BLM Sagebrush Managers Give Feedback on Eight Climate Web Applications

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(Manuscript received 22 March 2016, in final form 15 July 2016)

ABSTRACT

Sagebrush ecosystems have endured fragmentation and degradation from multiple disturbances. Climate change poses an additional threat that can exacerbate current stresses. Web-based climate applications can provide information to help land managers prepare for challenges. To develop useful and usable tools for land managers' needs, the collaboration of scientist, web tool developer, and user is needed. Climate scientists and web tool developers at Conservation Biology Institute (CBI) worked with Oregon and Idaho Bureau of Land Management (BLM) sagebrush land managers assessing managers' needs and defining criteria for useful and usable web-based climate applications. During phone interviews, land managers evaluated a series of climate-related web applications and provided insight on how future applications can best meet their needs. They identified climate variables associated with their management activities, such as the seasonality of precipitation and temperature. They provided feedback about website accessibility, terminology, climate model description, spatial and temporal scale appropriateness, graphics effectiveness, and general content credibility and consistency. Managers are interested in changes in climate, but also in climate change impacts, such as vegetation shifts. Managers need seasonal and multiannual weather forecasts for routine activities and 10–20-yr climate projections for planning exercises, but currently an information gap exists between available weather forecasts (≤12 months) and climate projections (30-yr averages). It was also found that scientific jargon contributes to misunderstandings and misinterpretation of climate information, and this study confirmed the need for better climate science education, through enhanced explanation and collaborative efforts that promote understanding and use of existing web applications.

1. Introduction

Many studies have assessed the usability of climate change and climate information in adaptation planning and natural resource decision-making (Archie et al. 2012, 2014; Dilling et al. 2015; Ellenwood et al. 2012; Feldman and Ingram 2009; Kemp et al. 2015; Kirchhoff et al. 2013; Lemos et al. 2012; Theoharides et al. 2009). Although climate change information has become widely available, it is generally underutilized, and few adaptation efforts based on scientific assessments have been implemented by federal public lands agencies (Archie et al. 2012; Kemp et al. 2015; Moser and Ekstrom 2010; Weichselgartner and Kasperson 2010). As an example, comprehensive strategies to address how climate-related challenges will affect sagebrush management strategies are generally lacking, despite the large amount of funding spent to increase critical landscape resilience. Sage grouse habitat in the Intermountain West is already threatened by energy extraction, agriculture expansion, livestock grazing, invasive exotics expansion, and urbanization (Connelly et al. 2004; Knick et al. 2003; Miller et al. 1994; Shultz 2012; U.S. Fish and Wildlife Service 2013). Climate change will only exacerbate the vulnerability of sage grouse habitat, possibly reducing its breeding range by 71% by 2080 (National Audubon Society 2013). A gap in useful climate information for natural resource management is often cited as a critical problem resulting from an independent research process that limits interdisciplinary understanding and generates unsuitable information (Archie et al. 2012, 2014; Dilling et al. 2015; Dilling and

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DOI: 10.1175/WCAS-D-16-0034.1

Lemos 2011; Feldman and Ingram 2009; Lemos et al. 2012; Tribbia and Moser 2008). Recently, the U.S. Government Accountability Office (GAO) released a report reiterating that the climate information needs of decision-makers were not being met (GAO 2015). In this study, we confirmed that the barriers to making climate information useful to managers are the lack of data accessibility, the lack of direct relevance to management objectives, and the limited background knowledge of managers (about climate science education) and scientists (about management practices) (Archie et al. 2012; Jantarasami et al. 2010; Kemp et al. 2015), all of which can be easily addressed through co-production (Cash et al. 2003; Dilling and Lemos 2011). Involving managers from the onset of projects that generate and communicate climate change information ensures that the most salient and legitimate products are identified and that their credibility or uncertainty is clearly explained and understood by users so that usable products are readily available to managers evaluating new strategies.

A common problem with climate change information access is the lack of awareness of what is already available and the locations of credible sources (Bierbaum et al. 2013; Dilling and Lemos 2011; Dow et al. 2009). Accessible and robust climate change information may still be insufficient for managers if it is served at inappropriate spatial and temporal scales (Barsugli et al. 2013; Bierbaum et al. 2013; Brown 2015). Even with the availability of downscaled climate products, users may succumb to what Barsugli et al. (2013, p. 424) call the ''practitioner's dilemma'': that is, wondering ''how to choose an appropriate data set, assess its credibility, and use it wisely.'' Climate change information requires some background education because of its complexity. Managers are unlikely to have the time to become experts in the latest climate model developments or to decipher the jargon; to spend the time interpreting the myriad maps and graphics provided in multitudes of publications; or to ultimately be able to use this information in their management decision process (Dilling and Lemos 2011; Dilling et al. 2015; Dow et al. 2009; Kemp et al. 2015).

The usefulness of web applications depends on the site usability. Dumas and Redish (1999) recommend a user-directed site that is easy to use and promotes productivity and task accomplishment. Research in usability testing (Nielsen 2000; Oakley and Daudert 2016) provides information to web developers and researchers about how users interact with and perform tasks within an application. However, despite numerous publications about the lack of useful climate change information and the ways to produce usable web applications, few studies have incorporated detailed feedback from users specifically testing existing climate-related web applications. Our project aspired to bridge that gap and provide fast interactions between web designers, climate scientists, and land managers.[1]

Case study

Intent on creating a more useful and useable climate-related web application, web developers and climate scientists at the Conservation Biology Institute in Corvallis, Oregon, wanted to know how current climate-related applications, particularly in-house and external applications, measured up to user expectation. Through experiences with research communication in Oregon and conversations with Bureau of Land Management (BLM) colleagues, it became clear that trying to deliver relevant climate information for sagebrush land management would provide an ideal case study. Climate change is expected to exacerbate the vulnerability of sagebrush to already existing threats, and the relationships between those various factors are complex (Abatzoglou and Kolden 2011, Bradley 2010; Homer et al. 2015; Neilson et al. 2005). Facilitating a better understanding of the role of climate can help land managers to more easily separate the impacts of weather, which affect their short-term decisions, from the importance of climate for their long-term planning efforts to design strategies to ensure sagebrush ecosystem survival (Compagnoni 2013; Dalgleish et al. 2011).

The ''sagebrush ocean'' (Shultz 2012) in the western United States is the largest semiarid shrub ecosystem in North America and one of the three largest biomes in the United States (Anderson and Inouye 2001; Barbour and Billings 1988; Miller et al. 1994; Miller and Eddleman 2000). The BLM, along with the United States Forest Service, manages 35 million acres of remaining priority sage grouse habitat.[2] Moreover, the BLM considers the conservation and restoration of sagebrush ecosystems one of their top priorities (Bureau of Land Management 2002; Knick et al. 2003). Consequently, with BLM support, we reached out to BLM land managers in eastern Oregon and western Idaho who work in sagebrush areas. Individual phone interviews were held with each land manager, during which we asked them to review eight climate-related

[1] Unfortunately there was no funding in this particular project to design a sagebrush focus application right away, so managers' recommendations were used to refine an application funded by another source (http://climateconsole.org).

[2] Information is included in a pdf at http://www.blm.gov/wo/st/en/prog/more/sagegrouse/frequently_asked_questions.html#thirds.

web applications and provide feedback about them. In this paper, we have summarized the land managers' feedback and their recommendations in order to identify climate change information most useful to them and web application characteristics most effective at delivering this information.

2. Methods

a. Participants

A sagebrush land manager is defined as a land manager with sagebrush in her or his district or who is involved in management of sagebrush landscapes. We contacted BLM managers with a variety of official titles, such as weed coordinator, invasive species manager, fire ecologist, wildlife biologist, range management specialist, botanist, natural resource specialist, field manager, state manager, supervisors, and others. Using a purposive (nonrandom) sampling technique (Tongco 2007), participants were specifically selected based on job title, job area, and sagebrush management association. Care was given to interview a representative from most BLM districts in Oregon and Idaho; however, some districts were represented by more than one individual (e.g., two field managers or a field manager and a supervisor), and some districts had no representative. Initial participants were identified through the BLM Portland Office (L. Evers 2014, personal communication). Additionally, snowball sampling from land manager recommendations helped identify new contacts.

A Natural Resources undergraduate student from Oregon State University started the project by performing a basic literature review on sagebrush issues before initiating contact with 30 sagebrush land managers by phone and e-mail. In total, 22 sagebrush managers were interviewed. Managers who were contacted but could not participate were either no longer available at the contact information provided or had not previously held or did not currently hold a position related to sagebrush management. The student performed the interviews and was the only contact with project participants. All participants' names were kept anonymous.

b. Interview protocol

Phone interviews with sagebrush land managers were conducted in November and December 2014. Except for one interview with three land managers from the same BLM district office, interviews were conducted between a single land manager and the student. All the interviews were recorded and transcribed manually by the student, and each name was assigned a number that was associated with the transcript of the interview to maintain the anonymity of the results. Transcriptions were sent to each manager for approval and to ensure content accuracy.

Interview questions were semistructured to allow for some flexibility during the interviews so that similarities and differences could be easily cross-examined across all interviews. Interviews lasted between 1 and 1.5 h each, totaling approximately 21.5 h. Interviews consisted of two parts, including 1) a preliminary discussion where the managers explained what their specific activities were and how their work is affected by climate (educating the interviewer) and 2) feedback on web-based sagebrush-related maps as well as on eight climate-related web applications. After a first few interviews it became clear that more time was needed for participants to thoroughly comment on all eight web applications. As a result, the preliminary discussion was shortened and the eight web applications were assessed before the online maps, which eventually were excluded from the interviews all together. This allowed for the managers' more complete feedback on the climate-related web applications, which was better aligned with the original project goal.

The web applications assessed by interview participants are listed in a table (Table 1), with their associated links at the time of the interviews. These eight web applications were first selected based on the quality of their source [government agencies directly involved in climate information delivery, such as NOAA and USGS, and the Conservation Biology Institute's (CBI) own web tools] and their longevity. The sites also needed to be publicly accessible and to require some level of user interaction, such as selecting climate variables or climate models, to test for their user-friendliness. Finally, these applications were chosen for the variety of their visualization tools (e.g., maps, graphs, color scales, and information boxes). Overall, we selected sites that could provide valuable information to refine the type of climate applications staff at Conservation Biology Institute are building for a variety of projects.

Each transcribed interview was analyzed manually to report links between management activities and climate variables and associate web application components to land manager feedback (Archie et al. 2012). Frequency counts were used to tally the number of land managers who mentioned a particular climate variable as important (Table 2). Direct statements from participants in which climate variables were associated with land management activities were noted and documented in a table (Table 3). As a result of time constraints, some participants were unable to comment on all eight web applications. However, the eight applications included

TABLE 1. Climate-related web applications used during interviews that took place between November and December 2014. Since the publication of this article, the links to the web applications may have changed, been updated, or even discarded: for example, the USGS National Climate Change Viewer has a new address (http://www.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp; 2 Nov 2015).

Climate application	URL
1. NOAA Three-Month Outlooks	http://www.cpc.ncep.noaa.gov/products/predictions/90day/
2. NOAA Snow Cover Maps	http://www.ncdc.noaa.gov/snow-and-ice/snow-cover.php
3. NOAA U.S. Climate Extremes Index	http://www.ncdc.noaa.gov/extremes/cei/graph/nw/5/01-12
4. NOAA Climate at a Glance	http://gis.ncdc.noaa.gov/map/cag/#app=cdo
5. AdaptWest	http://adaptwest.databasin.org/app/ecoregion_climate_explorer
6. (USGS) National Climate Change Viewer	http://www.usgs.gov/climate_landuse/clu_rd/apps/nccv_viewer.asp
7. (Desert Research Institute) WestWide Drought Tracker	http://www.wrcc.dri.edu/wwdt/index.php
8. (CBI) Integrated Climate Scenarios	http://consbio.webfactional.com/integratedscenarios/

most of the same components (e.g., historical information, climate models, temporal and spatial scales, variables, graphics, and charts). To control for information gaps, participant feedback was tallied for application components rather than for individual web applications. Each application component was listed in a table with similar components combined under one theme (e.g., climate variable). All land manager statements were then grouped by theme. If reoccurring statements did not fit any of the existing themes, new themes were created [e.g., access, consistency and durability, geographical information systems (GIS), and planning]. Similar statements within each theme were summarized into one general statement. The number of participants who made each statement was tallied (see Tables 4–10). The purpose of comparing land manager statements about each component was to highlight similarities and differences in what users need and about feature usability and usefulness. Some comments were prompted by interviewer questions, but land managers often supplied comments spontaneously when viewing and using the applications.

3. Results

Interview feedback clearly showed the importance of climate on land management activities and the managers' understanding of climate model projections and climate scenarios, as well as the importance of appropriate spatial and temporal scales, of the quality of graphics and charts used, of web accessibility, of site consistency, of its compatibility with desktop GIS and planning, and of the availability of climate impacts.

a. How climate variables relate to management

Interview participants first described their own activities (e.g., field work versus writing planning documents) and the climate variables they associated with these activities. We summarized the number of land managers who mentioned a particular climate variable (Table 2), how land managers related these variables to their activities (Table 3), and specific comments about variables included within the eight climate-related web applications (Table 4).

The climate variables most frequently mentioned by nearly 90% of participants were, as one might expect, precipitation and temperature (Table 2). But just as important was the seasonality of precipitation and temperature. As one manager expressed, ''If I knew after seeding in the fall what my next spring growing season will have in terms of precipitation and temperature for successful plant emergence and establishment, then I would be successful as a land manager in meeting my objectives.'' Managers talked about the impact of early spring rains versus later spring rains in the establishment of invasive annual grasses versus native perennial grasses; the effect of early winter versus late

TABLE 2. Important climate and nonclimate variables mentioned by BLM sagebrush land managers during interviews. Variables (left column) are tallied (right column) based on how many managers mentioned that variable during the interview.

Variables	No. of managers
Precipitation	20
Rain	18
Snow	19
Timing of precipitation	19
Temperature	19
Timing of temperature	14
Humidity	8
Evaporation/evaporation deficit	6
Wind	20
Wind speed	6
Drought	14
Elevation	6
Soil moisture/moisture availability	15
Soil type	7
Grazing	12
Funding	7

TABLE 3. Management activities and related climate and nonclimate variables. Land management activities (left column) are related to climate variables (middle column) and nonclimate variables (right column), based on land managers' interviews. The following acronyms are used: National Environmental Policy Act (NEPA); Emergency Stabilization and Rehabilitation treatment plans (ESR); Environmental Assessment (EA); Risk Management Plan (RMP); interagency Fire and Invasive Species Team (FIAT); animal unit per month (AUM); all-terrain vehicle (ATV); and utility task vehicle (UTV).

Activity	Climate variable	Other variable
Planning (e.g., NEPA, ESR, EAs, RMP, FIAT, AUMs, and grazing permits)	None	Sufficient guidance material, data accuracy, website stability, public acceptance, and funding
Seeding and hand planting	Precipitation and temperature (timing: fall and spring important), snow amount and timing, wind, evaporation deficit, and drought	Soil available moisture, soil type, vegetation change, seed availability, and funding
Herbicide application (e.g., aerial, ATV, UTV, backpack sprayers, and roadside treatment)	Wind, humidity, and precipitation timing	Runoff
Mechanical removal (e.g., logging, mastication, and chainsaws)	Precipitation, snow, and temperature	None
Biological control	Temperature and precipitation (timing), humidity, and drought	None
Controlled fire	Wind, precipitation, temperature, and relative humidity	Manpower
Buffers, fuel breaks, and green stripping	Precipitation and temperature	Manpower, fire severity, and funding

winter snowpack on the amount of available soil moisture for native vegetation and wildlife; and about the effect of early summer versus midsummer temperature spikes and drought on ecosystem processes (Table 3). Fall, winter, and spring conditions are important for management activities, such as seeding, and for the sagebrush phenological cycle. Summer is also an important season since precipitation and temperature drive vegetation (fuels) moisture content and fire occurrence. Precipitation includes both rain and snow, and the important individual function of each was noted by over 80% of participants (Table 2). ''Both rain and snow precipitation are important, but for different reasons. Native plants in the Great Basin are adapted to cold, snowy winters and hot dry summers. When we're working with bluebunch wheatgrass, it is preadapted to the temperature and precipitation regime. But if using something like crested wheatgrass or forage kochia it is a lot more broadly adapted to different weather conditions, but still dependent on spring or summer moisture to establish,'' explained one interviewee. Rain was commonly associated with seeding, vegetation growth or dieback, or summer monsoons. Snow was most commonly mentioned in relation to its direct effect on spring soil moisture as well as on soil available water for fall and winter seeding. Twenty-seven percent of managers we interviewed were interested in knowing the amount of snow accumulation (Table 4), especially when viewing the NOAA Snow Cover Maps web application page. One manager explained, ''Deep snow is good, because if

TABLE 4. Additional interview feedback about climate variables. Manager feedback was given for eight existing web-based climate applications described in Table 1. Comments (middle column) were organized by theme (left column) and tallied (right column) based on how many managers made that particular comment or brought up the topic during the interview. For the purposes of this study, the term ''useful'' is used in place of other adjectives, such as ''good,'' ''needed,'' ''important,'' ''valuable,'' or synonyms, to describe web application components.

Manager feedback		No. of managers
Climate variables	Variables need definition and explanation	7
	Variable averages useful	3
	Variable anomalies (or % change) useful	6
	Amount of snow accumulation received useful	6
	Familiar with PDSI	6
	Not familiar with PDSI	12
	Drought indices useful	12
	Drought indices need definition	12

plantings are early and we get snowpack on top of them, there is a lot of moisture on the site. The snow also helps minimize competition from other species. For example, many of the planted species are evolved to sprout in the fall, put out a basal rosette of leaves and then go to sleep for the winter. Snow accumulation on top of these species minimizes the establishment of competing species until the snow melts.'' The way climate variables are aggregated can affect how managers interpret the information. Of the managers, 14% wanted temperature and precipitation averages, while 27% were interested in the percent change from normal (Table 4). Most managers, however, expressed no preference for either averages or percent change.

Wind was mentioned by nearly 90% of managers (Table 2) as an important variable, and participants gave many reasons why wind plays an important role in sagebrush management (Table 3). Both wind speed and direction affect activities, such as aerial herbicide application or aerial seeding. One manager told the student, ''If it's too windy you can't apply the herbicides. We'll treat thousands of acres with aerial application. It doesn't take a lot of wind to make us stop. If wind gusts reach 10 mph or above then we'll probably have to shut down.'' Wind can cause duff layers to blow away and exacerbate wind erosion. It can affect snow accumulation rates or cause snow drifts. It can increase evapotranspiration rates, which may lead to faster plant (fuel) desiccation. Wind also spreads light seeds from invasive vegetation, such as skeleton weed, causing expansion of exotics over vast areas and into new territory. Wind obviously also plays an important role in spreading fire.

Drought and soil moisture (or soil water availability) also ranked high among important variables for managers (Table 2). Land managers defined drought as a combination of lack of precipitation, increased temperatures, and increased evaporative demand. Drought through reduced soil available water causes plant water stress and affects fine fuel drying—an important index in fire management. One participant explained, ''It's not the precipitation as much as it's the available precipitation. If we get a rain here we can still have dry soil in a couple of hours with a little wind or sun on it.'' Drought indices were considered useful by 55% of interviewed managers (Table 4), but the most common drought index used in web applications, the Palmer Drought Severity Index (PDSI)[3], was only known or previously used by 27% of participants. Close to 55% of managers did not use it or even know what PDSI was. In fact, participants felt that both drought indices and variables used in web applications needed to be better defined and explained, because terms such as ''evaporation deficit'' (a variable found in the USGS National Climate Change Viewer) were not intuitive to them (Table 4).

Several managers wanted to mention non-climate-related variables (Table 3), such as grazing, which can affect landscape health depending on the type of grazing regime and its timing, certainly dependent on climate, and the number of grazers. About a third of managers also emphasized that the level of funding was a critical determinant in their management activities, as it defined how much of an area they could manage and/or restore and when restoration or management activities could take place. Other climate- and non-climate-related variables mentioned by participants are included in Tables 2 and 3.

b. Climate models

When evaluating the different climate models and the different emission scenarios presented within each web application, 64% of managers wanted to see robust comparisons between the various climate models and between scenarios (Table 5). One manager stated, ''I think it's useful to have the ensemble means, but also to compare models because it gives more credibility to the results.'' It was also important for 73% of managers to understand differences between climate models. One manager expressed, ''There are several different models here. Is there a place to figure out what each of these different models provides? To me it's just a bunch of letters and numbers. Having a list I can understand and the ability to compare other models would be helpful. Maybe a key to the models? As a manager I don't know what all the models represent. It would be like me providing fire models to a climate scientist. The acronyms wouldn't be understood.'' Defining terms such as ''representative concentration pathway'' (RCP)[4] was mentioned as an important need. Over half of the interviewed managers (59%) had not heard of or did not know what an RCP scenario was; only two managers were familiar with the term and with climate model scenarios in general (Table 5). ''Prior to this interview I

[3] The Palmer Drought Severity Index is a measurement of dryness based on recent precipitation and temperature. It was developed by meteorologist Wayne Palmer, who first published his method in the 1965 paper ''Meteorological drought'' for the Office of Climatology of the U.S. Weather Bureau (Palmer 1965).

[4] RCPs are four CO_2 concentration trajectories adopted by the IPCC for its Fifth Assessment Report (AR5) in 2014. The four RCPs—RCP2.6, RCP4.5, RCP6, and RCP8.5—are named for the radiative forcing levels models reach by 2100 relative to preindustrial values (+2.6, +4.5, +6.0, and +8.5 W m^{-2}, respectively).

TABLE 5. As in Table 4 but for the interview feedback about climate models and scenarios.

	Manager feedback	No. of managers
Climate models	Ensemble averages useful	7
	Comparisons between different climate model projections useful	14
	Climate models and projections need definition and explanation	16
	Familiar with RCP scenarios	2
	Not familiar with RCP scenarios	13
	RCP should be defined	14

didn't know what RCP scenarios were, such as RCP 4.5 or RCP 8.5 [. . .]. I think it's important to see the difference between the RCP scenarios, but RCP should be defined so someone can easily understand what it is,'' explained one manager. We interpret such participant statements to infer that some level of climate education took place during the collaborative study.

c. *Temporal scale*

Of the eight web applications assessed by managers, four included only historical [often PRISM (Daly et al. 2008)] data and provided no future outlook or projection. Some managers found the historical information useful for comparing with what they had experienced (Table 6): ''The historical information is great because we can compare past to present and see a shift,'' and ''If I was trying to understand why we might see medusahead more in one year than in another year I would need to look at both historical and current data.''

Managers wanted information on the source of historical information (Table 6). Managers felt that the length of the historical information (periods referred to as ''normal'') should be similar to that of the projections. For example, a 30-yr precipitation projection should not be compared to a 100-yr average historical record. A few managers had concerns with century-long historical averages, since they hide extreme events that greatly affect landscape processes.

The need for both near-term and long-term climate information was expressed throughout the interviews. At least 36% of managers commented on the need for information about future climate when it was not provided (Table 6). Managers requested near-term weather forecasts with monthly, seasonal (e.g., 3–6 months), annual, and multiyear information. The longer climate projection periods mentioned included 5-yr, 10-yr, and 10–20 yr (Table 6). However the temporal scale most needed was seasonal: 86% of interviewed managers related their management activities to seasonal weather events, such as summer droughts and winter snowfall, which affect soil moisture availability; and spring and fall rains, which affect seeding success and vegetation growth. One participant requested ''bimonthly to 3 month and more 'robust' predictions that go from fall through spring and with a fair amount of confidence. This would help us answer questions about when we should plant for successful establishment.'' Seasonal outlooks, such as the NOAA Three-Month Outlook, do exist and are available on the web, but few managers made mention of using such sites. Other temporal scales needed by managers included annual forecasts, which were requested by 46% of managers, as well as multiyear forecasts, requested by half of the participants (Table 6). Some managers specifically asked for annual information for up to three years, as this fell within the window of plant

TABLE 6. As in Table 4 but for the interview feedback about temporal scale.

	Manager feedback	No. of managers
Historical information	Information needed about source of historical or baseline data	6
	Useful to compare historical data with field observations	6
	Historical or projected averages over large periods cause information to be lost	3
Useful temporal scale	Future information beyond historical	8
	Near-term projections	10
	Water year	7
	Monthly weather forecast	7
	3–6-month weather forecast	19
	Annual forecast	10
	Annual forecast over a series of years	11
	5–10-yr projections	6
	Decadal projections (10 yr)	5
	Duodecadal projections (10–20 yr)	5

TABLE 7. As in Table 4 but for the interview feedback about spatial scale.

Manager feedback		No. of managers
Useful spatial scale	Finer scale than available	8
	Ecoregions	7
	Regions	2
	States	3
	Counties	9
	Problem: District split between a few ecoregions	3

establishment and matched field planning timelines. Unfortunately, outlooks do not currently extend beyond six months, and climate change projections are best used as 30-yr averages, because of the uncertainty associated with model products. Even the longer decadal and duodecadal temporal scales requested by 23% of managers currently fall outside the window of what is recommended by climate modelers. Yet these 10–20-yr timelines are what managers must work with for federal and state planning objectives, such as the National Environmental Policy Act (NEPA), BLM Rapid Ecoregional Assessments (REAs), and Risk Management Plans (RMPs).

d. *Spatial scale*

Managers expressed the need for finescale spatial data to apply climate information to their management area and its key geographical features (Table 7). Both counties and ecoregions were preferred by 41% and 32% of the participants, respectively. However, each provided a different level of information for managers, as one manager explained: ''Both counties and ecoregions are useful for spatial scale. The counties allow you to know where you are. But the ecoregions have similar trends.'' Counties were also valuable because some management areas extended across several ecoregions. These scales are already included in several web applications, notably the WestWide Drought Tracker, CBI's AdaptWest Climate Explorer, and CBI's Integrated Climate Scenarios.

e. *Graphics and charts*

Managers gave feedback about a variety of graphics used in web applications (Table 8). Participants expected colors and color keys to be well defined and individual colors to have good separation. For example, the use of multiple ''shades'' of a color may leave little contrast between two different colors, which led to interpretation difficulties during a few interviews. Also chart axes should be scaled appropriately. One participant explained, ''The axis increments are pretty rough (i.e., 300–400 mm). But this is probably because there is such a big range within the ecoregion. If you're going year by year for the same ecoregion you should be able to tell with much finer precision.'' For example, increments of 10 in. in precipitation along an axis can be unhelpful for managers who need to know if their district will receive between 2 and 3 in. It should also be noted that, although many climate-related web applications use metric units, participants preferred U.S. units or a way to toggle between both (Table 8).

About 14% of managers liked the ability to compare different variables in multiple side-by-side graphs (Table 8). But comparing multiple graphs with multiple axis increments can also lead to interpretation errors. During the interviews, managers had trouble understanding some of the information provided by charts and graphs, and 41% of managers needed better explanations than those given on the site (Table 8). One way to get around misinterpretation is to match numerical values to individual, easily separated colors for each point or map area. Numerical values can be nested into charts or graphs and only appear when users move the cursor over areas where more information is needed. These ''pop-ups'' or ''hover-overs,'' terms widely used by web developers, can prevent misunderstanding of variable meanings by including definitions and further explanation.

TABLE 8. As in Table 4 but for the interview feedback about graphics and charts.

Manager feedback		No. of managers
Graphics	Hover over pop-ups useful	5
	Colors should be intuitive	7
	Colors should be easily distinguishable from one another	5
	Each color used in maps or graphs should be included in color bar or should match specific value	8
Charts	Useful if axis intervals could be changed	5
	Toggle between metric and U.S. units useful	2
	Graphs need definition and explanation	9
	Interesting to compare different variables with multiple side-by-side graphs	3

TABLE 9. As in Table 4 but for the interview feedback about access.

	Manager feedback	No. of managers
Access	Problems with web application/s launching or working properly	12
	Climate information through an online website useful	9
	Climate information websites should be updated once a year or more	5

f. Access

The most common remark about application accessibility was related to browser compatibility (Table 9). In total, 55% of interviewed managers experienced some access issue. During some interviews, seven of the eight web applications either did not open for certain web browsers, triggered Adobe update warnings, or had restricted access to parts of the site or particular graphics. A common problem was that many BLM managers were using agency-specific software, such as Internet Explorer, while many climate applications are designed for more recent web browsers, such as Firefox or Chrome. Despite these access issues experienced by participants, approximately 41% of the managers agreed that climate information was best presented online (Table 9). They also preferred that websites be updated at least annually, or as soon as significant changes occur.

g. Consistency, compatibility, and planning requirements

We found that managers needed consistent and credible information to avoid skepticism and to ensure consistency across agencies. One interviewee provided an experience of insufficient consistency: ''an example of a time that we used climate data from a website: the data on the website was changed after our analysis was complete, causing a problem with our administrative record not accurately reflecting our NEPA analysis.'' Some managers (32%) were also concerned with information accuracy (Table 10). They often compared the historical data they found within the web application to their own experience. They commented on projections by relating or disassociating results with recent changes they had seen in the field or with reports and scientific articles that agreed or disagreed with those results. To further evaluate the data, at least 18% of managers requested and searched for metadata within the application to discover their source.

In total, 59% of managers found climate information in the eight web applications useful for planning (Table 10). For planning, 14% of managers wanted downloadable summaries that could be incorporated into reports and used as a reference. Having the ability to download GIS map layers from the web application to use with in-house spatial datasets and to include in analysis and planning documents was also reported as very helpful (Table 10). Close to 50% of the managers interviewed made statements about using GIS themselves to generate maps, and, among these, 27% had an in-office GIS expert.

h. Climate impacts

On average, a quarter of the land managers who were interviewed were interested in climate impacts (Table 11). We define climate impacts here as the effects of climate on both natural resources and society. Land managers were specifically interested in vegetation shifts, including the spread of juniper and invasive annual grasses, plant migration, and wildlife habitat changes. One manager emphasized, ''A main concern or question I have is about the final impacts. What are they going to be? What will be the seasonality and the amounts of moisture? What's going to happen and how are climate variables going to impact the communities

TABLE 10. As in Table 4 but for the interview feedback about consistency, compatibility, and planning.

	Manager feedback	No. of managers
Consistency and credibility	Information provided by web applications should be preserved with versioning (updates get new version no.)	3
	Observed trends matching historical or projected trends reinforce confidence in application	7
	Web application should include metadata	4
GIS software	Use ArcGIS or another desktop GIS software package	10
	Have a GIS specialist	6
	Useful if web application map layers compatible with ArcGIS or another GIS software package	5
Planning	Download summaries useful	3
	Climate information web applications useful for planning	13

TABLE 11. As in Table 4 but for the interview feedback about impacts related to climate.

	Manager feedback	No. of managers
Impacts	Interested in climate impacts	4
	Interested in vegetation impacts	5
	Interested in fire severity/projected fire	7

that existed historically? Where is the climate headed and what is the plant community response going to be?'' Managers were also interested in changes in fire regimes and fire severity, especially in the wake of increased fine fuel loads, dead sagebrush stands, and extended droughts. Another manager stated, ''One of the biggest effects I've seen, as far as climate variables, is the increase in fire severity. But this big shift in fire severity has just started to happen in the past few years.''

4. Discussion

During the preliminary discussion, most managers wanted information on weather and climate to inform their management activities and planning. However, only a few of these managers were already using web-based climate applications to meet these needs. The web applications most frequently mentioned included NOAA applications (e.g., Drought Monitor), USDA applications [e.g., Fire Effects Monitoring and Inventory System (FIREMON) and Fire Behavior Prediction and Fuel Modeling System (BehavePlus)], and Natural Resources Conservation Service (NRCS) applications [e.g., Snow Telemetry (SNOTEL)], but these applications represent only a small sample of what exists. So why are these web applications, which have become plentiful in the past few years, still not being used? Our project confirmed that the usefulness and usability of climate information is directly related to information access, relevant scales, and background education (Archie et al. 2012; Dilling et al. 2015; Dilling and Lemos 2011; Jantarasami et al. 2010; Kemp et al. 2015).

First, access is critical. Over half of our interviewees had access issues with seven of the eight interactive web applications explored during the interviews. Web applications would not open or work properly because of web browser incompatibility, in this case mostly with Internet Explorer. Another problem identified was the shift of web applications from one link to another or the outright disappearance of the application from the web. In both situations, the application once used by land managers could no longer be accessed.

Second, the spatial scale of climate models is, in general, too coarse for local projections. Coarse spatial scale projections provide trends over large areas where local conditions may decouple from regional trends because of topography or proximity to water features. For example, precipitation averaged over the state of Oregon will not reflect areas of high precipitation in the Coast Range or the Cascades, nor the semidesertic conditions east of the Cascades. Therefore, the spatial resolution of future climate projections should be fine enough to provide usable information to land managers. But fine spatial resolutions come at a cost because techniques to generate them have limitations. Two types of downscaling methods have been used to account for finescale features and provide relevant climate drivers to drive hydrologic- and ecosystem-response models. Statistical downscaling derives relationships between observations (from weather stations) and simulation results from a general circulation model. These statistical relationships are applied to the climate model's future climate projections to generate finer-scale projections. This method assumes that correlations between coarse- and finescale climate remain the same (stationary) in the future. In dynamic downscaling, a regional climate model simulates climate processes at higher resolution for a region of the globe using a global climate model's results for boundary conditions at the edges of that region. This method does not assume stationary relationships between past and future climatic patterns, but it is much more computationally expensive and maintains the global climate model biases. More often than not, information on the evolution and limitations of downscaling techniques that provide finescale climate information is not readily available to managers, and the reasons for differences between downscaled climate datasets from various sources are rarely explained (Tabor and Williams 2010).

The temporal scale also needs to match managers' activities. Currently, the temporal information available to land managers includes 3–6-month weather outlooks and long-term climate projections for 30–50 years or more. But land managers need seasonal and annual information for up to 3 years and near-term projections of only 10–20 years. However, weather forecasts extending beyond 3 to 6 months become increasingly unreliable because of natural climate variability. Climate projections are commonly averaged over the long term, usually 30 years, because projections under 30 years can be misinterpreted. Individual year projections may be incorrectly used as forecasts. Thus, there is a clear information gap, as weather and climate projections that are most crucial for land management strategies do not currently exist. More importantly, the lack of feasibility for scientists to fill that gap needs to be clearly explained to managers.

Readily available and detailed information is necessary for managers to gauge the relevance of the information that is delivered. Although the need for training to use web applications and climate change information was never directly stated, statements made during the interview suggest basic climate change educational needs and a gap in understanding. Information barriers were identified and include the multiplicity of locations for climate change applications, the lack of clear definitions of climate variables and climate change terminology, missing explanations on charts and graphs, the limitations of downscaling methods, and missing background information on climate models and scenarios. A few managers expressed insecurity in not knowing which climate model was ''best'' for their area. But, in fact, the different climate models show a range of possibilities, and one should not be looking for the ''best'' model but should be aware of the full extent of possible climate futures. Every model has its own limitations, but this message is often missing in web applications.

Throughout the study, managers mentioned their need for information on climate impacts, and the effects of climate on both natural resources and society, as opposed to just changes in climate. Land managers were interested in changes in vegetation cover and fire severity or timing. Providing sites where future climate impacts are clearly displayed could help develop new management strategies. However, unlike climate change projections, climate change impact projections have not been widely accessible, and impacts model ensembles are rare.

Communication between climate scientists and land managers is challenging when discipline-specific jargon cause either misunderstanding or misinterpretation (Oakley and Daudert 2016; Pellmar and Eisenberg 2000). Collaboration at the onset of research projects is an effective strategy for engaging stakeholders and overcoming information barriers, thus leading to the creation of coproduced science (Dilling and Berggren 2015; Chambers and Pellant 2008; Kemp et al. 2015; Moss et al. 2013). Examples of climate jargon include the terms PDSI and RCP, which were often unknown, but also ''drought'' and ''normal'' periods, often interpreted differently than in the scientific literature. The National Weather Service ''Drought fact sheet'' (National Weather Service 2012) defines drought as ''a deficiency in precipitation over an extended period,'' but land managers believed drought to include not only low precipitation, but also high temperatures (high evaporative demand) and low soil water availability. Normal periods can be mistaken for ordinary periods, when in fact they correspond to 30-yr historical averages according to the World Meteorological Organization (WMO) (www.wmo.int). Terms that are used even more broadly, such as water deficit, vegetation class, and net primary production (NPP), need to be described to ensure correct interpretation by users.

Finally, other important issues that may affect the use of climate-related web applications include information credibility and consistency. Interview participants often compared the historical model results with their experience on the ground as a way to confirm the information presented. This method of ''model versus local knowledge'' does not take into account the discrepancy between the climate model spatial resolution and the point observation, whether from a meteorological station record or personal observation. While the goal of this paper is not to discuss the lack of appropriateness of such a validation exercise [others have done it extensively; e.g., the classic paper by Rastetter (1996)], this raises one more issue: gaining managers' trust by providing information to explain how such a comparison might be flawed.

Land managers were also concerned with how information would persist within the application. The records from web application reports, such as climate projections, should remain the same when others access the website at a later time. The reliability and longevity of web application information is important to fend off skepticism and justify an application's mention in planning documents. However, managers would also like frequent updates incorporated into web-based climate applications at least once a year. The contrast between updated information and information consistency can be solved through web application versioning. Versioning allows older information to be maintained while allowing regular updates, such as new climate projection ensembles.

5. Conclusions

With BLM funding focused on sagebrush management, our intent was first to gather enough information from potential users to design customized web sites that address specific needs of sagebrush managers and ultimately help them address the challenges of climate change. We have reported on this first phase of our project, as Conservation Biology Institute staff will next embark on building those sagebrush-focused web pages and tools with further feedback from managers interested in pursuing this collaboration effort.

Climate change is adding an additional level of stress to many ecosystems, particularly the already vulnerable sagebrush biome. While we cannot offer extensive guidance on how to improve all future climate-related web applications, we want to share with other web developers the lessons we learnt from the managers' feedback: web applications must be accessible, given agency-specific software constraints; spatial and temporal scales must be relevant to management activities; extensive documentation of models and scenarios must be readily available; climate impacts relevant to land management activities should also be presented (multiple climate models and multiple impacts models); graphics should include good color separation and scale increments; and terminology should be clearly explained. It was clear that training opportunities for managers to learn about existing web applications and understand how to use them were important. Even through our phone conversations, managers were learning about websites they had not been aware of but were interested in. Equally important, these calls were opportunities for managers to explain their day-to-day work to allow web developers and scientists to better understand how their products might be used.

Our assessment of land manager needs in the sagebrush country of eastern Oregon and western Idaho is the first step toward what we hope will develop into improved communication between our climate scientists, our web developers, and BLM land managers. Our goal is to establish effective collaborations while designing practical web applications to deliver usable information for effective land stewardship. We found that our project provided land managers with some level of climate education. Equally important, it provided our climate scientists and web developers insight into managers' needs. As one might expect, because of the nature of phone interviews, we were unable to "see" the nonverbal web interactions of managers, but we hope to include future workshops with on-site training to further collaboration and improve our web applications.

Communication issues are widespread and usability projects should incorporate feedback from a variety of federal, state, tribal, and private landowners and managers. Our study had a very limited scope. But we confirm that, through collaboration, climate scientists can begin to assist and support land stewards by developing user-friendly information-rich climate-delivery applications that provide some insight into the challenges ahead. We talked to one land manager who clearly understood the challenge and was already integrating it in his work: "I'm still not one-hundred percent sure that this will be the scenario that we will see. [...] It's the information and best science that we have available to work with at this time. [...] We try to use these kinds of tools to show that what we're trying to do on the ground is supported by the best information we have available." We hope to work with many more managers with such understanding.

Acknowledgments. Project funding was provided by the Bureau of Land Management through Oregon State University (Award L14AC00103**)**. A special thanks to all the BLM land managers who participated in the interviews. We also want to thank Dr. Louisa Evers (BLM) for her continued guidance and support, Dr. Kim Sheehan and her husband, who helped design early versions of our survey, and Drs. Barry Baker and David King for their help editing the paper. Thanks to the Corvallis, Oregon, staff of the Conservation Biology Institute, including Dr. J. Strittholt, P. Frost, T. Sheehan, M. Gough, B. Ward, and many others, who provided working space and dedicated their time and thoughts to this project.

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