017). In a space for written narratives, volunteers may note how precipitation (or lack thereof) has impacted their local environment and community. Training materials available on the CoCoRaHS website offer guidance for completing the form and assessing conditions, but volunteers are encouraged to write about topics most important to them or where they have expertise (https://www.cocorahs.org/Content.aspx?page=condition). When the new form and web map launched in October 2016, the condition monitoring project expanded from the Carolinas-only pilot to the entire CoCoRaHS network.

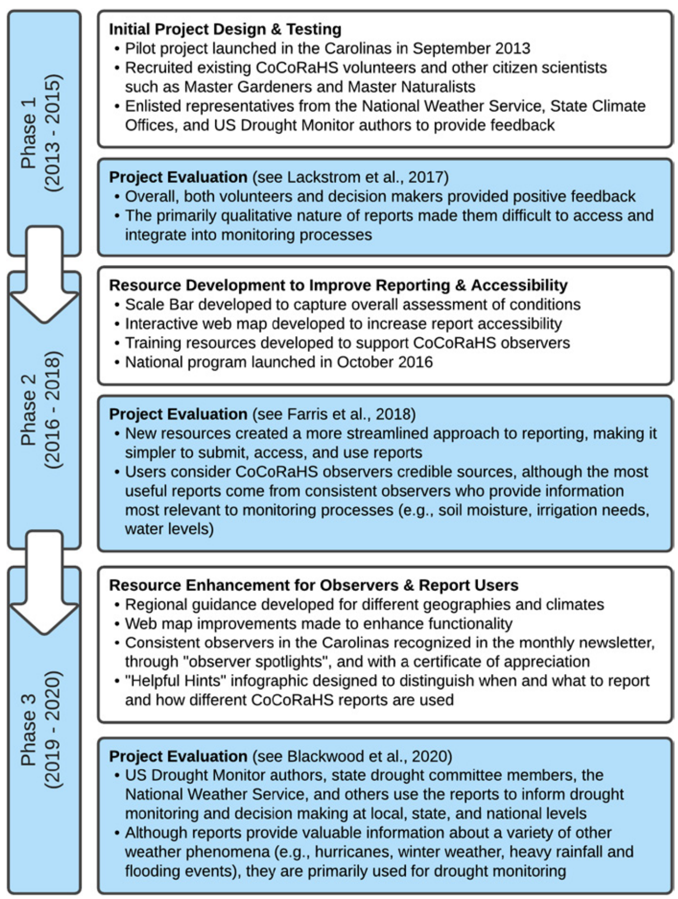

Fig. 1. Evolution of the condition monitoring project. (Sources: Blackwood et al. 2020; Farris et al. 2018; Lackstrom et al. 2017.)

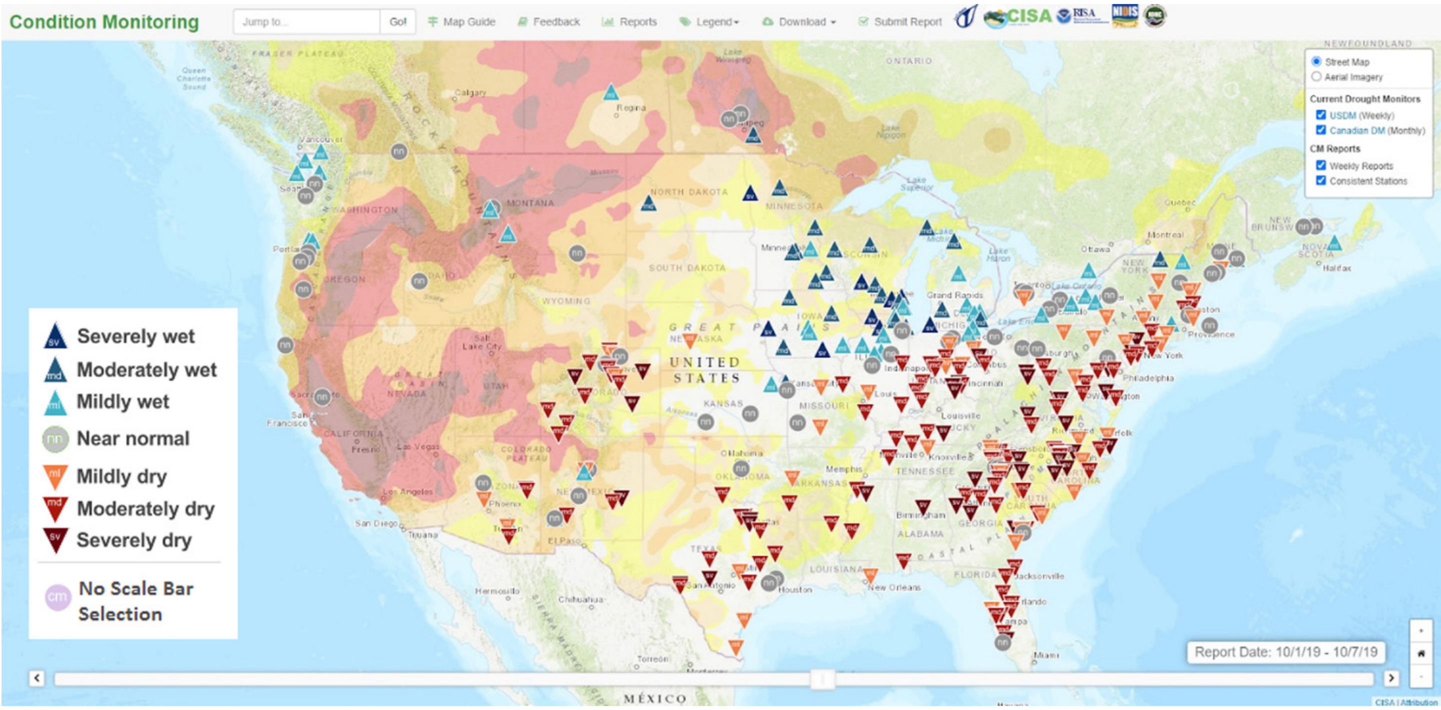

Fig. 2. Condition monitoring web map, displaying reports submitted from 1 to 7 Oct 2019, the height of drought coverage according to the U.S. Drought Monitor during the flash drought discussed in the "Assessing usefulness" section. This interactive map was created to make reports more accessible and useful to decision-makers and the volunteer reporters. Qualitative narratives are accessible by clicking on the observers' location, as indicated by their scale bar selection. (Source: https://www.cocorahs.org/Maps/conditionmonitoring./)

Subsequent user feedback informed map improvements, such as the search and download functions, the time slider feature, and the "consistent stations" layer which displays reports from those observers who have submitted at least 20 reports in the last 12 months. As decision-makers indicated that consistent reporters provided the most useful information, we incorporated this message into phase 3 training materials and volunteer outreach.

Third, we devoted considerable resources to supporting the Carolinas' condition monitoring volunteers through regular outreach and education. Volunteer feedback surveys in phases 1 and 2 indicated that frequent communications, tailored training materials, and opportunities to learn about other volunteers sustained interest in condition monitoring and helped foster a sense of community (Farris et al. 2018; Lackstrom et al. 2017). We used this feedback to improve the various resources we disseminated. A monthly newsletter included drought status updates for the region, examples of how the reports were used, and an "observer spotlight" to feature those volunteers who reported consistently. Other efforts included a blog, handwritten thank-you notes, and conference calls that convened both volunteers and SCO and NWS office personnel so they could share their experiences with the project (Blackwood et al. 2020; Farris et al. 2018).

Summary of volunteer participation and the climate context (October 2016–June 2020). From October 2016 to June 2020, the study period detailed here, 4,889 CoCoRaHS observers from across the United States and Canada submitted 59,019 condition monitoring reports. These totals include 431 observers (8.82% of the total) and 7,217 reports (12.23% of the total) from the Carolinas (appendix A). The relatively large percentage of participants from the Carolinas is not surprising, due to CISA's promotion of the project in that region. The number of reports submitted by individuals in the Carolinas ranged from 291 (highest value) to 1 (lowest value); 168 observers (40.68% of Carolinas observers) submitted only one report.

Sixty volunteers submitted reports for at least 4 of the 5 years, accounting for 4,997 reports (69.24% of Carolinas reports).

The climate of the Carolinas can be broadly characterized as humid subtropical with no distinct wet or dry seasons. Annual precipitation amounts range from 1,000 to 1,600 mm (40–60 in.), with coastal regions on the higher end of this range because of summer sea-breeze circulation and the influence of tropical cyclones in the summer and fall. The Appalachian Mountains border both states on the west, where both locally lower and much higher amounts of annual precipitation are observed due to orographic effects. Midlatitude cyclones and frontal systems that move west to east across the continent dominate precipitation patterns during the cooler months of the year, while localized convective systems dominate precipitation in the summer. A regular part of the climate, droughts can develop quickly in the summer months due to the localized nature of precipitation and lead to agricultural impacts. Absent the ample rains from summer or fall tropical systems, droughts can persist through the cooler months to bring hydrological impacts as well as enhanced fire activity.

The 45 months of reports analyzed for this research encompass a range of Carolinas' climate patterns and extreme events including droughts, wildfires, hurricanes, and record-breaking warm and wet periods (Fig. 3). Specifically, the period saw two impactful hurricanes (Matthew in 2016 and Florence in 2018) that caused widespread and prolonged flooding in the eastern part of the region. Several droughts emerged during this period, beginning with a severe event that was mostly confined to the western edges of the Carolinas in fall 2016 and coincided with Hurricane Matthew. A longer but less severe event spanned 2017–18 and was most intense in the central Carolinas. A series of shorter-lived drought events exacerbated by heat impacted the eastern (early 2019) and central and western (mid-to-late 2019 into early 2020) parts of the Carolinas.

Volunteers are encouraged to report regularly regardless of conditions (wet, normal, or dry), not only when a drought reaches severe levels. The histogram of scale bar selections during this period indicates volunteers report a range of conditions (Fig. 4). Despite a higher percentage of dry reports, overall, reports documenting wet, normal, and dry conditions align with the variable conditions experienced across the Carolinas. The report counts displayed in Fig. 3 also suggest that drier periods (2016, 2017, 2019) receive more participation compared to wetter periods. We note that fifty of the 7,217 reports submitted by Carolinas' observers did not include a scale bar value. These reports were removed to generate Fig. 4 and to conduct the report analyses presented in the next section.

Assessing usefulness

To assess the usefulness of the condition monitoring approach and reports for drought monitoring, we drew from literature about climate information use (Lemos et al. 2012), volunteered geographic information (Goodchild and Li 2012), and citizen science methods (Freitag et al. 2016), all of which highlight how multiple, interacting factors shape both the production and application of new information. In the case of condition monitoring, we expected that the actual information or product (i.e., the condition monitoring reports), the information providers (i.e., CoCoRaHS volunteers), and qualities of the users (i.e., individuals and groups with drought monitoring responsibilities), would jointly contribute to the use and usefulness of the reports. As part of the final project evaluation, we used data collected throughout the project to further investigate two key aspects of information usability, credibility and salience, and to reflect on whether and how reports were used. Here we consider credibility as the extent to which an information user perceives a product, the information it contains, and its originating source to be accurate, valid, of high quality, and reliable (Flanagin and Metzger 2008; McNie 2013). Salience refers to the extent to which information fits the organizational

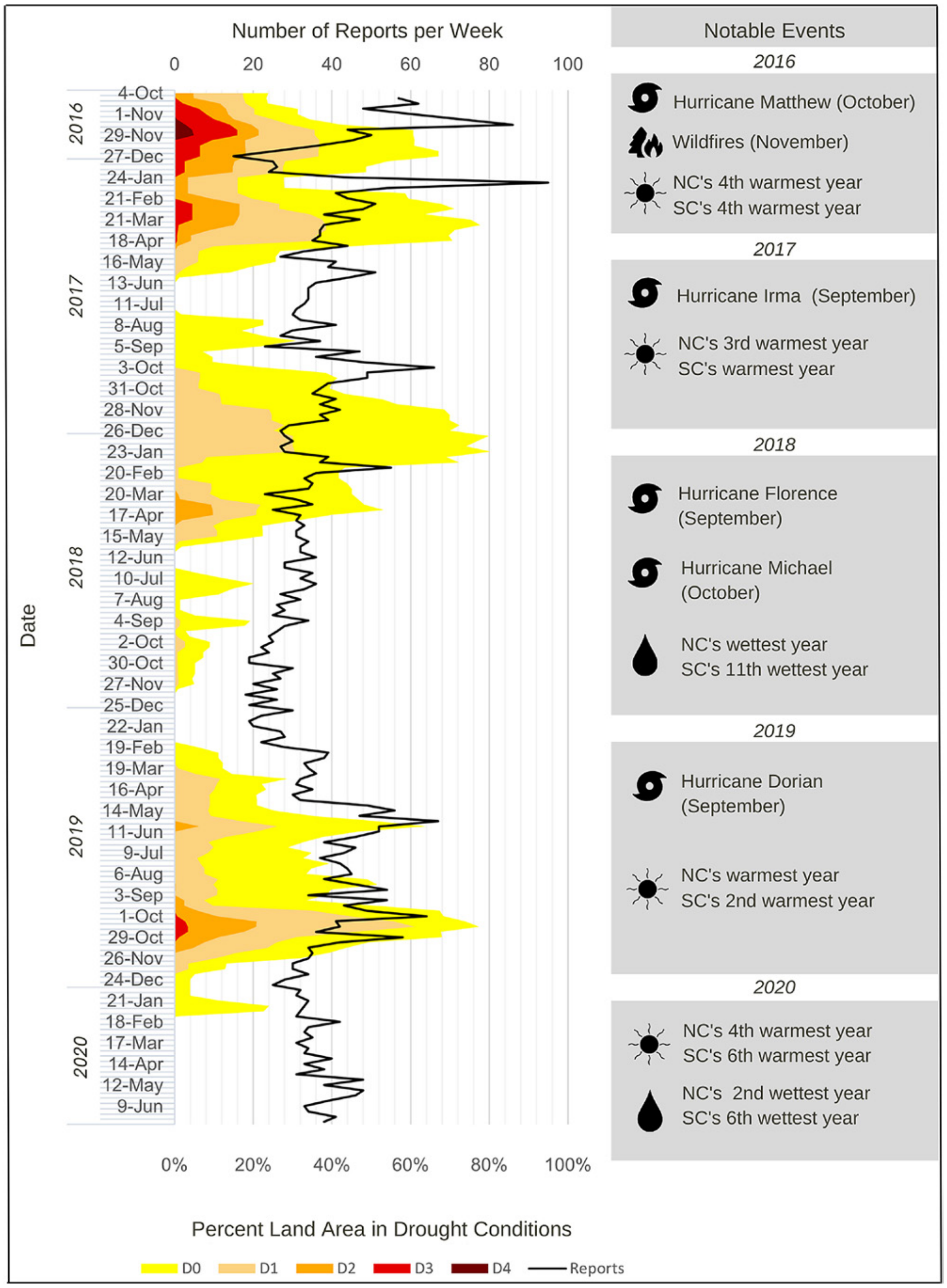

Fig. 3. **Weekly condition monitoring report submissions and combined North and South Carolina USDM drought designations, with notable weather events and climate conditions annotated in gray boxes. The number of reports submitted each week ranged from 15 (low value; week of 27 Dec 2016) to 95 (high value; week of 31 Jan 2017), with a mean of 37 reports. From October 2016 to June 2020, North Carolina and South Carolina experienced ≥D0 conditions in some part of each state 70.91% and 76.53% of the time, respectively. Drought designations were obtained from the U.S. Drought Monitor (https://droughtmonitor.unl.edu/; D0 = Abnormally Dry; D1 = Moderate Drought; D2 = Severe Drought; D3 = Extreme Drought; and D4 = Exceptional Drought). Annual climate rankings were obtained from the National Oceanic and Atmospheric Administration (NOAA) Climate at a Glance tool (https://www.ncdc.noaa.gov/cag/).**

and institutional setting in which the user works, responds to decision-makers' specific needs and fundamental interests, and is presented in a timely manner and at pertinent spatial scales (Dilling and Lemos 2011; McNie 2013).

Drawing from the reports submitted by the North Carolina and South Carolina volunteers from October 2016 to June 2020, we first analyzed the extent to which their scale bar

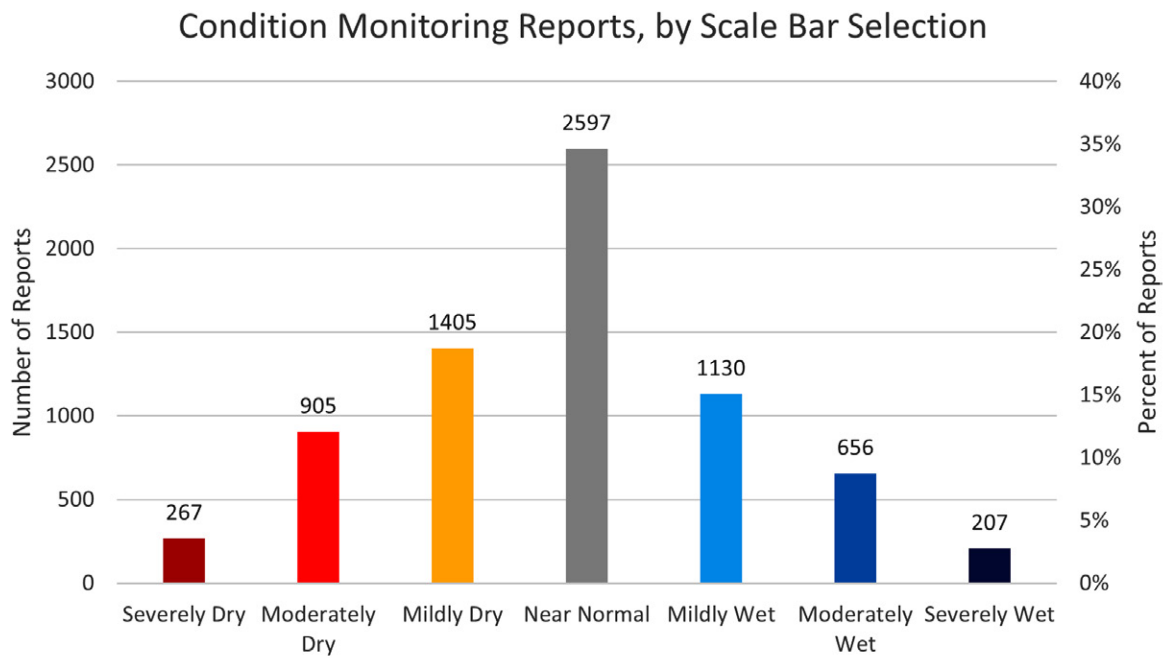

Fig. 4. Condition monitoring reports submitted by CoCoRaHS volunteers in the Carolinas (October 2016–June 2020; total = 7,167), organized by scale bar selection. Each bar shows the exact number of reports submitted for each category (severely dry to severely wet). The colors of the scale bar categories match those used in the condition monitoring web map.

assessments corresponded to quantitative indicators typically employed in drought monitoring. Second, we investigated how volunteers' qualitative observations depict changing conditions by analyzing the reports submitted in 2019 when the Carolinas experienced two flash droughts. Flash droughts are different from "typical" droughts in that they develop and intensify rapidly, sometimes within only 1–2 weeks, and can be challenging to identify and monitor. They are often accompanied by high temperatures or heat waves, high evapotranspiration rates, declines in soil moisture, and vegetation stress (Otkin et al. 2018; Pendergrass et al. 2020). As both states received exceptional precipitation in 2018 (Fig. 3), focusing on 2019 provided an opportunity to trace when and how volunteers documented the evolution of drought conditions (onset, intensification, recovery) over this specific period, starting from a wet or normal baseline. Third, we synthesized key findings obtained through decision-maker feedback in phases 2 and 3 about their perceptions of the condition monitoring approach and actual use of the reports. The University of South Carolina (UofSC) Office of Research Compliance, an administrative office supporting the UofSC Institutional Review Board, reviewed the study and determined it met Non-Human Subject criteria.

Scale bar analysis.

Methods. To assess volunteers' ability to provide reliable information for their location, we examined the extent to which their assessments of conditions via the seven-point scale bar correspond to three commonly used numeric drought indices: the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI), and the Evaporative Demand Drought Index (EDDI). We used time scales of 14, 30, 90, and 180 days because they reflect the scales used by state-level groups in North Carolina and South Carolina for weekly drought monitoring and would therefore offer the most practical insights for their real time use of CoCoRaHS observers' reports. Each of these indices represent dryness or wetness as standard deviations above or below the mean (centered at zero). Positive SPI and SPEI indicate wetter-than-normal conditions while positive EDDI indicate drier-than-normal conditions. We used the 7,167 reports submitted by Carolinas' observers from October 2016 to June 2020 and obtained the SPI, SPEI, and EDDI values for the grid cells closest to each observer's latitude and longitude and corresponding to each report date from Climate Toolbox (https://climatetoolbox.org/), which uses gridMET data (Abatzoglou 2013). We first assigned numeric values to the scale bar values (severely dry = −3, near normal = 0, severely wet = 3) and then aggregated (by averaging) scale bar values and drought indices to USDM weeks to better reflect how the data are used in drought monitoring activities. To compare the datasets, we computed Pearson correlation coefficients between these weekly averaged values.

Table 1. Pearson correlation coefficients between volunteers' scale bar selections and drought indices (EDDI, SPI, and SPEI) for four different time scales that align with those used by state-level drought monitoring groups in North Carolina and South Carolina. Correlations were computed for the October 2016–June 2020 period. All correlations are statistically significant ($p < 0.01$). Positive scale bar selections, SPI, and SPEI indicate wetter-than normal conditions while positive EDDI indicate drier-than-normal conditions. Negative correlations between scale bar and EDDI values therefore indicate that both EDDI and volunteers' reports agree on the direction of dryness or wetness.

Time scale (days)	Drought index		
	EDDI	SPI	SPEI
14	0.62	0.76	0.78
30	−0.57	0.75	0.77
90	−0.59	0.68	0.72
180	−0.38	0.54	0.56

Results and discussion. Observers' scale bar assessments generally reflect meteorological conditions as measured by SPI, SPEI, and EDDI and are strongly correlated with these indicators (Table 1). The strongest correlations occur at the 14-day time scale and with the SPEI. Based on our actual use (coauthor Ward) and assessments of report content (below), observers reference both precipitation and temperature in their observations and appear to consider conditions and impacts holistically. This could explain why the correlations are slightly stronger with SPEI, as it considers both precipitation and potential evapotranspiration, than either the SPI or EDDI which are each based on only one variable.

The 14-day SPEI and volunteers' scale bar selections generally align well, as when both indicators capture the emerging dry conditions that spread across the Carolinas in late spring and early fall 2019, and when conditions began to return to normal (Fig. 5). However, we also note several discrepancies between the two indictors. For example, the 14-day SPEI in February 2019 shows short-term dryness. While scale bar values similarly show drying conditions, the intensity remains at near normal levels, likely due to lingering wetness from the record rainfall in 2018. At other times in 2019 (June, November, December), scale bar selections indicate drier conditions compared to the SPEI, suggesting on-the-ground improvements lag the quantitative indicator. While Fig. 5 shows only one time scale (14-day) and drought index (SPEI), it highlights the type of information condition monitoring reports can contribute to the "convergence of evidence" used to determine the weekly USDM. As the scale bar selections correspond well with the shorter-term indicators, they may have some utility in providing early warning of emerging or evolving drought conditions.

Report content analysis.

Methods. To assess volunteers' ability to detect changing conditions and provide timely and relevant information for drought monitoring, we explored how their narratives articulated conditions and impacts over time, to compare with the categorical assessments of conditions gathered via the scale bar. More specifically, we conducted a qualitative analysis of the report content between June and August 2021. First, two project team members independently reviewed and coded the text from the 2,022 reports submitted in 2019. A third coder then

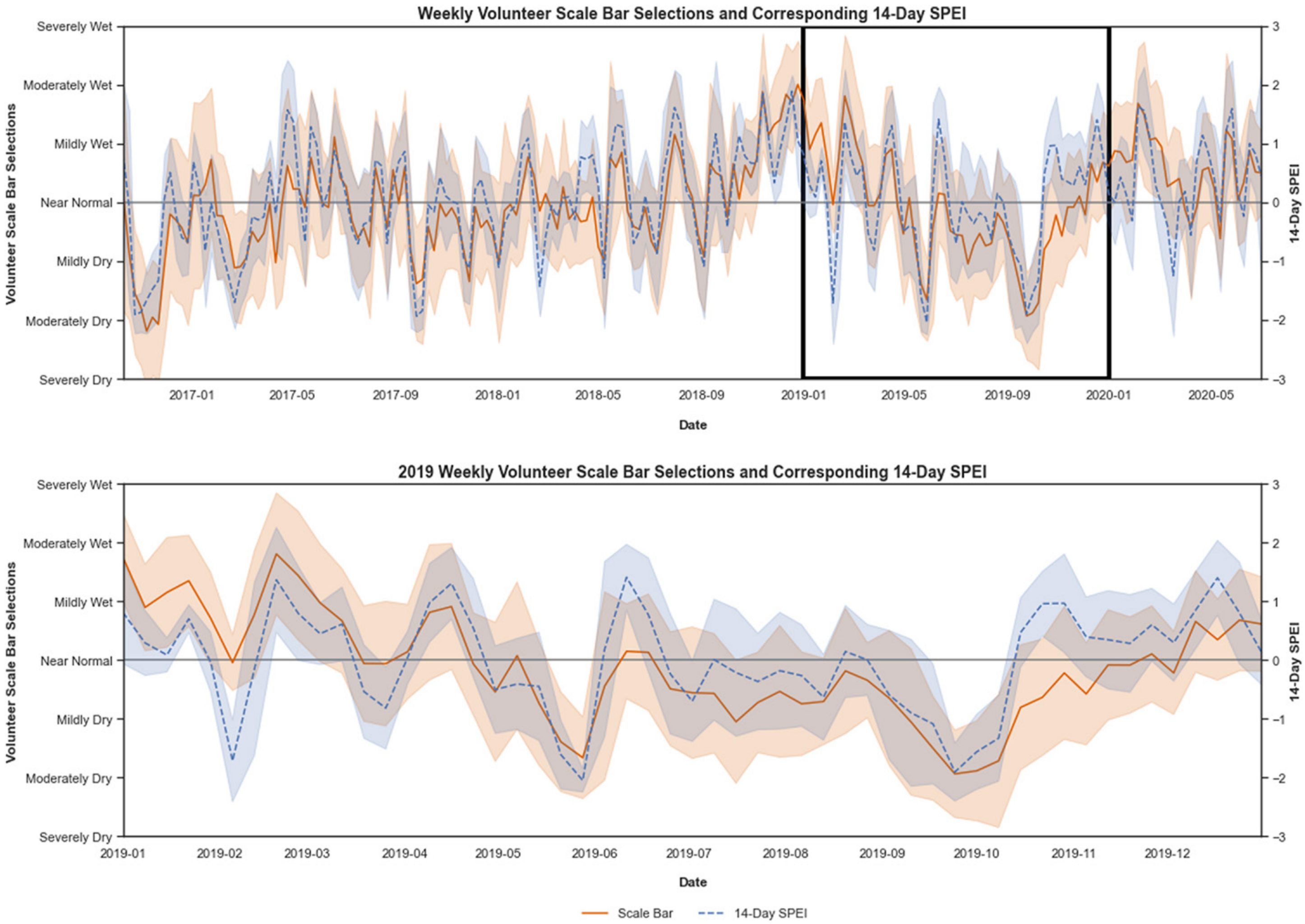

Fig. 5. Comparison of volunteers' scale bar selections with the 14-day SPEI for (top) the full study period and (bottom) 2019 when dry conditions emerged in both the spring and the fall. Weekly averages were computed by obtaining all available scale bar selections in the Carolinas for each week and averaging these. The 14-day SPEI corresponding to each volunteer's location and observation date were also obtained and averaged for each week. Shaded areas show ±1 standard deviation around the weekly averages.

reviewed inconsistencies and made final recommendations, and the full group discussed any lingering questions. The reports' word count ranged from 1 (e.g., "dry") to 644 (the longest report submitted). The mean equaled 68; slightly more than half (55%) of all reports contained less than 50 words. Appendix B contains descriptions of the wet, normal, dry, and improving categories used to code the reports, as well as the number of reports coded at each category. For the dry category, we looked for indications of conditions becoming drier over a 1–2-week period, to correspond with the time scale at which flash droughts emerge and strengthen. We also looked for signs of improving conditions, information not captured by the scale bar. In some cases, it was necessary to review the scale bar selections in an observer's successive reports to make a final determination. Brief reports presented challenges as they contained little to no context specifying what had changed from the previous submission(s), for example "no need to run irrigation" and "a little rain over last week." Reports describing longer-term (several weeks to seasonal) patterns were difficult because they would often describe dissimilar conditions occurring simultaneously. For example, a report might indicate vegetation improvements due to recent rainfall, as well as lingering impacts on soil moisture at lower levels and local surface water bodies. We coded such reports as "improving" to reflect some positive change from the previous report(s).

Second, to better understand how these condition monitoring reports add value to the suite of quantitative indicators commonly used in drought monitoring processes, we reviewed and developed more detailed codes for all "dry" or "improving" reports (n = 1,022). Initial coding categories corresponded to the various types of impacts we expected to see in the reports (i.e., meteorological, agricultural, hydrological, socioeconomic, and ecological). We refined these categories and descriptions to better align with how volunteers tended to describe the indicators and impacts they observed (appendix C; Table 2, column A).

Because users highly value "consistent" observers, we also sought to characterize differences between those observers who reported recurringly in 2019 and those who reported more sporadically. We determined the 2019 consistent observers based on the number of reports submitted (≥12 for the year) and the variance between report submission dates, to include volunteers who tend to submit condition monitoring reports at >2-week intervals. Through this process we identified 37 consistent observers (1,540 reports) and 132 "episodic" reporters (482 reports). Of the consistent observer group, 35 reported, on average, every 1–2 weeks, one reported approximately twice per month, and one reported once per month.

Results and discussion. Most wet reports occurred in the first few months, a carryover from the wet 2018, and then were scattered throughout the year, depending on appearances of localized thunderstorms, frontal systems, and Hurricane Dorian. Figure 6 shows the "dry" and "improving" reports submitted each week, in conjunction with USDM designations. The uptick in dry reports in late April and early September appear to indicate periods of intensification reflected in the USDM in subsequent weeks, suggesting that volunteers can provide an early warning signal. The "improving" reports also appear to align with USDM classifications

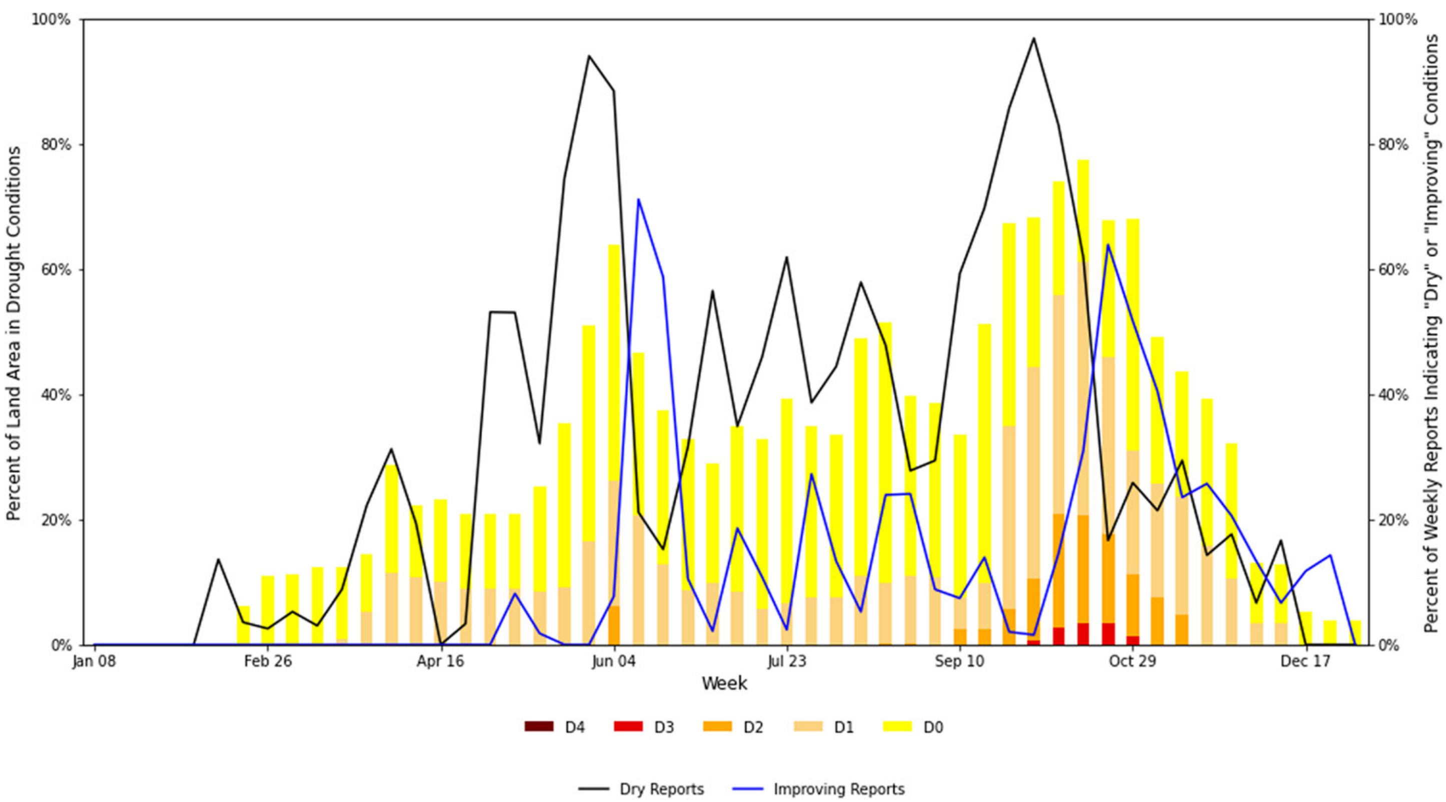

Fig. 6. **Dry and improving conditions depicted by condition monitoring reports submitted in 2019, compared with USDM designations. Reports submitted by both consistent and episodic reporters are included.**

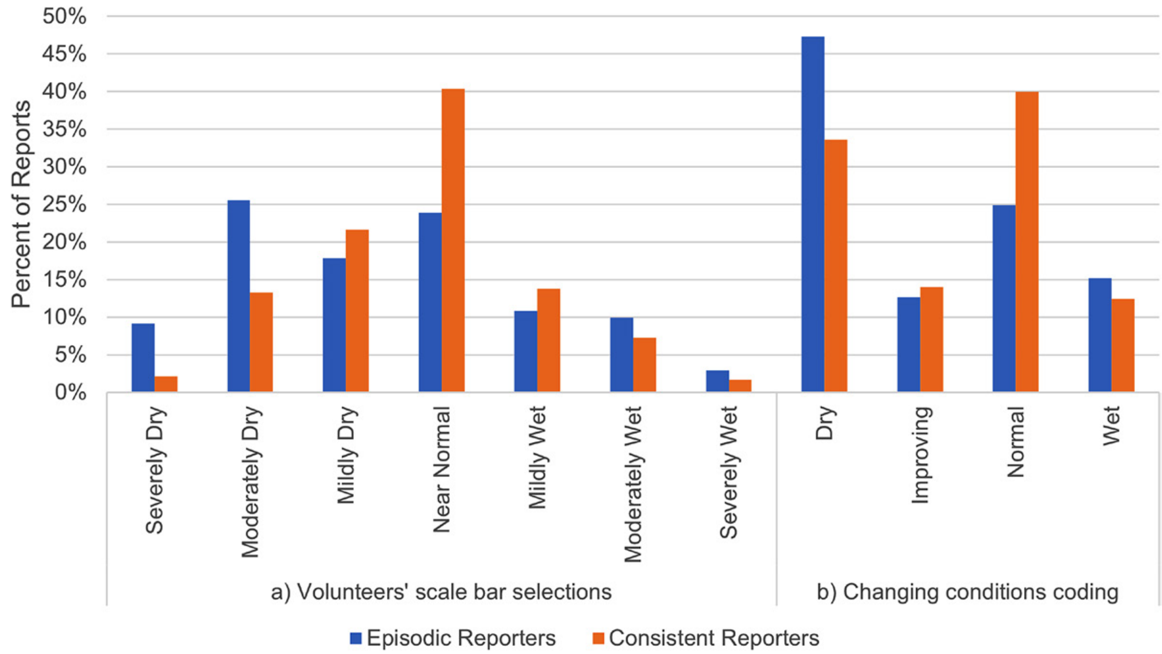

Fig. 7. Comparison of consistent and episodic reporters' depiction of conditions, based on (a) their scale bar selections and (b) the qualitative coding of report narratives. The changing conditions coding categories correspond to those listed in appendix B.

as drought conditions waned. Notably, some volunteers continued to indicate improving conditions even after no drought remained on the USDM, demonstrating the uneven nature of drought recovery.

Figure 7 illustrates the primary difference between the consistent and episodic reporters. Episodic reporters are more likely to report when they observe or experience dry conditions and impacts, while consistent reporters tend to report across the range of conditions. These results reinforce users' feedback about the higher value they place on observations from consistent reporters and their perceived ability to detect when drought emerges, intensifies, and weakens at their location, this project's initial motivation.

The most prevalent information contained in the reports pertained to precipitation and temperature patterns and the status of plants, irrigation activities, soil moisture, and hydrologic features (i.e., drainage ditches, wells, ponds, streams, and wetlands) found in volunteers' "backyards" or neighborhoods (Table 2). Fewer reports contained information about impacts to agriculture, fire, wildlife, regional hydrologic features (i.e., major rivers, large reservoirs), air quality, water quality, energy generation and use, water use, and recreation. Exceptions include the consistent observers whose reports feature the wildlife activity (41%; i.e., birds, mammals) and air quality conditions (41%; i.e., dust, pollen, allergies) they directly observe and experience in their daily lives. Some observers do engage in agricultural activities and report on their specific farm or pasture conditions (38%), but other agriculture-related reports provide more general observations of crop or pasture conditions at the community or county level. The lack of water resource-related reports makes sense given that both states had record wet years the previous year (NOAA/NCEI 2021; Fig. 3) and that hydrologic drought indicators (e.g., water supply impacts) tend to lag meteorological drought conditions.

Report content can vary considerably, as Table 2 suggests, and Fig. 8 exemplifies. Some reports include a great deal of detail, while others focus on only one or two indicators, such as precipitation or plants. The more comprehensive reports include information about the

Table 2. Drought indicator and impact content contained in the condition monitoring reports. Appendix C provides the coding category descriptions (first column). The next three columns show the breakdown for reports coded as "dry" (n = 745), "improving" (n = 277), and the "combined" total of "dry" and "improving" (n = 1,022). The rows are organized according to the most to least prevalent information contained in the combined "dry" and "improving" reports. The last three columns show the breakdown according to consistent reporters (n = 37) and episodic reporters (n = 101; note that not all episodic reporters submitted "dry" or "improving" reports) and the "combined" total (n = 138).

	Percentage of reports containing content			Percentage of observers providing content		
Coding category	Combined	Dry	Improving	Combined	Consistent	Episodic
Precipitation	76	69	96	78	97	70
Plants	53	52	55	80	100	72
Temperature	33	35	26	50	95	34
Irrigation	30	36	15	43	78	31
Soil moisture	29	29	29	59	92	48
Backyard hydrology	27	26	32	38	76	25
Other weather	14	16	9	40	73	28
Agriculture	11	12	10	28	38	24
Fire	9	10	8	16	27	12
Wildlife	9	10	7	17	41	9
Regional hydrology	7	7	7	11	19	8
Air quality	6	8	3	21	41	14
Societal effects	3	4	2	12	24	8
Water quality	2	1	2	4	16	0

impacts of precipitation and temperature anomalies and extremes in a way that many drought indicators and indices do not. For example, 58% of the "dry" and "improving" reports were coded at three or more categories, helping to capture the complexity of different drought stages (i.e., topsoil layers and plants show signs of stress, while deeper soil moisture levels or water resources may not yet be impacted). In contrast, many quantitative tools such as the SPEI give an indication of environmental conditions, but decision-makers and monitoring groups can only infer what this means for on-the-ground impacts or improvements.

Decision-maker feedback.

Methods. Efforts with report users focused on ascertaining how they valued, used, and/or would consider using the data for drought monitoring and management decisions (Wiggins et al. 2018), how they viewed the credibility and quality of the volunteers' observations (Freitag et al. 2016), and any organizational factors affecting report use (Dilling and Lemos 2011). We purposefully targeted organizations with responsibilities for drought monitoring and response in our outreach, focusing on those located in the Carolinas and individuals who we expected would most likely use and benefit from the reports. More than 50 individuals participated, representing the NWS, state drought response committees, SCOs, the Southeast Regional Climate Center, the USDM, NDMC, and CoCoRaHS (Table 3).

During phase 1, we conducted semi-structured interviews with 17 decision-makers to assess their perceptions of the reports' credibility, reliability, and potential use. Although decision-makers considered the volunteers' reports informative, they did not use the reports due to the lack of an efficient method to access them. The subsequent development of the condition monitoring scale bar and interactive web map (Fig. 2) removed this barrier and then allowed us to investigate actual use of the reports in phases 2 and 3.

Overview of Conditions	Condition Monitoring Report Examples
Spring early onset: Wet conditions characterized much of the Carolinas through winter and early spring of 2019. South Carolina observers noted drying in March, although April rains brought the return of wetter conditions	"January and February together recorded a 3.0" deficit for the year. We've had small amounts of rain this past week, but with warmer temperatures, it is necessary to monitor more closely lawn and garden irrigation. Pollen is also now a factor. Very messy! Lagoon levels are beginning to drop some and birds and other wildlife are looking for water. It would be nice to have a soaking day long rain!" (SC-BF-10, 3 March 2019, scale bar selection = mildly dry)
Spring intensification: Conditions began to shift as an early heatwave led to North Carolina's third warmest May on record and record-setting temperatures topped 100 degrees F throughout South Carolina	"No significant rain for 6 weeks. Need to water vegetation in yard and garden. Water level in retention pond is down by 3.5 feet. Air temperatures in the 90s causing accelerated evaporation of pond and bird baths." (SC-DC-55, 26 May 2019, scale bar selection = moderately dry)
Spring recovery: Drought severity peaked during the week of June 4 but subsided as storms brought relief	"After 5" of rain this week the soil has returned to normal. Grass [has] turned green in most spots and has started to grow again. Lagoons have been refreshed with new water and the fish and alligators are happy." (SC-BF-2, 10 June 2019, scale bar selection = normal)
Summer variability and near-normal conditions: Summer weather was characterized by spotty thunderstorms. Sporadic rainfall and some below-average temperatures in late July and August kept dry conditions at bay for many areas	"We've had 2.49" so far in July, with 0.82" in the last seven days. We had to water grass late last week when the lawn was starting to show stress, but rains this week have the lawn looking good." (SC-RC-12, 27 July 2019, scale bar selection = normal)
Summer onset: Drought began to emerge again throughout South Carolina and into North Carolina in late summer	"With only 0.20 of rain over the past 7 days, we are experiencing dry conditions. Water levels are just below what would be normal but not significantly low. Risk of fire is a little higher than it has been as well. Our Christmas Trees are doing fine but could use some rain in the next few days. Our vegetable garden is beginning to play out but there is still enough moisture to keep tomatoes coming." (NC-MS-19, 2 September 2019, scale bar selection = mildly dry)
Drought buster (or bust): Hurricane Dorian made landfall near Cape Hatteras, NC on Sept 6, which alleviated dryness along the coast. However, the hurricane failed to bring widespread rainfall.	"It was a dry week, but Hurricane Dorian brought 1.81 inches of steady rain yesterday. That replenished moisture to normal conditions." (NC-WK-203, 6 September 2019, scale bar selection = normal) "Hurricane Dorian missed my area. We got 0.46" of rain and that is all for the week. Dry but not arid. The Eno River remains very low." (NC-OR-41, 7 September 2019, scale bar selection = dry)
Intensification: After Dorian, another round of unseasonably hot and dry weather through September and October led to the second flash drought of 2019	"No rainfall in nearly a month. Grass is brown. Hay fields are not growing any. Farmers are still cutting fields that grew from rain received earlier in the summer. Once cut, the grass is not growing any. Pastures are not growing, and farmers are having to feed hay early. This could cause hay shortages this winter. Soybeans are turning and losing their leaves earlier than usual. The dry weather is good for the corn that is being harvested. Small blueberry bushes need to be watered to keep them from dying. The danger for wildfires is increasing." (NC-CT-39, 21 September 2019, scale bar selection = moderately dry)
Slow recovery: Conditions began to improve in late October. Condition monitoring observers record a lingering recovery lasting into December	"With just over 2 inches of rain during the past week our dry conditions have improved somewhat. We are still dry but the recent precipitation has helped our springs and creeks. The much needed rain has helped to reduce the risk of fire as well." (Station NC-MS-19, 25 November 2019, scale bar selection = moderately dry)

Fig. 8. Examples of condition monitoring reports at different stages of the 2019 flash droughts.

In phase 2, 31 report users provided feedback (13 interviews, 18 online surveys) about the new report form and interactive web map, as well as the use and usability of the reports for drought-related decisions. We offered two formats (interviews or online survey) to make participation as easy as possible. Both formats used an identical survey with a combination of closed- and open-ended questions. Summary statistics were generated for closed-ended questions, while

Table 3. Organizations represented by the individuals who provided user feedback. Some organizations were represented by more than one individual during the different project phases. Feedback was received via online surveys, semi-structured interviews, and focus group webinars.

Operating Level	Organization	Phase 1	Phase 2	Phase 3
Local	NWS Weather Forecast Offices, South Carolina (Charleston, Columbia, Greenville–Spartanburg)	×	×	×
	NWS Weather Forecast Offices, North Carolina (Newport–Morehead City, Wilmington)	×	×	×
	NWS Weather Forecast Offices, Virginia (Blacksburg, Wakefield) Note: These WFOs serve counties in NC	×	×	×
	York County, SC Soil and Water Conservation District	×	×	
State	NC Drought Management Advisory Council (including the State Climate Office of NC)	×	×	×
	SC Drought Response Committee (including the SC State Climatology Office)	×	×	×
Regional	NWS Eastern Region		×	
	NWS Southeast River Forecast Center		×	
	Southeast Regional Climate Center		×	×
National	CoCoRaHS	×	×	×
	National Drought Mitigation Center	×	×	×
	National Integrated Drought Information System	×	×	×
	U.S. Drought Monitor Authors	×	×	

interviews allowed for follow-up questions and additional information more suitable for qualitative analysis (Farris et al. 2018). Seventeen individuals participated in phase 3 webinars to discuss ongoing use of the reports and their potential usefulness for monitoring weather and climate events beyond drought (Blackwood et al. 2020). We used an evaluation coding approach (Saldaña 2013) to review and code the qualitative data collected during each phase.

Results and discussion. Overall, the decision-makers and report users who provided feedback consider the CoCoRaHS volunteers to be credible and reliable sources of information. Although any drought impacts information is considered potentially useful, CoCoRaHS observers' unique, place-based knowledge allows them to provide context, fill geographic gaps for areas not well covered by existing observational networks, and ground truth changing conditions as indicated by the numeric indicators and indices typically used by monitoring groups, qualities highlighted by other citizen science efforts (e.g., Hicks et al. 2019; Paul et al. 2018; Starkey et al. 2017).

Most notably, decision-makers and the report users valued consistency over other report(er) characteristics. They consider those volunteers who reported regularly as being more in tune with shifts from normal or expected conditions to abnormally dry or wet conditions. Additionally, users perceived those volunteers who base their observations on the same location or landscape feature as providing more robust comparisons over time and particularly valuable in areas that may be transitioning from one drought level to another. The reporting differences between consistent and episodic observers shown by the qualitative coding and analysis (Fig. 7, Table 2) supports this perception.

Most decision-makers with whom we engaged indicated using the reports; however, the extent and nature of report use varied and depended on the individual organization's principal activities as well as the interests and responsibilities of individual staff members within their organization. Having staff capacity and a regular assessment process appeared to facilitate the reports' use and utility. For example, the State Climate Office of North Carolina was an early adopter of the reports, primarily because a staff person (coauthor Ward) possessed the time, interest, and responsibility to do so as part of her formal role on the North Carolina Drought Management Advisory Council (NC DMAC). The NC DMAC meets weekly to assess conditions and provide recommendations to the USDM, following the convergence of evidence approach used by the USDM (Rippey et al. 2021; Svoboda et al. 2002; Ward et al. 2022). Other project participants who contribute to the USDM weekly email listserv as local and regional experts, including those from NWS offices and the South Carolina State Climatology Office, indicated reviewing the reports to better understand drought conditions and even referencing them when providing their input. These users reported that the color-coded scale bar values on the web map alert them to areas to investigate further, where conditions may be deteriorating (or improving) and where a more in-depth look at other indicators is warranted. In contrast with the NC DMAC, the South Carolina Drought Response Committee meets only when drought conditions develop, worsen, or improve, and their assessments focus on the indicators and indices established by the SC Drought Regulations (Altman et al. 2017), suggesting institutional constraints and fewer opportunities for new information (i.e., the condition monitoring reports) to be considered or integrated into South Carolina's existing process (Dilling and Lemos 2011; Lemos et al. 2012).

During phase 3, some feedback participants also discussed the utility of the reports for other responsibilities, such as when writing weekly, quarterly, or seasonal weather and climate overviews or when documenting impactful events such as hurricanes and tropical storms. Operationally, the reports are not widely used beyond drought monitoring, and a few factors appear to contribute to this result (Blackwood et al. 2020). First, the initial design and marketing of condition monitoring to users focused on their drought-related information needs, rather than all possible weather events or conditions. Second, condition monitoring reports may compete with the many, already available and used tools for other event types and conditions (e.g., winter weather, tropical systems, tornadoes, flood conditions) (Dilling and Lemos 2011).

Reflections on the condition monitoring approach and using volunteered data for drought monitoring

In this article we shared key findings from this multiyear effort to systematically collect (near) real-time drought impacts data. Based on our involvement and documentation of this effort, we reflect on the strengths and limitations associated with using volunteered information for drought monitoring, implications for the longer-term feasibility of the effort, and recommendations for future work and investments.

Strengths. The condition monitoring project pursued a novel approach to drought impact reporting by seeking to overcome the limitations of one-off reporting and bias toward severe or extreme drought levels that characterize contemporaneous reporting efforts, limitations we identified through a combination of literature reviews, comparisons with similar efforts, and consultations with colleagues (e.g., Brennan et al. 2012; Lackstrom et al. 2013; Meadow et al. 2013; Smith et al. 2014). Project evaluations indicated that regular reporting enables both the volunteer reporters and report users to assess baseline and evolving conditions, not just a drought's peak severity and impacts. The NDMC DIR has replicated the general approach (i.e., promotion of consistent monitoring, scale bar categories for wet and dry conditions) through its Condition Monitoring Observer Reports (CMOR) tool, although participants have tended to be drought-affected stakeholders rather than citizen scientists (Smith et al. 2021). As CoCoRaHS volunteers report on all types of conditions throughout the year, their submissions also include impacts of other extreme events (e.g., freeze events, tropical storms, flooding), information that can be used for monitoring and assessing hazards other than drought (Blackwood et al. 2020).

Using a combination of qualitative and quantitative assessments, decision-makers indicated that condition monitoring reports from CoCoRaHS volunteers provide valuable, local information that helps them "ground truth" other indicators and indices, thereby contributing to the convergence of evidence used to determine drought status for affected areas. Our analysis of the report content corroborates users' perceptions of the report(er)s' credibility and salience. Volunteers' scale bar selections align with commonly used quantitative indicators (namely, the SPEI, SPI, and EDDI). Their written narratives offer timely and relevant information about drought onset and intensification, potentially providing early warning of impacts. Our review of volunteers' reports suggests that consistent observers, in particular, may be able to fill other drought monitoring gaps. For example, during "dry" and "improving" periods, consistent observers often provided information about soil moisture, plant conditions, and irrigation needs (Table 2). While efforts are underway to enhance existing soil moisture networks (Cosh et al. 2021), volunteers' information could alert decision-makers to drying conditions for areas where soil moisture information is unavailable or difficult to access. Additionally, their observations of air quality, "backyard hydrology" (i.e., local streams, wetlands, and ponds), and wildlife may shed light on impacts and conditions that are often difficult to measure and directly connect to drought, such as those associated with human health (Lookadoo and Bell 2020) and ecological drought (Crausbay et al. 2017).

Limitations. We found many benefits of engaging with the CoCoRaHS network: the volunteers' data were already trusted and utilized, and users indicated they value the hyperlocal scope (e.g., the backyard) of condition monitoring observations for drought monitoring. However, in terms of condition monitoring participation, we see gaps in the observations' overall geographic coverage, as well as inconsistencies in reporting frequency and content. For example, geographic gaps exist both nationally (e.g., Fig. 2, which shows greater concentration of reports in the eastern part of the country) and within the Carolinas (appendix A), where more populated areas of the two states generally, but not always, show greater participation (appendix D).

Regarding report timing, many of the consistent observers report every 1–2 weeks, which coincides with existing drought monitoring processes. Reports submitted at lengthier intervals might lose some value if they are unable to capture rapidly changing conditions, particularly in flash drought situations. Although consistent observers provide the bulk of the reports, they comprise a minority of the reporters. For places where participation and observations are sparse or not submitted regularly, committees and agencies with monitoring responsibilities rely primarily on other tools that may not fully represent on-the-ground effects, critical information for local-level response and communications (Purdy et al. 2019; Ward et al. 2022). In short, while the condition monitoring observers can provide accurate and relevant drought impacts information for their location, relying on volunteers means that this network does not cover all areas experiencing severe drought conditions (appendix D). One limitation of this study is that the Carolinas did not experience an extended, severe drought during the project period, making it difficult to know how the number, geographic coverage, and content of the reports might change during such an event.

Filling in these geographic and temporal gaps by recruiting more observers, engaging with different types of communities to gain new perspectives on drought impacts, and encouraging more consistent reporting may be the obvious solution, but relying on volunteers prompts a broader consideration of the resources required and potential tradeoffs involved. Sustaining volunteer-based monitoring efforts requires dedicated funding, staff, and other resources to provide training, perform data management (e.g., data access, quality assurance, quality control), and ensure the utility of the collected data for decision-making (Conrad and

Hilchey 2011). Beyond these instrumental aspects of supporting a monitoring network, it is also important to note that volunteers' motivations and interests may be fluid, affecting why and what they report as they engage with the process over time (Lawrence 2006).

Recommendations for additional investments in drought impact monitoring. Because drought and its impacts are multifaceted, strategic investments in a variety of spaces, including volunteer and professional networks, could help to further reduce information needs and gaps. Meadow et al. (2013) recommended using trained agency staff to report drought status on a regular basis, in lieu of volunteers who may lack clear incentives to sustain participation or lack understanding of the complexities associated with drought and its impacts. While dedicated, locally based professionals, such as extension agents, could help to improve the consistency of report content and their frequency, those programs may also have limited capacity to assume new tasks and responsibilities without additional funding, staff, and training (Lakai et al. 2012; Silliman and Cummings 2019; Tobin et al. 2017). Other investments could target expansion of mesonet monitoring networks (Mahmood et al. 2017) or explore new methods of obtaining and using information from less conventional sources such as social media (Smith et al. 2020). We recommend that future work examine the relative accuracy of and user trust in these various approaches, as well as the resources needed to maintain each.

Specific to condition monitoring, we offer two recommendations to enhance the reporting process and operational use of the reports. The first recommendation addresses the difficulty in determining the direction of change indicated by the reports. The map-based display of condition monitoring reports shows a snapshot of the scale bar selections for a given week, but this provides no point of reference for how conditions are changing unless the user scrolls through maps over several weeks. CoCoRaHS addressed this limitation by creating a separate Summary Report page with interactive charts displaying observers' scale bar selections for user-selected time and spatial scales (https://www.cocorahs.org/ViewData/conditionmonitoring/). Integrating the web map and the summary charts into a single tool could better support report users as they make sense of and integrate these data into their drought monitoring processes. Additionally, modifying the report form to provide a standardized way for volunteers to specify which types of conditions are changing (e.g., soil moisture, vegetation stress), and the direction of change (e.g., deteriorating, improving), would likely improve the efficiency of the report review process and generate data that could be applied to other monitoring and research activities (Denny et al. 2014). However, we recommend retaining the qualitative narratives, as their rich information helped users understand the nuances of on-the-ground conditions.

The second recommendation advocates increased support for report users, particularly those operating at the state and local levels. We found that information provided by the condition monitoring reports best fit with the monitoring and decision-making conducted by state monitoring committees, state climate offices, and local contributors to the USDM (e.g., the NWS Weather Forecast Offices). As having a designated person with responsibility for regular drought monitoring facilitated report use, we see a need for ongoing engagement with those individuals to increase their awareness of the information available through the reports. They are likely to be familiar with the observers and/or their locations and already know the geographic and climate context, important for interpreting the reports. In turn, they could provide guidance to the volunteers on which specific indicators and impact are most useful for their decision-making processes, feedback that could motivate and sustain volunteer participation (Farris et al. 2018).

Overall, the project reveals the tenuous balance between new information and tools, the information providers who develop and disseminate them, and the information users who are expected to benefit from them. Report users spent time becoming familiar with the condition monitoring program, assessing reports for their value, and integrating them with other drought monitoring routines and information. We also cannot overlook the investments made by the volunteers and their willingness to learn, actively participate, and adjust as we updated reporting guidance. For the condition monitoring effort to continue to grow and provide useful information for drought monitoring, we note that the design and implementation of the project entailed substantial personnel, time, and monetary resources to cultivate a network of volunteers and provide needed support (i.e., communications, outreach, and training) and to engage with report users. While existing, trusted networks and relationships enabled us to initiate the project, conducting meaningful and purposeful engagements and following up on participant recommendations was critical to maintaining trust and interest. CoCoRaHS has built a strong network of volunteers that provides an invaluable data source for a wide range of users, but the program lacks dedicated funding. To support the recommendations presented here and CoCoRaHS more broadly, a long-term, sustained funding mechanism is necessary. Condition monitoring has proven valuable as a drought monitoring tool where resources were dedicated to the program. Additional investments to expand the network would serve to support both volunteers and report users and fill geographic and information gaps for drought monitoring and decision-making.

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Data availability statement. The condition monitoring reports, and associated data analyzed in this study, are publicly available through the interactive map: https://www.cocorahs.org/Maps/conditionmonitoring/. Historical drought index data for each observers' location were obtained from the Climate Toolbox Historical Climate Tracker tool (https://climatetoolbox.org/tool/historical-climate-tracker). Data that support findings about report use and usefulness, to include methods, survey data, and focus group summaries, are available upon request from the corresponding author, Kirsten Lackstrom (lackstro@mailbox.sc.edu). Final project reports and documents can also be found at https://www.cisa.sc.edu/cocorahs.html.

Appendix A: Observer map

Figure A1 shows the number and locations of the volunteers in the Carolinas who participated in condition monitoring and submitted at least one report between October 2016 and June 2020. The size of the dots indicates how many reports were submitted by each observer.

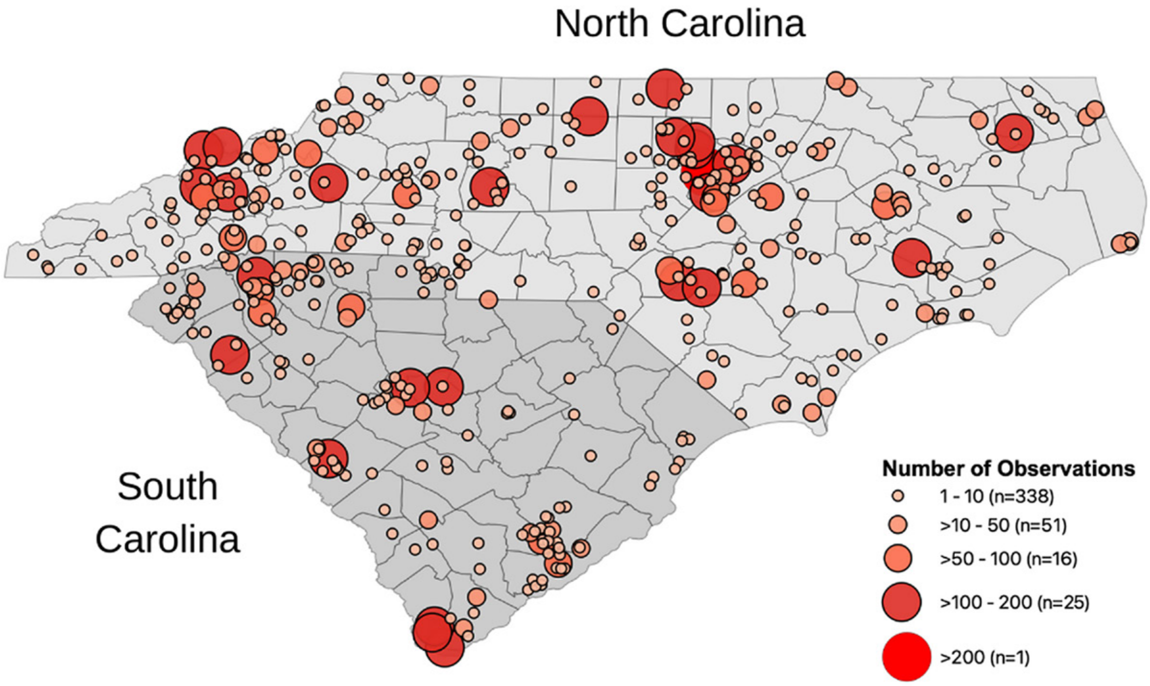

Fig. A1. Locations and report contributions of volunteers submitting condition monitoring reports from October 2016 to June 2020.

Appendix B: "Changing conditions" coding categories and descriptions

Table B1 shows coding categories used to capture volunteers' descriptions of changing conditions in their condition monitoring narratives, with the number of reports coded for each category. This coding was conducted for the 2019 reports only (n = 2,022).

Table B1. "Changing conditions" coding categories, report content (bulleted items), reporter type, and number of reports coded at each.

Coding category and report content	Reporter type	Reporter totals
Wet	Consistent	191
• More rainfall or wetter conditions than what a location would normally experience		
• Saturated, soggy, or muddy land surface conditions; standing water, pooling	Episodic	73
• Above-normal levels and flooding for water bodies	Combined	264
Normal	Consistent	616
• Precipitation amounts and observations of the local environment, but no adverse effects from too little or too much rainfall received in the short-term (approximately 1–2 weeks)	Episodic	120
• As the Carolinas experience weather and climate variability in all seasons, the default condition was "normal" unless a report indicated an adverse effect	Combined	736
Dry or drying	Consistent	517
• Conditions are dry, getting drier, or showing beginning signs of dryness		
• Indicators include lack of recent rainfall, vegetation stress, dry(ing) soils, or irrigation of plants and grass	Episodic	228
• Not included: reports of "drying out" after a storm or wet period	Combined	745
Improving from drought or dry conditions	Consistent	216
• Conditions are not quite yet normal but are better compared to previous weeks; report may reference previous dryness	Episodic	61
• Scale bar selection or narrative may indicate "wet" conditions, but overall, the report describes changes from a previous, very dry, starting point	Combined	277

Appendix C: Coding categories and descriptions for "dry" and "improving" reports

Table C1 shows coding categories used to assess the type of content provided in condition monitoring narratives. This coding was conducted only for the 2019 reports coded as "dry" or "improving" (n = 1,022).

Table C1. Coding categories and descriptions for "dry" and "improving" reports.

Coding category	Description
Agriculture	Observations of field, crop, and pasture conditions
Air quality	Air quality conditions and related effects (dust, pollen, allergies)
Backyard hydrology	Conditions and water levels in an observer's "backyard" and/or nearby communities or natural areas; birdbaths, pools, drainage ditches, wells, ponds, lagoons, creeks, streams, wetlands
Fire	References to fire danger, hazards, risks; red flag warnings, fire weather statements, wildfire occurrences, burn restrictions or bans (dry category); lack of or lifting of burn bans (improving category)
Irrigation	Specific references to irrigation or watering activities for gardens, landscaping, agricultural products
Other weather	Comments regarding extreme events (storms, tropical cyclones, hurricanes) or meteorological conditions (evapotranspiration, humidity, wind, cloud cover)
Plants	Plant and vegetation conditions in backyard gardens, local environment; stress, wilting, decreased or lack of production (dry category); recovery, reduced stress, renewed growth (improving category)
Precipitation	Precipitation amounts received for a specific period; general observations of drier- or wetter-than-normal patterns
Regional hydrology	References to regional surface water bodies (reservoirs, lakes, rivers); general references to water supplies
Societal effects	Observations of effects such as energy generation and usage, increase or decrease of recreational opportunities, water restrictions
Soil moisture	Soil or ground conditions; dry, cracked, hard, dusty (dry category); damp, moist, muddy, replenished (improving category)
Temperature	Temperature measurements; general observations of warmer- or cooler-than-normal patterns, heat wave(s)
Water quality	Observations of water quality (color, turbidity, oxygen levels) in backyard hydrologic features
Wildlife	Observations of wildlife activity, primarily birds and mammals

Appendix D: Geographic coverage of reports

The scale bar and report analyses discussed in the article examined volunteers' ability to provide accurate and relevant information about drought impacts for their location. Here we look at the geographic distribution of the reports and how they align with drought conditions in 2019. We organized the condition monitoring reports by climate division (Fig. D1) and

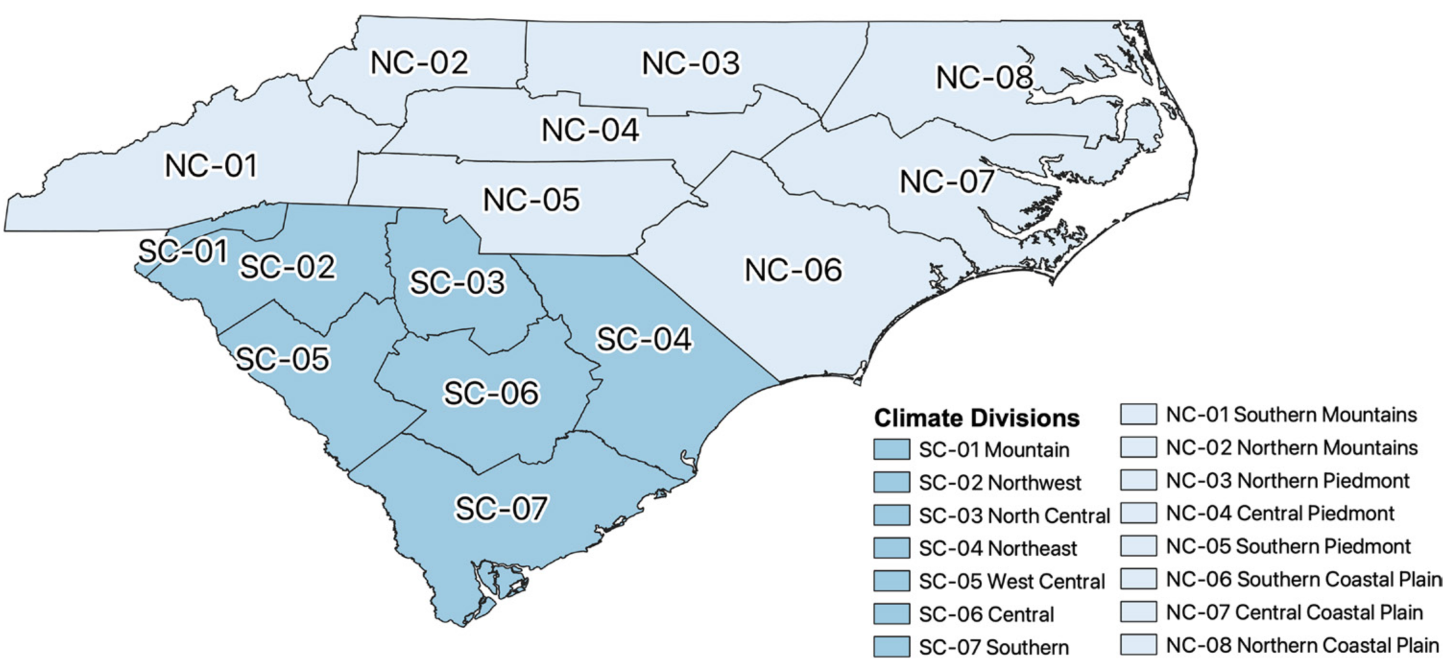

Fig. D1. North Carolina and South Carolina climate divisions.

compared the number of reports submitted each week with the severity of drought conditions (Fig. D2). The graphs in Fig. D2 illustrate the uneven nature of the volunteer network, where several climate divisions are well covered by reports and others have minimal observations. We note that the climate divisions with fewer reports are not void of populated areas or severe drought conditions. For example, NC-05 and SC-03 encompass the Charlotte, NC, metropolitan area and experienced the fall 2019 flash drought, but had very few reports. In contrast, the rural, less populated NC-01 had several observers who provided regular reports. Future research could conduct a more in-depth investigation of the factors motivating volunteer participation and how best to expand the network to fill coverage gaps.

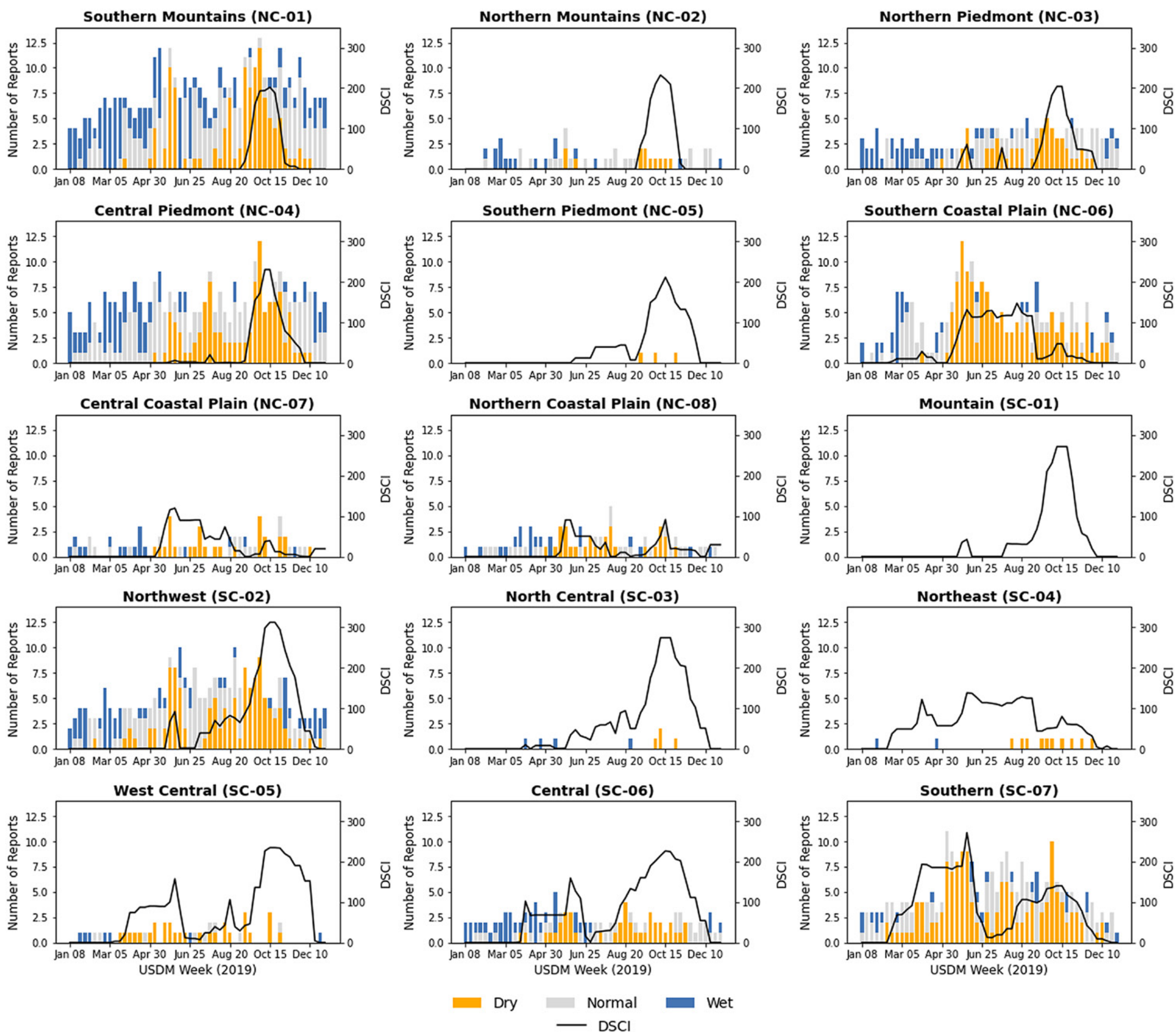

Fig. D2. Condition monitoring reports submitted in 2019, shown by climate division (Fig. D1). Individual graphs show the number of dry, normal, and wet reports for each week (left *y* axis) and drought conditions depicted by the Drought Severity and Coverage Index (DSCI; right *y* axis). The dry, normal, and wet designations on the graphs represent volunteers' scale bar selections. The "dry" category aggregates the severely dry, moderately dry, and mildly dry reports. The "normal" category consists of the near normal reports. The "wet" category aggregates the severely wet, moderately wet, and mildly wet reports. The DSCI summarizes the USDM status (D0–D4) for a given week with a single number on a scale from 0 (no drought in an area) to 500 (all of an area in D4) (Akyuz 2017).

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