BAMS Article

Linking Drought Impacts to Drought Severity at the State Level

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ABSTRACT: The U.S. Drought Monitor (USDM), a weekly map depicting severity and spatial extent of drought, is used to communicate about drought in state and federal decision-making, and as a trigger in response policies, including the distribution of hundreds of millions of dollars for agricultural financial relief in the United States annually. An accompanying classification table helps interpret the map and includes a column of possible impacts associated with each level of drought severity. However, the column describing potential drought impacts is generalized for the entire United States. To provide more geographically specific interpretation of drought, state and regionally specific drought impact classification tables were developed by linking impacts chronicled in the Drought Impact Reporter (DIR) to USDM severity levels across the United States and Puerto Rico and identifying recurrent themes at each level. After creating state-level tables of impacts observed for each level of drought, a nationwide survey was administered to drought experts and decision-makers (n = 89), including the USDM authors, to understand whether the tables provided accurate descriptions of drought impacts in their state. Seventy-six percent of respondents indicated the state table was an *acceptable* or *good* characterization of drought impacts for their respective state. This classification scheme was created with a reproducible qualitative methodology that used past observations to identify themes in drought impacts across multiple sectors to concisely describe expected impacts at different levels of drought in each state.

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Motivation

Linking drought impact information to drought monitoring has long been cited as a need in the drought community (Western Governors Association 2004; Hayes et al. 2011; Meadow et al. 2013; Lackstrom et al. 2017). By associating qualitative descriptions of drought impacts with levels of drought, a more complete characterization of drought can be formed to improve drought planning, reporting, and early warning tools.

The United States Drought Monitor (USDM; Svoboda et al. 2002) is a weekly map displaying drought location and severity across the United States, Puerto Rico, U.S. Virgin Islands, and U.S.-affiliated Pacific Islands (https://droughtmonitor.unl.edu). The authors of the USDM synthesize dozens of quantitative indices, qualitative information, and expert observer feedback into five color-coded drought severity categories (synonymous with intensity categories) displayed on the map (Fig. 1). The USDM caters to diverse end-users including policymakers, businesses, industries, academics, media outlets, and agencies at the local, state, federal, and tribal level (NDMC 2017). The USDM's web page was viewed over 5.7 million times in 2018, and the map plays an instrumental role in federal and state policy and decision-making that includes the distribution of hundreds of millions of dollars for agricultural financial relief in the United States (NDMC 2018).

A drought early warning system is "a linked information and communication system" that improves preparedness and management of drought (Pulwarty and Sivakumar 2014). Understanding the risks faced by populations is as important a component of drought early warning as is monitoring and prediction (Pulwarty and Sivakumar 2014). This link is necessary for decision-makers to be able to use the information for planning and response. The USDM weekly map provides information about current conditions of drought, but the map does not itself describe the risks that might be experienced in a community as drought emerges. Understanding

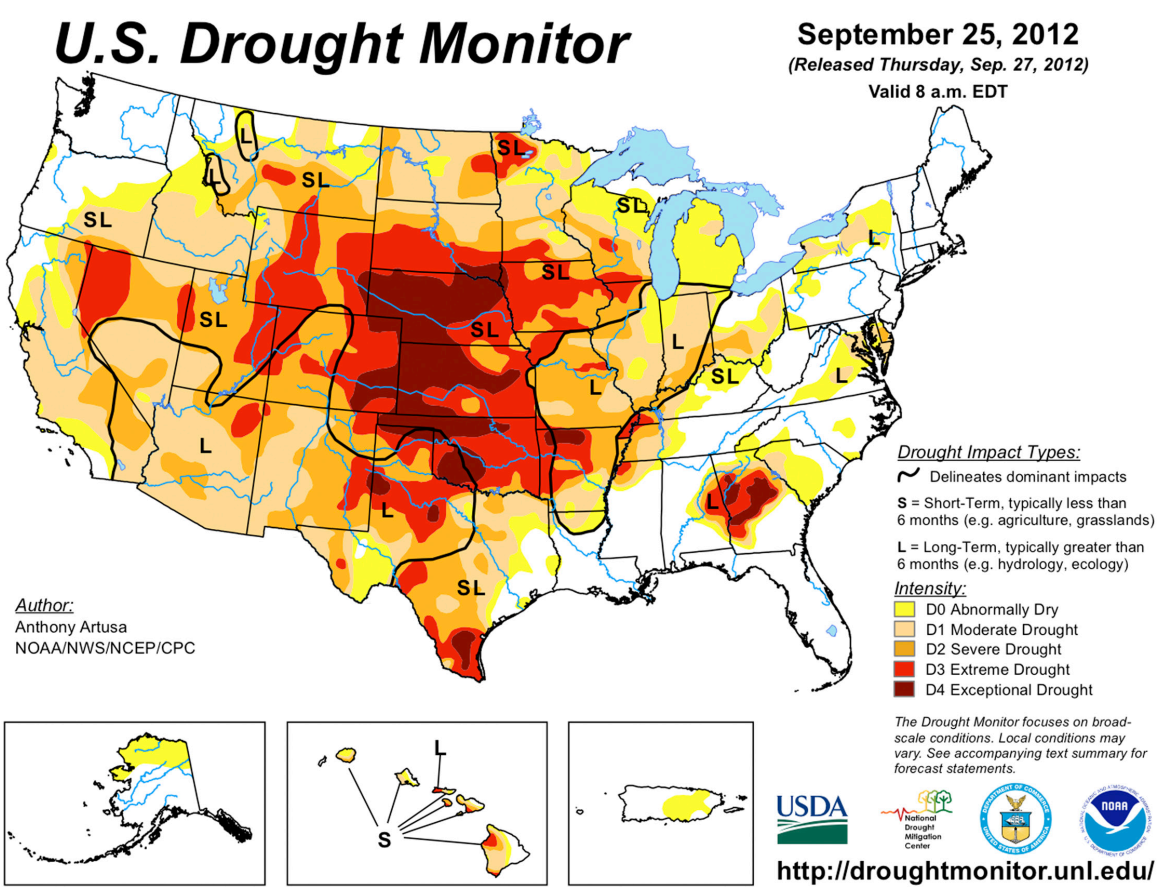

Fig. 1. An example of the USDM map. Color scale represents drought severity level.

the need to connect drought indicators to impacts, USDM authors in 1999 developed a general table of potential impacts by drought severity level for the entire nation. While developed by leading drought experts, the table of potential impacts did not represent local, on-the-ground knowledge of drought impacts experienced by the diversity of sectors and communities that exist across the United States. This lack of local context may hinder use of monitoring tools such as the USDM by decision-makers (Dilling et al. 2015).

To increase the resolution of anticipated drought impacts and to reflect greater diversity of sectors, state- and region-specific drought impact tables were developed by classifying multisector, qualitative impacts chronicled in the DIR (Wilhite et al. 2007; Smith et al. 2014) by USDM status across the United States and Puerto Rico. Since 2005, the DIR provides an inventory of impacts observed within each state, which serves as the basis for new state-specific impact tables. The state tables were launched on the USDM website on 16 September 2019 (https://droughtmonitor.unl.edu/Data/StateImpacts.aspx). This paper describes a recent effort to update the U.S. Drought Monitor impacts table, using local knowledge and reporting of impacts and drought severity to develop more usable drought early warning information for decision-making. The process described might be considered a form of consultative knowledge coproduction that engages both scientific indicators of drought and local knowledge about the ways that different severities of drought are experienced in society and the environment (Meadow et al. 2015). This process links drought severity to impacts in order to develop more relevant drought classification information for decision-makers.

Methods

This project expanded on a similar undertaking, which focused on linking drought indicators and impacts in North Carolina. Stakeholder feedback from North Carolina suggested more or different data could make the localized lists of observed impacts more representative, and that seasonal factors make it difficult to compare different droughts (Collins et al. 2016). A steering committee comprised of two staff members and two graduate students from the National Drought Mitigation Center (NDMC) at the University of Nebraska–Lincoln was initially created to lead the project. The initial task was to develop new regional- or state-level table of possible impacts for multiple sectors, for a selected group of trial states. The tables would draw on impacts archived in the DIR and classify impacts according to USDM severity levels.

The “possible impacts” column in the USDM classification table (Fig. 2) characterizes drought severity with agriculture and water supply impacts generally experienced nationwide. One of our objectives was to expand the table to represent additional sectors that are often affected by drought but are overlooked. To do so, we turned to the DIR, a first-of-its-kind national database that collects drought impacts from media and observer reports for eight sectors: agriculture, water supply, the environment, tourism and recreation, business, health, energy, and fire, as well as relief and response actions (https://droughtreporter.unl.edu/map). We utilized the DIR because it offers a methodologically consistent longitudinal archive that has systematically covered drought events since 2005, with more than 26,000 impacts to date (D. Gutzmer 2019, personal communication). In fact, the original motivation behind creating the DIR was to better link impacts to indicators like the USDM (Western Governors Association 2004; Wilhite et al. 2007; Smith et al. 2014). The impact data in the DIR can easily be exported and filtered based on impact start date, county, state, and affected sector. Historic USDM severity data can also be exported and filtered by date, county, and drought severity level.

The methodological roadmap used to develop the state impact tables is illustrated in Fig. 3. The first step in developing the state-level descriptions was to link the two datasets (DIR and USDM) with parallel fields of location and date using a customized script. The script assigned reported impacts to the highest USDM category affecting any portion of a specific county for

Intensity	Description	Possible Impacts
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures; Coming out of drought: some lingering water deficits; pastures or crops not fully recovered
D1	Moderate Drought	Some damage to crops, pastures; Streams, reservoirs, or wells low, some water shortages developing or imminent; Voluntary water-use restrictions requested
D2	Severe Drought	Crop or pasture losses likely; Water shortages common; Water restrictions imposed
D3	Extreme Drought	Major crop/pasture losses; Widespread water shortages or restrictions
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; Shortages of water in reservoirs, streams, and wells creating water emergencies

Fig. 2. The drought impact classification table lists general impacts associated with each USDM severity level.

a given week, based on impact start date. This produced a comprehensive list, upward of 2,500 entries per state, of every impact recorded by the DIR and its corresponding drought severity for every state. We limited the impacts analyzed to those recorded during the period of onset of a single drought event for each state. Criteria for selecting each state's drought event included timing (after 2005, to coincide with data available in the DIR), occurrence of the highest drought severity level experienced by the state, and an absence of immediate prior drought event. The stage of drought onset, defined for this research, is the time from the beginning of a drought event to its peak, as indicated by the severity level documented on the USDM time series charts (Fig. 4). Narrowing impacts to those recorded during drought emergence was a means to simplify this preliminary effort of this research and avoid impacts that are the result of long-term drought. For example, a USDM class of D0 (abnormal dryness) during the onset of drought would typically include short-term impacts related to reductions in soil moisture and vegetation health. However during abatement, a D0 could include lingering impacts related to longer-term hydrologic deficits or ecosystem damage as well as short-term indicators of improvement.

After impacts were narrowed to one drought onset event per state, between 10 and 725 individual impact reports remained for each state. The number of reports is a function of the intensity of media coverage and observer attention, as well as the spatial and temporal extent

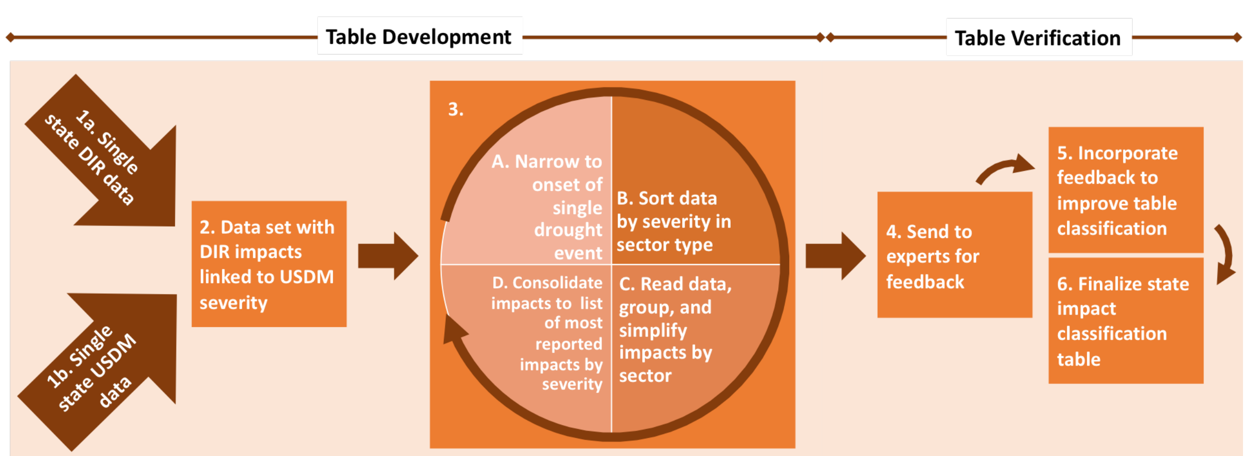

Fig. 3. The six-step methodology road map starts with a large volume of raw data inputs and results in a condensed and verified impact classification table.

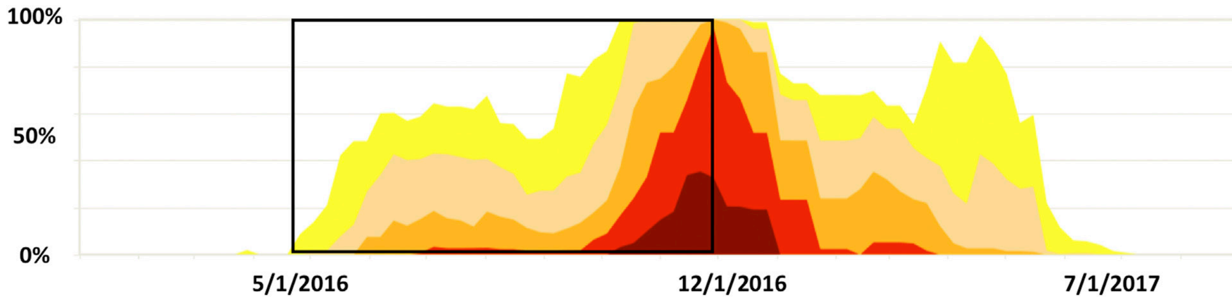

Fig. 4. An example segment of the USDM time series showing drought onset for the state of Alabama between May 2016 and December 2016 as indicated by the black box. Colors represent USDM drought severity levels. Impacts reported during the onset period are considered for the classification table.

of drought. Droughts in larger, more populous, semiarid states such as Texas or California tend to result in more impact reports than droughts in smaller, less water-stressed states that affect fewer people. Some states, such as most of the New England states, had limited impacts reported (Rhode Island reported 10; Vermont, 11; New Jersey, 13). To create a table with representative drought impacts, the researchers combined all the Northeast Climate Region states into one table (USDM 2020). For comparison, the combined 12 Northeast states reported 468 drought impacts in the selected drought event whereas California on its own had 735 accounts. This decision to create a regional table was also justified by the similarity of impacts reported across state lines in the Northeast. For example, many of these states reported impacts of the dairy industry, specialty crops, residential lawns, and water levels at like drought severity.

Next, in step 3B (Fig. 3), impacts were sorted by sector and drought severity level. The full impact reports were subsequently read, sector by sector, and summarized (step 3C). For example, if one newspaper stated, "The California Department of Forestry and Fire Protection has received about 50 percent more calls statewide" and a local resident also submitted, "We are experiencing an active fire season, and low humidity and very high temperatures are making fire-fighting difficult," and both parties were in D2 drought at the time, those reports would be clustered into an impact group summarized as "active fire season" at the D2 level. Furthermore, if the active fire season impact appeared in multiple severities, the impact would be categorized only in the severity class with the most reports. Finally, top recorded impact clusters in each severity were selected to assemble the final impact table (step 3D). The objective at this stage was to provide a concise, well-rounded representation of sectoral impacts most likely to occur during drought, but would be verified in the later steps. The minimum number of impacts retained in the table was dependent on the total number of impacts reported in the state and for each sector. This ensured states like California, with a huge number of reported impacts, did not have a final state table with over 100 impacts, and states with minimal reported impacts still had multiple sectors included.

After this basic process was developed, the researchers independently used the protocol to code the impacts for three states' tables: Montana, Texas, and Colorado. No formal intercoder reliability tests were administered; rather the researchers shared their results as a group, found them to be largely consistent among themselves, and together made any needed clarifications to the protocol.

The validity of the methodology and the coded impacts were addressed by engaging stakeholders in a number of ways to ground-truth the impact tables of these first three states. Engagements included short presentations and discussions with potential users of the tables, for example, the USDM authors and state drought committees. Potential users were informed of the protocol, asked to review the draft tables for their states, and asked to comment upon the appropriateness of both the methodology and the content in the tables. These engagements confirmed the methodology to develop the tables, and the content in the tables, were aligned with their on-the-ground experience and appropriately represented drought impacts in their areas. Once the final protocol was agreed upon, two researchers coded the remaining state tables.

No two drought events are alike, and similarly no two sets of impacts are identical from one drought event to another. Factors such as seasonality, spatial extent, duration, severity, human dependency, and drought preparedness all contribute to changes in the types of impacts experienced (Wilhite 1992). After all of the drought impact tables were developed, a final round of validity testing involving a survey was sent to stakeholders in each state and region to assess table content (Fig. 3, step 4). This online survey was administered by the NDMC to drought community members, comprising academic institutions and government agencies at local, state, and national levels such as the National Oceanic and Atmospheric Administration (NOAA), United States Department of Agriculture (USDA), United States Geographical Survey (USGS), National Integrated Drought Information System (NIDIS), and American Association of State Climatologists (AASC). Additional survey participants were recruited through snowball sampling as we asked colleagues to promote the survey through their personal networks. These colleagues live in or work directly with a state or region and bring local knowledge as well as professional expertise to the interpretation of drought conditions and impacts.

The survey asked participants (i) how accurately do the impacts reflect what you have seen during the onset of each drought severity, (ii) does the table accurately represent all geographic parts of the state, and (iii) what is your primary affiliation and sectors of involvement? Participants were asked to rate the characterization of listed impacts for each severity as *poor*, *acceptable*, or *good*. The assessment of *poor* signified the table failed to accurately characterize drought impacts affecting the state and was missing common, state-level impacts. *Acceptable* scores demonstrated the table generally characterized drought impacts with minor exceptions while *good* evaluations denoted an accurate characterization of state drought impacts. Both *acceptable* and *good* ratings were considered positive outcomes. Participants also had the option of providing written comments for the drought classification level and geographic questions. These open-ended responses proved extremely useful when understanding methodological challenges and modifying the table content to their final form. All survey responses were considered and incorporated into the tables by a modification process involving a panel of USDM authors before the tables were launched on the USDM online (Fig. 3, steps 5 and 6).

Results

The outcome of our study resulted in a set of 40 concise tables of probable impacts at each drought severity for every U.S. state or climate region, including Puerto Rico. As stated above, the states in the Northeast Climate Region were grouped into one table due to similar impacts reported across the region and to the lack of impacts reported in the DIR for those states. Figure 5 displays final impact tables for two states, North Carolina and Nebraska, to highlight unique features and sector diversity found in the new classification tables. Both tables include DIR sectors symbolized by icons on the left side of the table. Typically, agriculture, water supply, and fire impacts emerge early in drought as indicated by their presences at lower severity levels. As severity increases, represented in the table by warmer colors, drought begins to affect normal business and society functions. Illustrated here, Nebraska and North Carolina tables share several common impacts: crop and pastures are stressed and surface water levels decline in D1, fire danger increases in D2, hay is scarce and fish die in D3, and cattle sales, deer disease, and low water supply occur at the D4 level. Some impacts exist in both tables but appear at different drought levels. For example, water recreation is at the D2 level in North Carolina but categorized as D3 in Nebraska. This could be due to the Southeast's greater dependency on surface water. The states also present unique drought impacts. For

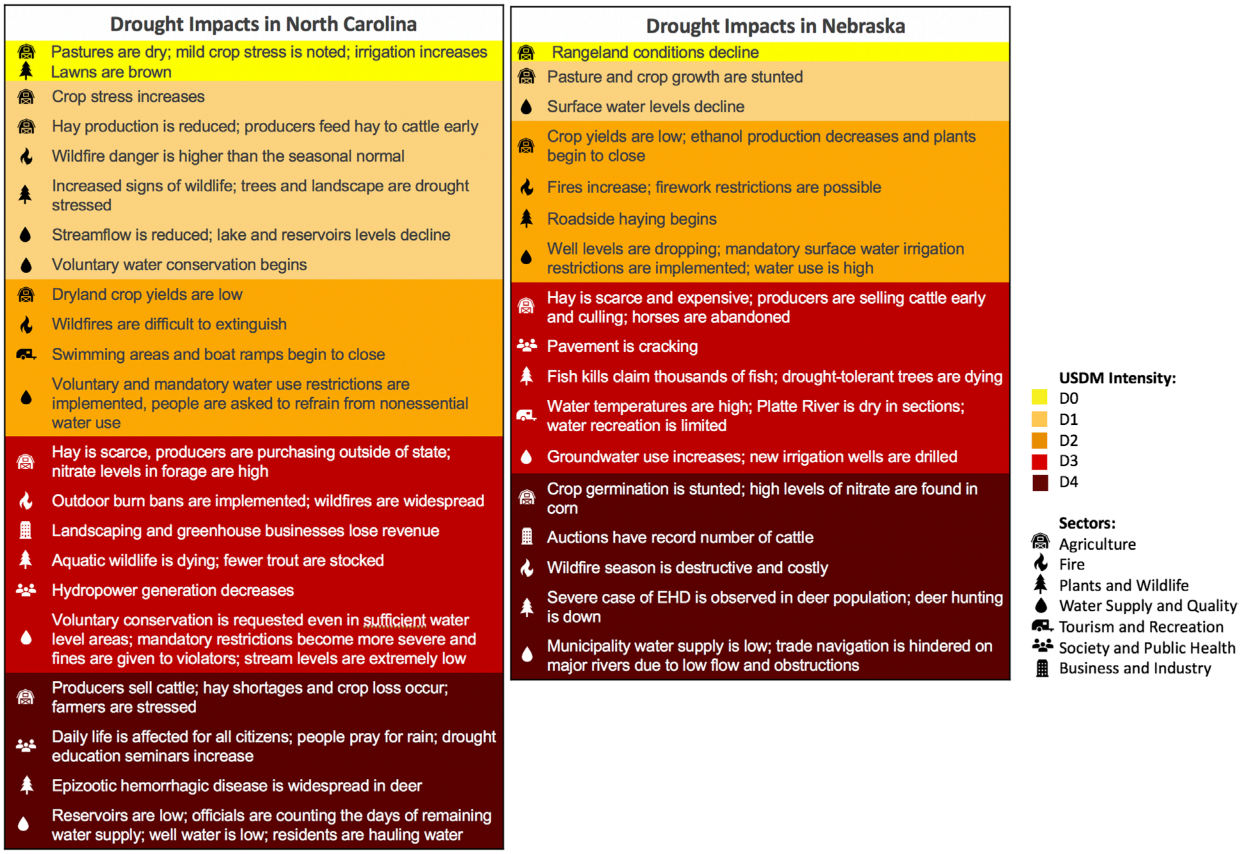

Fig. 5. North Carolina and Nebraska impact classification tables, two examples of the 40 updated multi-sector, state-level impact tables developed through this project.

example, the North Carolina table includes mitigation efforts such as increased voluntary and water conservation measures, drought education, decreases in hydropower generation, and effects on citizens' daily lives and activities. Nebraska's table contains drought impacts such as a decrease in ethanol production, roadside haying, culling cattle, pavement cracking, and compromised river trade navigation.

The tables also highlight regional characteristics around the country. For example, impacts in Oregon and Washington are tied to fish habitat and fishing restrictions, California's table includes negative impacts on seasonal farm workers, and South Carolina's table mentions the peach crop. The tables for the southern states of Texas and Oklahoma contain impacts on rangeland and cattle health and operations. States with winter tourism such as Colorado and Idaho include impacts related to the ski season. In comparison to the "possible impacts" column in the USDM classification table in Fig. 2, our state-specific version provides a unique list of reported observations of drought impacts within each state. The addition of these state-specific impacts for each drought category provides USDM end users a resource to understand how a given level of drought severity has affected their state in the past, which is a first step in identifying vulnerability.

Quantitatively, the results of the online survey (methodology described above) indicated a general consensus of the accuracy of the tables across the United States. Eighty-nine participants completed the survey for a response rate of 18%. With the exception of six states, each table elicited at least one survey reply (Fig. 6). The average number of responses was two per state with California contributing the most, with 13 responses. Overall, 76% of survey respondents rated their state table as *acceptable* or *good*. Grouping the states regionally, Northeast (56% good), Southeast (47% good), and South (38% good) tables received the best ratings (Fig. 7). Alaska's table was seen as the least accurate (67% poor). At the substate level, 64% of survey respondents denoted that their table accurately represented the region of the state they are most familiar with. States and subregions that were not as well represented by the tables included Mississippi, Oregon, coastal Georgia, the Snake River Plains in Idaho, western Montana, southeast Alaska, and rural Hawaii. Generally, as drought severity increased, the impact list improved in score. Said differently, inaccuracy was the highest for the D0 level, suggesting greatest variation of possible impacts or little media reporting (Fig. 8). This outcome could be due to the difficulty in defining when a drought begins, the lingering effects of a previous extreme drought, the lag time from the start of meteorological dryness to noticeable impacts, or a lag time in awareness of drought impacts.

All *poor* ratings and misrepresented geographic regions were justified with written comments in the survey. Three primary themes emerged from the 366 distinct written comments provided. One theme was to better address seasonality differences. For example, *poor snowpack* or *low runoff* are indicators of drought in the spring but would be normal conditions in fall months. Users suggested creating two tables to distinguish varying impacts that occur during summer and winter droughts. Another recommendation was to move specific impacts to a higher or lower severity level, "I would say that the last fire count and danger high, trees losing leaves, and wells stressed would be more indicative of D3 rather than D2." The majority of suggestions were for specific additions that were not represented in the table such as a comment from an Alaskan participant to "add water supply for hydropower generation, drinking water, fish migration or passage from low stream flows and high water temperature to produce potential for some fish die offs, snow pack issues." In the Alaskan case, this research was conducted prior to extreme drought conditions in 2018 and 2019, when these impacts were submitted to the DIR. As stated above, survey comments were considered and incorporated into the tables to improve the classification of impacts before the tables were finalized on the USDM online (Fig. 3, steps 5 and 6).

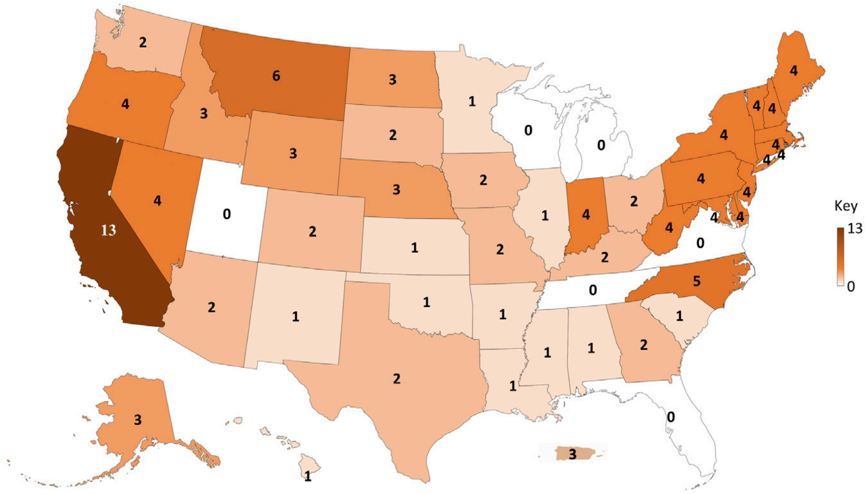

Fig. 6. Survey participant count. No survey results were submitted for the Florida, Michigan, Tennessee, Utah, Virginia, and Wisconsin tables.

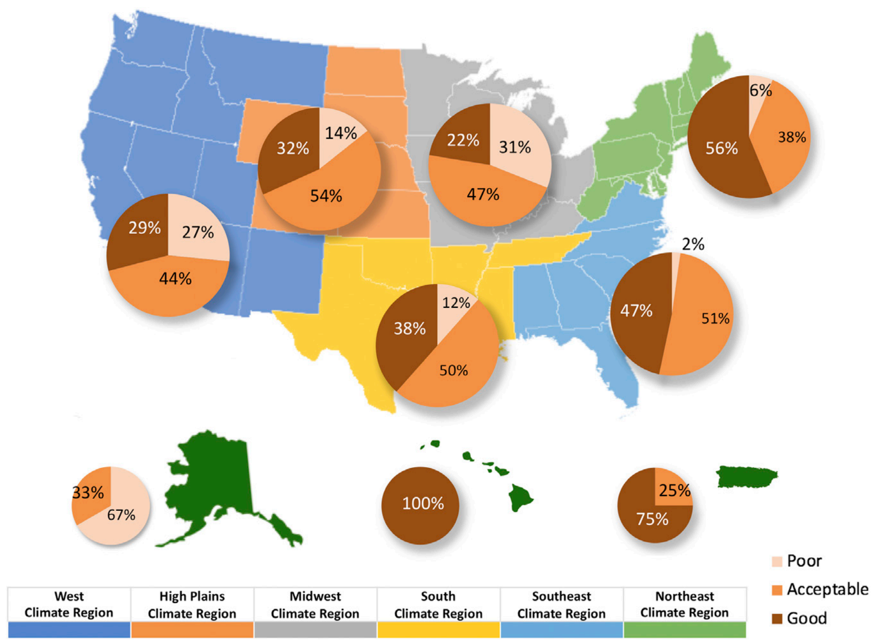

Fig. 7. Regional distribution of impact classification rating. Experts' ratings of the impact classification tables, by region. *Poor* is light orange, *acceptable* is orange, and *good* is brown. Overall, 76% of the survey respondents rated the state tables as *acceptable* or *good*.

Summary and future research

This assessment indicates our new tables capture drought impacts at a state level. These tables improved the characterization of drought severity by shifting away from a single table model to an impact table for every state or region. However, we had to overcome two challenges. First is the lack of drought in some regions of the country like the Northeast. We addressed this by grouping state impacts in a single table. Second is how drought gets reported in the media, especially during the early stages of drought. This was evident by the survey results; inaccuracy was the highest at lower severity levels such as D0 and D1. We see this project as an evolving process in which the impact tables can, and should, be updated as the DIR database grows with each drought that occurs in any given region or locale. This gives the potential to create 51 state tables (including Puerto Rico) in the future, teasing out the states currently grouped in the Northeast region. To this end, recent improvements to DIR impact monitoring report forms and an active partnership with state agencies seem to have contributed to a greater number of submissions to the DIR (NDMC 2019). To facilitate continued improvements, the USDM website provides a link with every state table (https://droughtmonitor.unl.edu/Data/StateImpacts.aspx). A user can suggest modifications if they believe an impact is absent or misrepresented. NDMC staff will review feedback and update impact tables upon confirming that suggested edits correspond to impacts documented in the DIR.

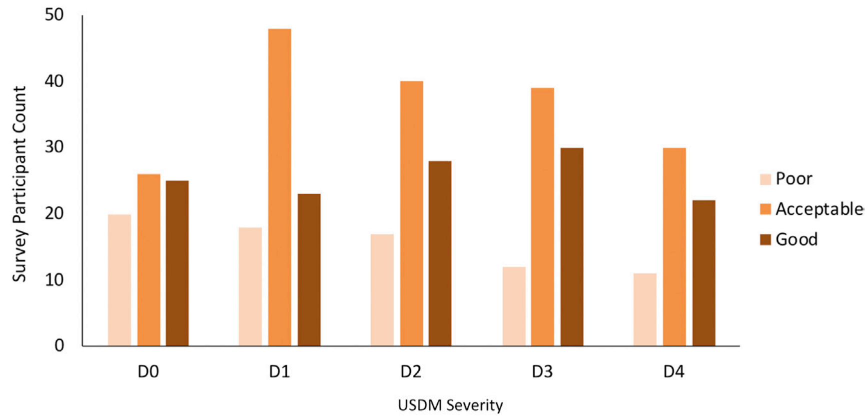

Fig. 8. Impact table characterization by severity level. Highest rank for each severity is *acceptable*. *Poor* rating is highest in D0. *Good* rating is highest in D3.

This project also identified recurrent themes in drought impacts for each state, which may suggest areas of interest or perceived hardship, where quantitative data collection could be systematically implemented to better inform management decisions, if it does not already exist. It is also important to keep in mind that these tables represent the development of drought to the apex of severity in a region. Additional research investigating impacts from other phases of drought (e.g., from the apex to the end of a drought) or entire multiyear events would be helpful for capturing the nuances associated with drought impacts and developing a more comprehensive characterization.

Our research focus was to devise impact tables for each state at each level of drought severity. We classified impacts according to USDM status for each state, and systematically derived concise descriptions of recurrent themes. The outcome of this process is more usable information about how drought severity is expressed in various geographies across various sectors. As a result of the consultative knowledge coproduction, U.S. Drought Monitor authors as well as other decision-makers have a greater understanding of how stakeholders from various sectors and regions identify and define impacts as drought emerges through levels of severity. Usability of the information should be enhanced by intentionally linking scientific drought indicators with existing knowledge of drought impacts of local decision-makers, improving its perceived legitimacy and credibility (Lemos et al. 2012). Ultimately, this characterization advances drought early warning, a crucial system for a climatologically changing future.

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