Indicators of Climate Change in Idaho: An Assessment Framework for Coupling Biophysical Change and Social Perception[a]

P. ZION KLOS,[b] JOHN T. ABATZOGLOU,[c] ALYCIA BEAN,[d] JAROD BLADES,[e] MELISSA A. CLARK,[f] MEGAN DODD,[g] TROY E. HALL,[h] AMANDA HARUCH,[g] PHILIP E. HIGUERA,[i] JOSEPH D. HOLBROOK,[j] VINCENT S. JANSEN,[d] KERRY KEMP,[b] AMBER LANKFORD,[j] TIMOTHY E. LINK,[b] TROY MAGNEY,[b] ARJAN J. H. MEDDENS,[c] LIZA MITCHELL,[j] BRANDON MOORE,[c] PENELOPE MORGAN,[i] BETH A. NEWINGHAM,[k] RYAN J. NIEMEYER,[b] BEN SODERQUIST,[b] ALEXIS A. SUAZO,[b] KERRI T. VIERLING,[j] VON WALDEN,[l] AND CHELSEA WALSH[m]

[b] *College of Natural Resources, University of Idaho, Moscow, Idaho*
[c] *Department of Geography, University of Idaho, Moscow, Idaho*
[d] *Environmental Sciences Program, University of Idaho, Moscow, Idaho*
[e] *Department of Plant and Earth Science, University of Wisconsin–River Falls, River Falls, Wisconsin*
[f] *Department of Conservation Social Sciences, University of Idaho, Moscow, Idaho*
[g] *English Department, University of Idaho, Moscow, Idaho*
[h] *Department of Forest Ecosystems and Society, Oregon State University, Corvallis, Oregon*
[i] *Department of Forest, Rangeland, and Fire Sciences, University of Idaho, Moscow, Idaho*
[j] *Department of Fish and Wildlife Sciences, University of Idaho, Moscow, Idaho*
[k] *Great Basin Rangelands Research Unit, USDA–Agricultural Research Service, Reno, Nevada*
[l] *Department of Civil and Environmental Engineering, Washington State University, Pullman, Washington*
[m] *Department of Plant, Soil and Entomological Science, University of Idaho, Moscow, Idaho*

(Manuscript received 28 October 2013, in final form 25 April 2015)

ABSTRACT

Climate change is well documented at the global scale, but local and regional changes are not as well understood. Finer, local- to regional-scale information is needed for creating specific, place-based planning and adaption efforts. Here the development of an indicator-focused climate change assessment in Idaho is described. This interdisciplinary framework couples end users' data needs with observed, biophysical changes at local to regional scales. An online statewide survey of natural resource professionals was conducted to assess the perceived impacts from climate change and determine the biophysical data needed to measure those impacts. Changes to water resources and wildfire risk were the highest areas of concern among resource professionals. Guided by the survey results, 15 biophysical indicator datasets were summarized that included direct climate metrics (e.g., air temperature) and indicators only partially influenced by climate (e.g., wildfire). Quantitative changes in indicators were determined using time series analysis from 1975 to 2010. Indicators displayed trends of varying likelihood over the analysis period, including increasing growing-season length, increasing annual temperature, increasing forest area burned, changing mountain bluebird and lilac phenology, increasing precipitation intensity, earlier center of timing of streamflow, and decreased 1 April snowpack; changes in volumetric streamflow, salmon migration dates, and stream temperature displayed the least likelihood. A final conceptual framework derived from the social and biophysical data provides an interdisciplinary case example useful for consideration by others when choosing indicators at local to regional scales for climate change assessments.

1. Introduction

Global observations have shown recent increases in mean surface temperature, upper-ocean heat content, sea level, and atmospheric water vapor together with decreases in sea ice, snow-cover extent, and glacier volume that provide strong evidence of a warming planet (IPCC 2014). Scientific evidence demonstrates that climate change is primarily attributable to anthropogenic drivers (IPCC 2014). However, the relationships

Denotes Open Access content.

[a] Supplemental information related to this paper is available at the Journals Online website: http://dx.doi.org/10.1175/WCAS-D-13-00070.s1.

Corresponding author address: P. Zion Klos, 875 Perimeter Drive MS 1133, Moscow, ID 83844-1133.
E-mail: zion@uidaho.edu

DOI: 10.1175/WCAS-D-13-00070.1

between atmospheric changes (e.g., precipitation, temperature) and the related impacts on human and natural systems are often hard to disentangle, particularly because these impacts are biophysically complex and only partially influenced by climate (USGCRP 2011b, 2012). Indicator-focused climate change assessments, which define climate change indicators as any time series variable useful for displaying the influence of changing climate over time, have been conducted from local to national spatial scales (e.g., Hayhoe et al. 2007; Pederson et al. 2010; Betts 2011; USGCRP 2011a; Blunden and Arndt 2013). Despite the diversity of indicator-focused studies, specific changes occurring within the inland northwest of the United States have not been synthesized, and no climate change assessment of indicators and data needs at an appropriate scale for Idaho end users currently exists.

End users represent a broad range of natural resource professionals, including those working for federal and state agencies, nongovernmental organizations, and other entities such as local governments or corporations. End-user engagement can inform scientific assessments and strengthen the overlap between societal need (e.g., perceived concerns, end-user data needs) and available climate-related data (biophysical indicators) to improve adaptation to climate-related impacts (Meyer 2012). Eliciting end users' input concerning their specific needs is especially important when empirical data are complex, uncertainty is prevalent, and the perspectives of end users are diverse (Moss et al. 2014). Studies have been conducted to explore perceptions of climate change and associated impacts, notably at national and regional scales (e.g., Hulme and Turnpenny 2004; Leiserowitz 2005; Leiserowitz and Smith 2010; Leiserowitz et al. 2011). Expert elicitation has also been sought for many climate change assessments seeking to provide salient information specifically tailored to end users (Cohen 1997; NRC 2010; EPA 2010; Craghan 2012; Melillo et al. 2014). Although end user and expert engagement has been conducted at national and regional scales, there is a need for targeted engagement at finer scales to address the needs of local end users.

Previous research shows that much of science is not used, or usable, by resource managers and decision-makers (Sarewitz and Pielke 2007). There are a variety of reasons for this, including institutional expectations that vary between research entities and policy makers or land managers, but one of the core problems is researchers' failure to understand end users' needs. In the case of climate science, the situation is especially challenging because the variables that are easily tracked and highly responsive to climate change (e.g., temperature or phenology) are often not directly aligned with the issues of importance to those charged with managing resources and protecting human communities (Kiem and Austin 2013; Vera et al. 2010). For instance, local communities may desire to know how climate change may impact the spread of disease, yet there is considerable uncertainty about how and when such impacts may become realized. In response, there have been calls for incorporating end users in prioritizing information needs (Dilling and Lemos 2011).

Idaho serves as a regional case example of a state-level political boundary with a diversity of end-user information needs regarding climate change. Idaho is distinctive in that it contains larger portions of federal land and designated wilderness (Gorte et al. 2012), as well as a lower overall population density (Mackun and Wilson, 2011), when compared to the national average. The heterogeneous nature of the landscape (e.g., forests, rangelands, and croplands), natural resource management, and climate across the state provide the opportunity to develop a template for an indicator-focused climate change assessment that overlaps available science with the data needs and climate concerns of its resource management community. Despite the diversity of end users with varied socioeconomic dependencies on natural resources, decisions commonly must be made within a unified political boundary (e.g., state level, regional management office, river basin treaty). This can create challenges for policy implementation, particularly when desired environmental policy actions are dependent on strong scientific understanding and high perceived risk (Lubell et al. 2006; Stoutenborough et al. 2013). To overcome this lack of specific knowledge and lack of perceived risk, local- to regional-scale assessments are needed to garner public support for collective action (Lubell et al. 2006; Stoutenborough et al. 2013).

In an effort to advance the broader science of climate change assessment and to provide detailed climate change information relevant to end users, we aim to 1) present our interdisciplinary framework for others seeking to choose and synthesize indicators for local- to regional-level climate change assessments and 2) provide a proof-of-concept case example that incorporates both an exploration of social needs/concerns and data on biophysical indicators of climate change across the state of Idaho. Considering the complex interdisciplinary nature of the study, the following text does not follow a traditional format. Instead we first highlight the framework of our interdisciplinary approach, and then display the methods and results for each the social and biophysical aspects of our study individually, before finally concluding with an integrated discussion.

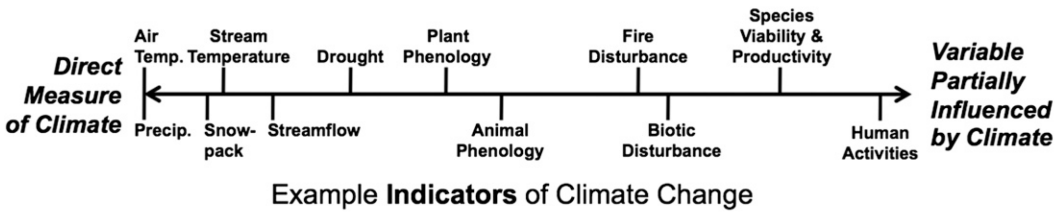

FIG. 1. Indicators of climate change across a conceptual spectrum from direct climate metrics to variables partially influenced by climate.

2. Interdisciplinary process

To develop a statewide indicator-focused assessment of climate change, we, an interdisciplinary team of social and biophysical scientists, conducted a statewide survey of natural resource managers and professionals to assess perceived impacts of climate change and explore what available biophysical data end users deemed most important for assessing climate impacts. We used the results to refine a set of climate-linked biophysical datasets as potential climate indicators. Based on survey results and data availability, we created the assessment framework for identifying potentially important climate change indicators. Indicators were defined as direct or near-direct climate metrics (e.g., temperature, precipitation) or were indirectly linked to climate (e.g., streamflow, wildfire, etc.). Using our prior process understanding, we placed indicators along a conceptual spectrum to qualify their differences in mechanistic relationship to direct climate variables, thus allowing us to highlight their biophysical complexity or level of difficulty involved in discerning trends related to anthropogenic climate change (Fig. 1). Within the conceptualization, variables (or direct metrics) that are closely linked to climate are toward the left side of the spectrum, whereas other variables that are only partially influenced by climate (being heavily controlled by other mechanisms as well, such as land management, ecological stressors, etc.) are placed farther toward the right side of the spectrum (Fig. 1). Biophysical complexity, in relation to climate, increases toward the right of the spectrum, as the alternative biophysical nonclimatic controls compound and additionally influence the final dependent variable.

To highlight the findings and broadly share them with other interested groups, the research team created both this manuscript and complementary outreach documents, which were rewritten and organized to be easily accessible and appealing to the general public. These secondary documents contain common language, reworked graphics, and aesthetic aspects suggested and edited by the communication specialists on the team. They include an executive summary, detailed report/booklet, website, and a pamphlet, the latter designed for distribution across Idaho. With approval of this manuscript and its findings by the peer-review process, these accompanying materials exist freely to the public through the University of Idaho.

3. Statewide climate-needs survey

a. Survey methods

Given the calls in the literature to engage stakeholders and end users in identifying science needs, our first step was to solicit input from individuals affiliated with some aspect of natural resource management in Idaho. Many of the proposed solutions are time and resource intensive, such as establishing boundary organizations or structured knowledge networks. In this paper, we adopted a relatively inexpensive, efficient approach to enhancing the connection between science and end users through the use of an online survey of key informants in Idaho. McKenna and Main (2013) articulate the value of using key informants to obtain expert information related to a community's needs; one recent example can be found in Berndtson et al. (2007), where researchers developed lists of potential study participants from staff recommendations, the literature, and snowball sampling to help identify grand challenges in public health.

An online survey was administered in February 2012 to evaluate which climate indicators were of primary concern to end users and which indicator datasets would be the most useful in their jobs (see the supplemental material, available at http://dx.doi.org/10.1175/WCAS-D-13-00070.s1, for a copy of the survey). Using a purposeful (Coyne 1997) and snowball sampling approach (Creswell 2009), we obtained participant contact information from agency and organizational websites, and asked survey participants to provide contact information for other potential participants, or to forward the online survey directly to their colleagues. Ritchie et al. (2003) recommend purposive sampling as appropriate when the sample is intended to represent individuals who meet key selection criteria, and they note that this approach helps ensure that all key groups are included. We specifically sought individuals who would be in a position to comment on the utility of climate science to management or policy decisions. Additionally, our selection criteria were attentive to covering the full suite of professions (natural resource managers, specialists, and community leaders) that would ultimately use the final products of this indicator-based assessment in their work, in a form of maximum variation sampling (Sandelowski 1995). Thus, our sampling approach is most appropriately characterized as what Patton (1990) calls stratified purposeful sampling, designed to achieve coverage of all groups. A total of 612 individuals were asked to participate. Participants included individuals working for state agencies (37%), federal agencies (32%), nongovernmental organizations (21%), and other entities (8%, corporate or private, and local governments).

The Internet survey was developed online using Qualtrics software and followed a modified Dillman method (Dillman et al. 2009), where participants were invited to participate through a work e-mail address and two weeks later received a reminder e-mail. The survey format included sequential questions about 1) perceived importance of climate change impacts within the state with a focus on natural hazards and social change and 2) indicators of climate change most desired for assessment within five designated systems: water, forest, rangeland, agricultural, and social systems. The survey first asked participants about their personal concern regarding a broad range of climate impacts, and then asked about relevance of climate data to their jobs in an attempt to avoid an order effect, which could have caused participants to answer all questions with respect to their work interests and induce undesired priming (Salancik 1984). Within the first part of the survey, all respondents were asked to choose up to five impacts they were personally concerned about from a broad set of possibilities (see supplemental material). The specific options within this broad set were designed to be far reaching in scope, but may have inadvertently primed the participants to focus their future answers only within the constructs of the impact options provided. Next they were asked to choose up to three responses (of the 12 possible, with three additional open-ended options) regarding direct measures of climate (i.e., direct temperature and precipitation metrics) they found most relevant to their job. They were then asked to choose one of the five designated systems (i.e., water, forest, rangeland, agricultural, social) that was most relevant to their job. This choice took them to one of the five possible subpages (one per designated system) where they could choose the top three indicators of the 12 or more options within that system. They were then asked if another one of the five designated systems was relevant to their job. If so, they were then directed to that designated system's subpage to again choose their top three most relevant indicators. After two (at most) designated system subpages the participants were then directed to the conclusion of the survey. The decision to limit respondents to no more than two systems was based on a need to minimize the burden on respondents, as the lists of indicators were quite long and because—given the breadth of respondents—we recognized that not all systems would be primarily important to all respondents.

We developed the survey questions collaboratively as a research group, with each discipline represented (e.g., hydrology, ecology, etc.), generating a comprehensive list of climate measures, potential impacts, and indicators that were considered most salient to each system and reflected the focus of similar work in other regions (Pederson et al. 2010; Betts 2011; USGCRP 2011a,b, 2012).

b. *Summary of survey findings*

A total of 100 surveys were completed, with respondent demographics mirroring those in the total population surveyed (Fig. 2). The top four concerns regarding climate change impacts were water resource availability (16% of respondents), extreme drought (14%), changes in plant productivity (14%), and wildland fire (10%; Fig. 2). Regardless of participant sector, concerns about biophysical impacts were consistently rated as the highest importance, and concerns about recreation and transportation impacts were rated as the lowest importance.

Based on a metric of "normalized importance," which is defined as the number of times an indicator was selected by an individual end user divided by the total number of selections within a system, participants identified precipitation indicators as being the top three most useful climate measures: annual rainfall versus snowfall (23%), seasonality trends (22%), and general precipitation (14%; Fig. 3). Of all responses, 43% represented water-related occupational specialties as indicated by the choice of system specialties (Fig. 3). The top indicators for end users who selected the water resources system were streamflow timing, annual volumetric stream discharge, and stream baseflow discharge. Participants who selected the forest system focused on wildland fire severity and vegetation/wildlife distributions. Rangeland participants focused on vegetation indicators (i.e., plant productivity, vegetation distribution, and plant phenology). Agricultural participants focused on precipitation patterns, drought characteristics, and growing season length as their top priorities. Participants working with social systems selected water-based

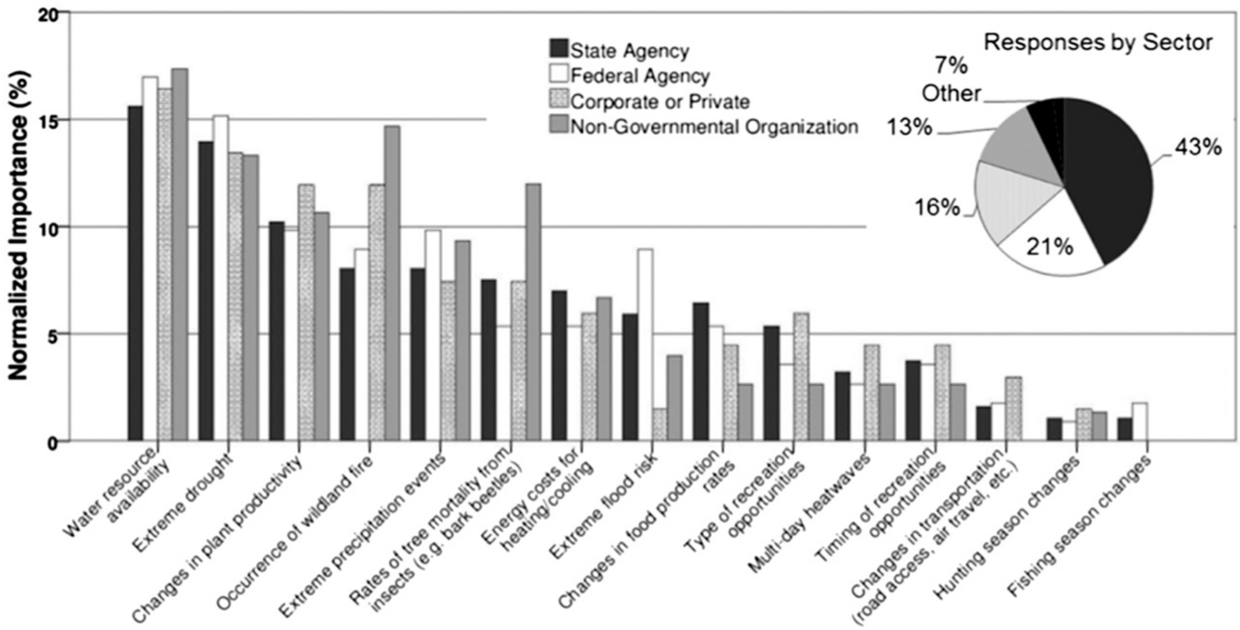

FIG. 2. Perceived importance of climate change *impacts* in Idaho (United States) by end users. Responses ($n = 440$) are stratified by sector of the respondent: state agency, federal agency, corporate or private, or nongovernmental organization (with the ''other'' category removed due to small sample size). The response rates of each sector are shown top right. ''Normalized importance'' is the number of times an impact was selected by an individual end user divided by the total number of selections within a sector.

recreation, timing of peak visitation, and recreation restrictions due to wildland fire as the top climate change–related indicators.

Overall, participants were most concerned with water-related impacts resulting from climate change and considered information about water resources availability to be the most important measures of climate change that were relevant and useful for their needs (Fig. 2). The topics of fire and vegetation were also top areas of participant interest. The occurrence and impacts of wildland fire ranked fourth for participant concern (Fig. 2), and indicators related to fire were among the top four most relevant in forest, rangeland, and social systems (Fig. 3). The impact of climate change on plant productivity and growth rates ranked third for participant concern overall (Fig. 2).

4. Statewide climate change indicators

a. Biophysical data selection

Biophysical indicators of climate change were identified based on existing datasets and results from the end-user survey. After the survey results were acquired, the final indicators were chosen based on a criterion of both high interest to end users, as indicated by the survey results, and available data. Indicators were classified into three categories: climatological, hydrological, and ecological. A comparative analysis of climate-related trends was conducted over the time period of 1975–2010, as 1) it covers the period of most noted anthropogenic forcing and increases in global mean temperature (e.g., Lean 2010), 2) most indicators have complete data over this time span, and 3) the prominent modes of regional climate variability that influence the U.S. Pacific Northwest, such as El Niño–Southern Oscillation (ENSO), the Pacific–North American pattern (PNA), and the Pacific decadal oscillation (PDO), did not exhibit any significant long-term trends during this time period. Independent decadal-scale trends in these modes of climate variability have altered the pace of warming regionally and thus partially influence changes observed in climate-related indicators, such as mountain snowpack (e.g., Mote 2006; Abatzoglou 2011; Abatzoglou et al. 2014b). To avoid selecting a time span that included a pronounced trend in regional climate variability, an ordinary least squares linear trend analysis was performed on mean annual PDO, PNA, and ENSO indices (Multivariable El Niño Index; Wolter and Timlin 1993) over variable time periods beginning in years 1950–85 and ending in 2010. Significant trends for these individual climate indices were identified for analyses starting prior to 1954 and after 1976. The 1975 start date was therefore selected to minimize the contribution of trends arising

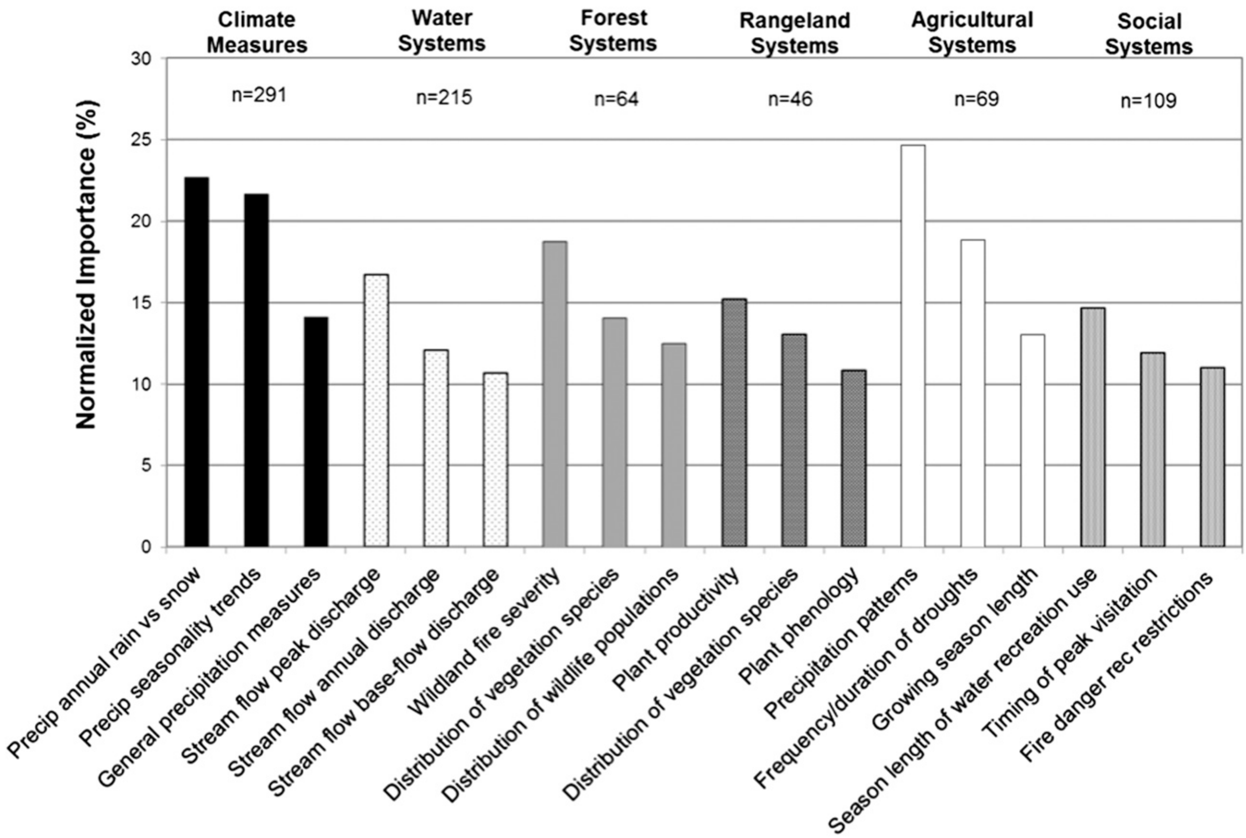

FIG. 3. Climate change *indicators* that participants reported would be most useful within their work, pooled across all stakeholder types and segregated by natural resource system (top three per system are shown). ''Normalized importance'' is the number of times an indicator was selected by an individual end user divided by the total number of selections within a system.

from internal climate variability and maximize the number of climate indictors for which datasets were available. For graphic representation, the baseline period from which anomalies were plotted against is 1971–2000, except where otherwise noted, due to sparse data (e.g., phenology).

b. Statistical methods of trend analysis

We estimated the significance and strength of trends in climate indicators from 1975 to 2010 using ordinary least squares linear regression. This approach allowed us to evaluate the relative strength of each independent climate indicator over the chosen time frame. We then qualitatively ranked the climate indicators according to the strength of their trends to demonstrate how well they relate to general trends of regional to global anthropogenic warming over the same time period. All indicator variables were tested to ensure they met the assumptions of an ordinary least squares regression, including that the distribution of each set of data followed a normal distribution with constant variances and that all of the observations were independent. To test the normality of each set of data, we used a Kolmogorov–Smirnov goodness-of-fit test (Gotelli and Ellison 2004); annual area burned was the only time series that did not pass this goodness-of-fit test and was thus log-transformed to meet the assumption of normality, as commonly done when analyzing annual area burned data (e.g., Collins et al. 2006). Furthermore, since time series with significant autocorrelation (e.g., nonindependent observations) are more likely to show linear trends through time, we assessed autocorrelation in each time series using the Durban–Watson statistic and the 95% confidence interval (CI) around the autocorrelation function for years 1–5, following Diggle et al. (2002). If either the Durban–Watson test was significant or any of the 95% CIs for lag 1–5 autocorrelation did not overlap 0 (i.e., no autocorrelation), we estimated the true probability that the slope (β_1) parameter in each regression did not equal 0 using a block-resampling bootstrap technique repeated 10 000 times [adapted from methods in Gavin et al. (2011)]. The block size for resampling was set equal to the largest lag with significant autocorrelation for a given time series, and the true

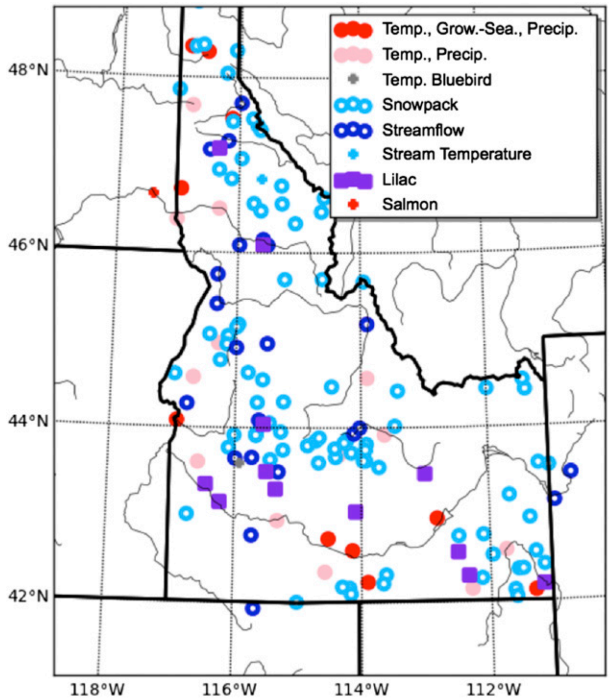

FIG. 4. Locations of point-source biophysical indicator data within Idaho. Distributed wildland fire data were aggregated across the entire state.

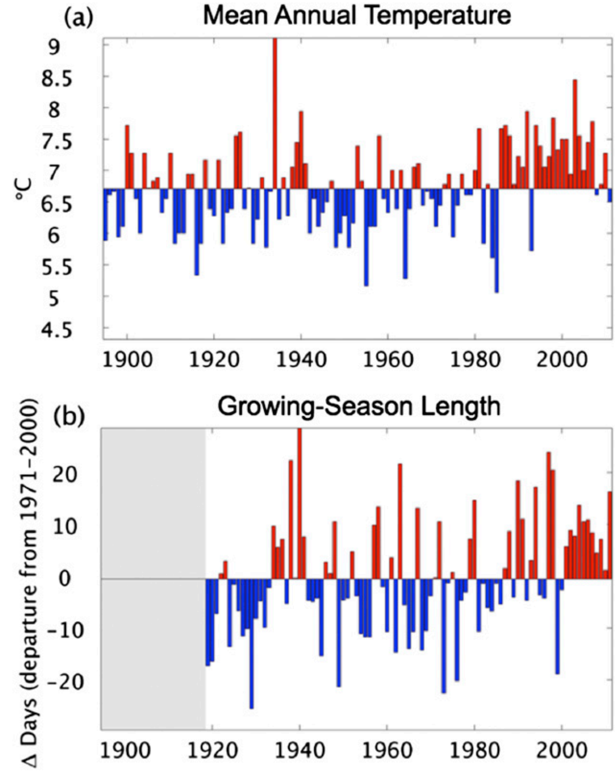

FIG. 5. Temperature indicators: (a) mean annual temperature across Idaho ($n = 29$ stations) and (b) departures from mean (1971–2000) growing season length as indicated by number of growing-season days across 12 stations in Idaho (see Fig. 4 for locations). Light gray shading in this and subsequent figures highlights time periods with insufficient data.

p value (p_auto) was estimated by comparing the observed β_1 parameter to the distribution of β_1 parameters from the 10 000 bootstrap samples. All reported p values assume an a priori one-tailed hypothesis test that the slope of the regression was different than zero. For slope analysis, the direction and strength of trends are only reported for significant ($p < 0.05$) and nonsignificant trends where $p < 0.20$. No slope is reported for trends with the lowest levels of confidence ($p > 0.20$).

c. Indicator data sources and methods

Time series data were acquired from diverse locations across Idaho to provide an integrated view of the state (Fig. 4). Temporally, datasets are displayed for their entire period of observation (Figs. 5–10), but time series trend analysis was only conducted over the 1975–2010 time period. Spatially, some datasets (e.g., temperature, precipitation, snowpack, burned area) are derived from a large number of observation sites and therefore have higher representation, while other data sources are less spatially representative of the state, such as stream temperature. Despite the shortcomings of spatial extent, these datasets were still included for analysis and discussion because they are the only long-term data available for the desired variables within the state.

1) DATA SOURCES AND METHODS FOR DIRECT CLIMATE METRICS

Daily maximum and minimum temperature and precipitation from the 29 U.S. Historical Climate Network (USHCN) stations located within Idaho (Fig. 4) were acquired for their period of record evaluated using quality assurance and control measures (Menne et al. 2009). Growing-season length, defined as the number of days between the last day in spring with overnight low temperatures below 0°C and the first autumn day with low temperatures below 0°C, was calculated for each station. However, because of spatial disconnect from agriculture, we narrowed our analysis for growing-season length to 12 stations below 1807 m in elevation and missing less than 10% of daily observations. Growing-season length for individual stations was normalized over a common 1971–2000 reference time period. This normalization period was chosen because complete data were available from all stations, thus eliminating the influence of varying means and standard deviations across stations with nonconcurrent records.

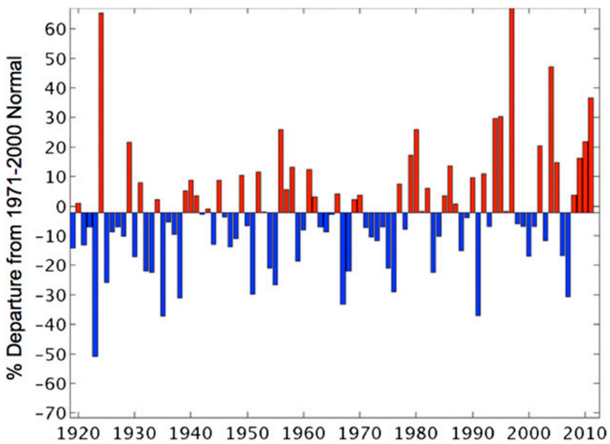

FIG. 6. Precipitation indicator: intensity of the most extreme one-day precipitation event of the spring (MAM) in a given year relative to the mean from 1971–2000 (normal) for 28 stations in Idaho (see Fig. 4 for locations).

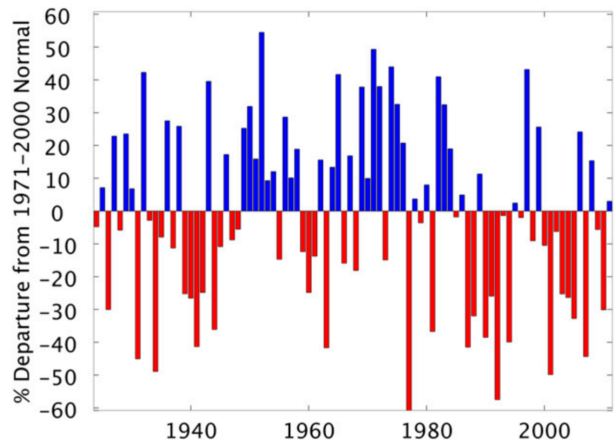

FIG. 7. Snowpack indicator: 1 April snow water equivalent (SWE) for each year relative to the mean of 1971–2000 (normal) for 126 sites in Idaho (see Fig. 4 for locations).

For each year we estimated the statewide-standardized anomaly based on the mean from all reporting stations.

For precipitation intensity, the largest single-day of accumulated precipitation annually and for the spring season [1 March–31 May (MAM)] was used [similar to Osborn et al. (2000)]. While all seasons are of interest, we identified spring as the most important for Idaho end users because of the high potential for saturated soil water content, runoff, and erosion (Williams et al. 2001). Data were compiled from time periods in which >15 of all the USHCN stations in Idaho had >80% of the data during a given spring (1920–2012). The deviation of the maximum one-day precipitation event from the mean of the analysis period (%) was computed and averaged across the stations. This synthesized change was normalized by the 1971–2000 time period using the median maximum precipitation amount for each station.

For snowpack, we compiled a long-term dataset of snow course records collected by the Natural Resources Conservation Service (NRCS) Water and Climate Center. A total of 126 locations in Idaho contained 1 April snow water equivalent (SWE) data for every year from 1975 to 2011. These data were normalized to the entire dataset within each site during the 1975–2011 period and these normalized values for each year were averaged across all 126 sites for a final statewide mean value for each year.

2) Hydrologic data sources and methods

Daily streamflow data were obtained from the United States Geological Survey (USGS) Hydro-Climatic Data Network for 26 gauges on watersheds that have experienced minimal land-use change, a low amount of human influence, and negligible water diversion from 1950 to 2005 [for specifics, see Slack and Landwehr (1992) and Clark (2010)], thus allowing for the influence of climate change to more easily be isolated from the other methods of anthropogenic forcing. To create a statewide aggregated assessment of flow changes, data were averaged across all stations. For average stream temperature, daily records were used from the USGS gauge at the Canyon Ranger Station on the North Fork of the Clearwater River within north-central Idaho (Fig. 4). These records have been kept since 1971, and they provide a uniquely long-term and robust stream temperature dataset within Idaho. Records from this site have been used previously to examine climate change impacts on stream temperature and salmonids (Isaak et al. 2012).

3) Ecological data sources and methods

Records of lilac (*Syringa vulgaris*) first bloom dates were acquired from the North American First Leaf and First Bloom Database, which contains observations collected by citizen scientists (USA National Phenology Network; Schwartz and Caprio 2003). From the database, we selected 13 monitoring sites in Idaho with at least 20 years of records from 1957 to 1993. Standardized anomalies of statewide first bloom data were estimated by calculating the average and standard deviation for the first 22 years of the record (1957–78, during the highest density of reported data), computing standardized bloom date anomalies for each station and year, and averaging all reporting sites within a given year.

Citizen scientists also collected bird nest phenology data. Nest phenology of the Mountain Bluebird (*Sialia currucoides*), Idaho's state bird, was collected by a citizen scientist who has examined nests and banded birds using bluebird nest boxes for approximately 30 years in southwestern Idaho, and who is certified by a Master Banding Permit issued by the Bird Banding Laboratory at the

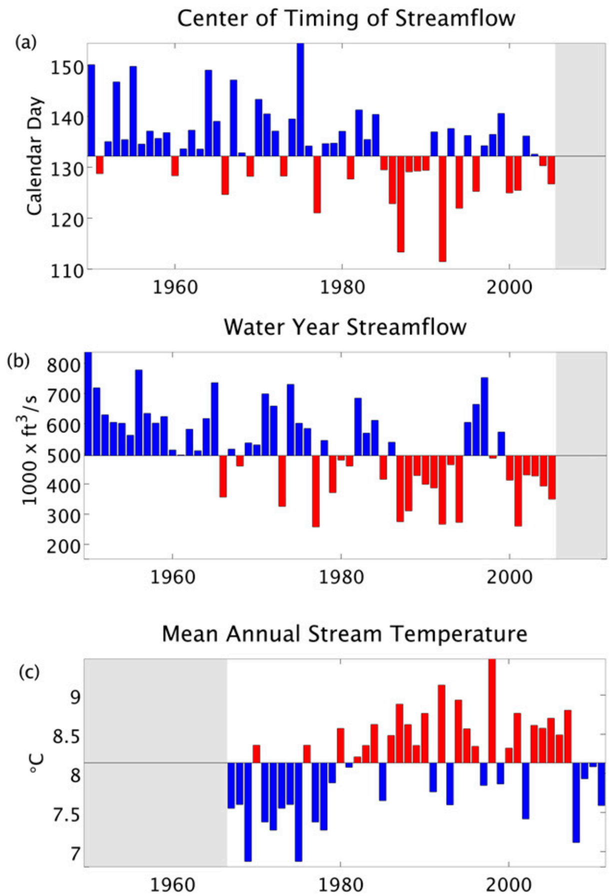

FIG. 8. Hydrologic indicators: (a) mean day of calendar year for center of timing of streamflow across 26 stations in Idaho, (b) mean water-year volumetric flow in a thousand cubic feet per second across the same 26 stations, and (c) annual mean stream temperature for the North Fork Clearwater River, north-central Idaho. See Fig. 4 for station locations. The horizontal line is the 1971–2000 mean for each dataset.

USGS (A. Larson 2012, personal communication). Nest records included year, number of eggs, number of eggs hatched, hatch date, and number fledged; these data span a temporal period of 1992–2006, 2009, and 2011 with 9–19 observations per year ($n = 17$). It was assumed that one egg was laid per day, which is true for nearly all songbirds, and that the incubation period was 13 days (Power 1966; Power and Lombardo 1996). Following Dunn and Winkler (1999) and Dolenec et al. (2011), we used these data to back-calculate to first egg date (i.e., first egg date = hatch date − 13 − number of eggs). April temperature data were acquired from the National Climatic Data Center for the weather station at Arrowrock Dam; 82% of nest initiations occurred in April. We were unable to conduct time series trend analysis because of the low number of observation years; thus, we used linear regression to examine the relationship between nesting date and temperature.

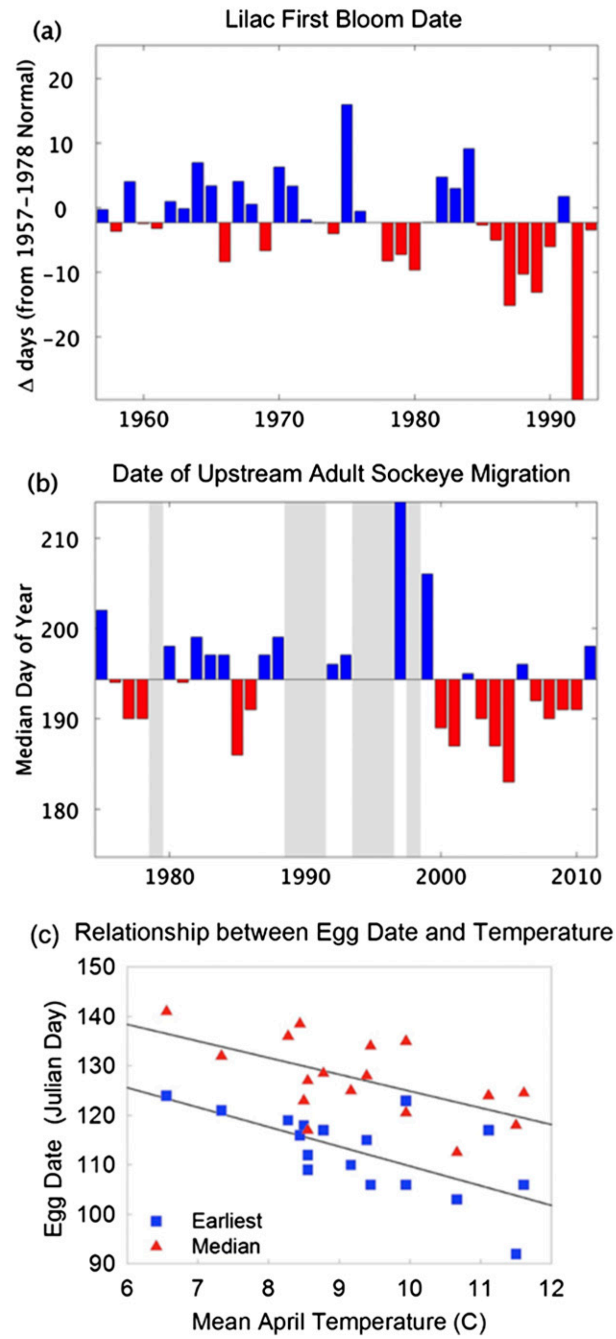

FIG. 9. Phenology indicators: (a) mean statewide (variable number of sites) day of year for first bloom of lilac relative to the average 1957–78 normal (mean of the analysis period), (b) median date of upstream adult sockeye salmon migration as recorded (gray = missing data) at Lower Granite Dam, the uppermost dam on the lower Snake River near the Washington/Idaho border, and (c) linear regression of mountain bluebird earliest and median egg date as a function of mean April temperatures; data ($n = 17$) are from locations near Arrowrock Dam, Elmore County, Idaho, from 1992–2006, 2009, and 2011.

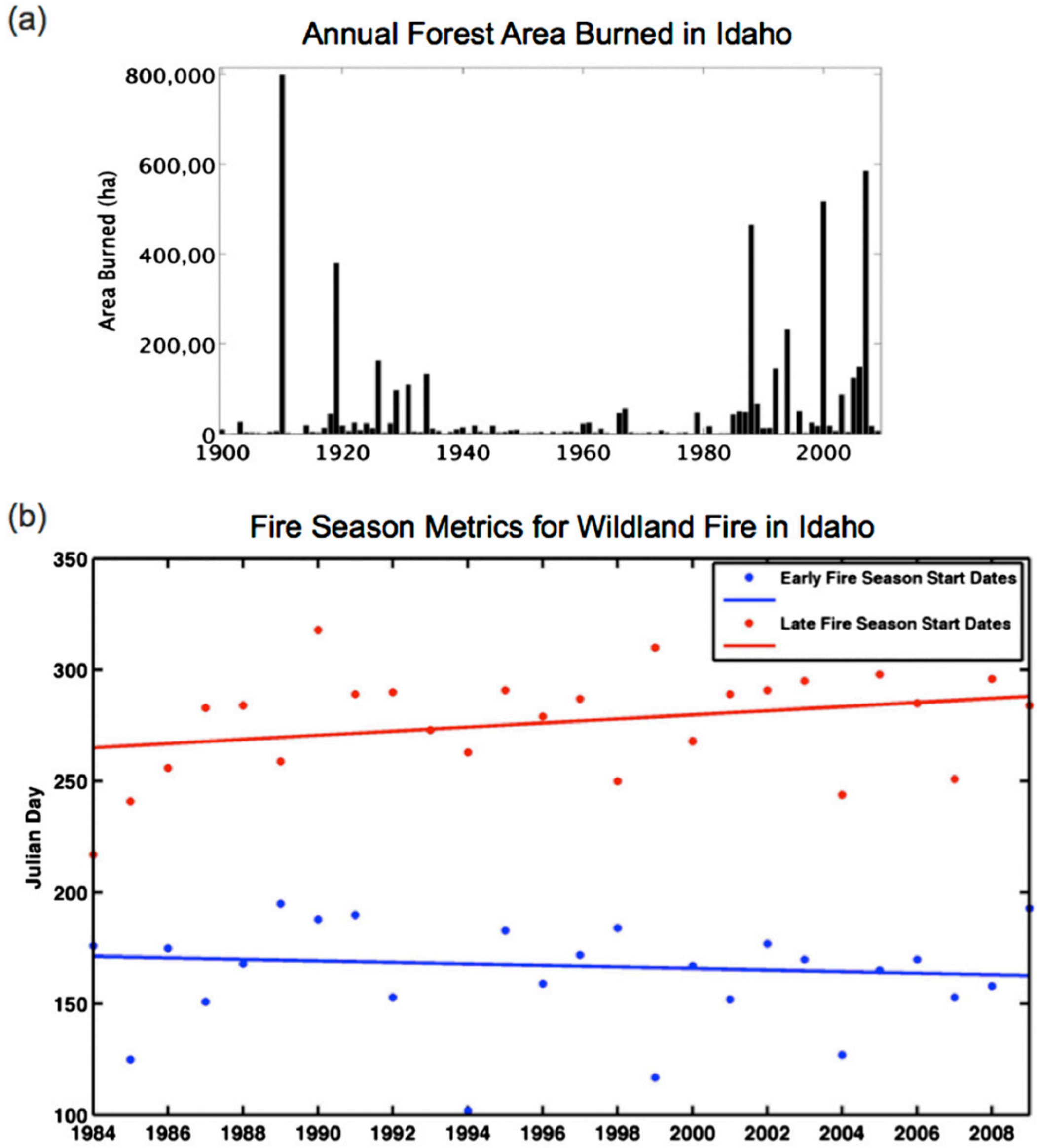

FIG. 10. Wildland fire indicators: (a) annual area burned by wildland fire in Idaho forests [updated from Morgan et al. (2008)] and (b) fire season metrics for all wildland fires greater than 400 ha in Idaho; fire season length is defined as the difference between the earliest fire start date (blue) and the latest fire start date (red) within a single year.

Phenological data also included the median date of summertime upstream migration for adult sockeye salmon (*Oncorhynchus nerka*). Fish count records, provided by the Columbia River Data Access in Real Time program, were acquired from 1975 to 2011 from Lower Granite Dam (the uppermost dam on the lower Snake River). Although this site is just outside of the state boundary, the vast majority of the upstream drainages it encapsulates are within Idaho (Fig. 4).

We analyzed updated fire-perimeter data from 1902–2009 that account for forest fires >0.5 ha on federally managed forest lands to examine trends in forest area burned by wildland fire within Idaho. This dataset comprises continuous values (decimal ha) for area burned and meets the assumptions for the ordinary least squares statistical analysis. Additionally, discovery dates from all large wildland fires (>400 ha) within the state (forested and nonforested) from 1984 to 2009 were obtained from the Monitoring Trends in Burn Severity Project. We used the discovery date of the first (early season) and last (late season) fire as a proxy for estimating the length of the summer fire season.

TABLE 1. Summary of trend likelihood, slope, and R^2 for linear regression analyses of biophysical climate change indicators within Idaho. Ranked by level of trend likelihood with indications for significant (in bold font, $p < 0.05$) and nonsignificant ($p > 0.05$) values.

Time series within Idaho (1975–2010)	p value (*p_auto)	Change per decade	R^2
Growing season length	**0.01**	**3.9 days longer**	**0.17**
Mean annual temperature	**0.01**	**0.24°C warmer**	**0.13**
Annual forest area burned (log. transformed)	**0.01***	**43 000 ha more**	**0.24**
Lilac bloom dates	**0.02**	**8.1 days earlier**	**0.22**
Extreme precipitation–spring	0.06	5.1% greater	0.07
Late fire season start date (1984–2009)	0.07	9.2 days later	0.09
Streamflow–center of timing	0.14	1.9 days earlier	0.04
Snowpack–1 April SWE	0.16	4.4% less	0.03
Extreme precipitation–annual	0.19*	2.9% greater	0.06
Early fire season start date (1984–2009)	0.27*	—	0.01
Salmon migration dates	0.40*	—	0.04
Streamflow–annual volume	0.43*	—	0.03
Stream temperature (1987–2011)	0.49	—	0

d. Indicator results from climate observations

1) TEMPERATURE AND GROWING SEASON

End users exhibited limited interest in mean annual temperature, likely due to its lack of direct impact to the end users. However, mean annual temperature is mechanistically linked to numerous indicators with much higher perceived impact and has served as a hallmark global climate indicator. Historically, mean annual temperature in Idaho shows a nonmonotonic increase, with the last two decades being the warmest on record (1894–2010, Fig. 5a). The 1975–2010 trend analysis revealed a warming trend of 0.24°C decade^{-1} ($p = 0.01$, Table 1), similar to that observed for the broader Pacific Northwest (Abatzoglou et al. 2014b).

Growing season length was among the top indicators desired by survey participants. The growing season in Idaho has increased over the entire period of record (1918–2010, Fig. 5b) with an increase of 3.9 days decade^{-1} from 1975–2010 ($p = 0.01$, Table 1). These results are consistent with observations across the Pacific Northwest (Abatzoglou et al. 2014b) and broader United States (Easterling 2002; Vose et al. 2005) and may be explained by increased overnight temperatures during the spring and autumn.

2) PRECIPITATION INTENSITY

The largest single-day precipitation total in spring (MAM) increased by 5.1% decade^{-1} over the 1975–2010 period ($p = 0.06$, Fig. 6, Table 1). Data across the state also suggest that the largest single-day annual precipitation amount increased 2.9% decade^{-1} over the 1975–2010 period ($p = 0.19$, Table 1). This is similar to findings that total precipitation over the contiguous United States has increased from 1910 to 1996, with 53% of the increase coming from the most intense (upper 10%) of precipitation events (Karl and Knight 1998).

3) SNOWPACK

The statewide average 1 April snow-water equivalent showed a long-term decrease (Fig. 7). Most notably, this decline is seen over the latter half of the twentieth century, which mirrors trends across the western United States (e.g., Mote et al. 2005). However, decreases in SWE of 4.4% decade^{-1} from 1975–2010 were not significant ($p = 0.16$, Table 1) in Idaho. Similarly, trends in the fraction of precipitation falling as snow in the Owyhee Mountains of southwestern Idaho have shown decreases over the last several decades (Nayak et al. 2010). This decrease in the percentage of annual precipitation occurring as snowfall is consistent with similar trends across the western United States since 1950 (e.g., Knowles et al. 2006; Abatzoglou 2011).

e. Indicator results from hydrologic systems

1) STREAMFLOW

Statewide, the center of timing (CT) for streamflow, which is defined as the day of the year when 50% of the water-year's streamflow has occurred, advanced from 1950 to 2005 (Fig. 8a, Table 1). Total volumetric water-year streamflow decreased during the 1950–2005 period (Fig. 8b, Table 1), similar to what others have found (Luce and Holden 2009; Clark 2010). For the shorter time period of analysis from 1975 to 2010, the CT of streamflow was 1.9 days earlier per decade ($p = 0.14$, Table 1). No trend was observed for volumetric water-year streamflow from 1975 to 2010 after accounting for autocorrelation (p_auto = 0.43). Since interannual variability in volumetric streamflow is closely linked to annual precipitation across the region (Abatzoglou et al. 2014a), it is subject to high interannual variability not directly associated with rising temperatures, making trends hard to detect within this 35-yr analysis period.

Additionally, as some subbasins exist at higher and lower elevations, the influence of the transition from snow to rain over time will have a varying effect on the landscape that may be difficult to detect in this statewide-integrated analysis.

2) STREAM TEMPERATURE

Mean annual stream temperature increased approximately 0.14°C decade^{-1}, with a total increase of 0.55°C over the 1970–2011 period of record (Fig. 8c, Table 1). When analyzed over the only period of available near-continuous data from 1987 to 2010, no significant trend was found for stream temperature changes ($p = 0.49$, Table 1). Since stream temperature is influenced not only by atmospheric conditions (e.g., solar radiation, air temperature, precipitation), but also by streamflow (discharge, friction, turbulence), physiography (slope, aspect, elevation, geology, riparian vegetation), and streambed properties (sediment, hyporheic exchange, groundwater), this make trends due to climatic drivers more challenging to detect (Caissie 2006).

f. Indicator results from ecological systems

1) PHENOLOGY

Lilacs bloomed increasingly earlier from 1957 to 1993 (Fig. 9a, Table 1). Over the period of trend analysis (1975–93), lilacs bloomed 8.1 days earlier per decade ($p = 0.02$), similar to elsewhere in the United States (Cayan et al. 2001; Schwartz et al. 2006; Betts 2011). In contrast, there was no change in timing of salmon upstream migration from 1975 to 2010 once we accounted for autocorrelation (p_auto = 0.40; Fig. 9b, Table 1). Timing of salmon migration is indirectly affected by climate via stream temperature and changes in the seasonal duration and intensity of flow regimes, but is also controlled by other ecological factors (McCullough 1999; Crozier and Zabel 2006). Therefore, any relationship may be difficult to detect.

For mountain bluebirds, earliest and median egg dates were related directly to mean April temperatures near the site (Fig. 9c). For every 1°C increase in mean April temperature, the earliest egg date was approximately 4 days earlier ($p < 0.01$, $R^2 = 0.45$) and the median egg date was approximately 3 days earlier ($p = 0.01$, $R^2 = 0.34$). These results corroborate other analyses of nest initiation and temperature (Dunn and Winkler 1999; Dolenec and Dolenec 2011; Dolenec et al. 2011).

2) WILDLAND FIRE

In Idaho, more forest area burned early (1910–35) and late (1984–2009) than in the middle of the twentieth century (Fig. 10a, Table 1; see Morgan et al. 2008). During 1975–2009, area burned increased by 43 000 ha decade^{-1} across Idaho forests (p_auto = 0.01). The discovery date of the last large fire each year (>404 ha) was delayed by 9.2 days decade^{-1} ($p = 0.07$, Fig. 10b, Table 1) over the 1984–2009 analysis period of available data. In contrast, no trend was observed in early fire season discovery dates (p_auto = 0.27, Fig. 10b, Table 1). When the annual length of the fire season is calculated by using both the earliest and latest discovery dates as the annual starting and end points, fire seasons are becoming longer by approximately 19 days decade^{-1} in forests over the past 25 years (Fig. 10b).

g. Summary of indicator findings

We found significant statewide trends ($p < 0.05$) for several indicators over the 1975–2010 period (Table 1). Mean annual air temperature has increased, growing seasons have become longer, lilacs have bloomed earlier, and more forest area has burned over time. We identified additional nonsignificant trends with lower levels of confidence ($0.05 < p < 0.17$) indicating higher maximum daily spring precipitation, earlier peak streamflow, decreased 1 April SWE, and a longer fire season measured as the late season fire discovery date (Table 1). In contrast, other indicators, including annual volumetric streamflow, timing of sockeye salmon migration, mean annual stream temperature, and early season fire discovery date, did not exhibit detectable trends from 1975 to 2010 ($p > 0.26$; Table 1). The lack of a trend in these latter indicators does not necessarily mean they are insensitive to anthropogenic warming. Alternatively, the possibility exists that 1) controlling factors aside from temperature are important drivers of these variables and/or 2) the observational period 1975–2010 was too short and the interannual variability too large to exhibit a strong change over the period of record.

The cumulative effects of climate change are expected to be various and compounded, particularly in some years due to extreme events. This interannual variability and extremes may be more important to some end users than mean values. For instance, in 2000, 2003, and 2007, fires were so widespread in Idaho that lives and property were widely threatened, costs of fire suppression were high, and both national and state firefighting resources were nearly inadequate to meet demands. The coincidence of extreme values for other indicators makes such years more challenging for natural resource management. In the same years (2000, 2003, and 2007) annual temperatures were high, the growing season was long, spring precipitation was low, 1 April SWE was low, peak streamflow was early, volumetric streamflow was low, stream temperatures were high, and the fire season extended late into the fall (Figs. 5–10). These combined effects can adversely impact ecosystems, recreation, and other ecosystem goods and services.

5. Statewide synthesis of survey and indicator findings

End users, including natural resource professionals and decision makers in Idaho, seek a variety of climate change assessment information. Of the top four climate change impacts highlighted by survey respondents (water availability, drought, plant productivity, and wildland fire), we were only able to obtain historical data to address water availability, drought, and wildland fire. First, the timing of in-stream water availability advanced with the CT of streamflow moving earlier into the year, especially when the observed 1 April SWE is low. Although we detected no trend in annual water-year volumetric streamflow from 1975 to 2005, longer-term trends from other studies (which include pre-1975 data) suggest a significant decrease in the volume of annual streamflow (Luce and Holden 2009; Clark 2010; Luce et al. 2013). Second, annual forest area burned increased over the 1975–2010 time period and the length of the wildfire season has increased by over a month. Unlike water- and fire-related impacts, readily available historical time series datasets for plant productivity information were not found within the state.

The top three direct measures of climate desired by respondents were precipitation focused. Our biophysical findings addressed respondent interests about precipitation trends through analysis focused on changes in extremes. Results indicate increases in intensity of precipitation, with the highest increase in the intensity of spring precipitation over the 1975–2010 period statewide.

Despite the diverse data reported here, gaps remain. First, we lack information about several other key variables identified by end users within Idaho, including distribution of plant and animal species and timing of outdoor recreation windows. Spatial resolution could also be improved for the biophysical datasets derived from only one location (e.g., stream temperature, etc.) through increased monitoring programs, some of which are already underway but currently lack long-term records (Isaak et al. 2012).

In this paper, we demonstrate the utility of involving stakeholders in identifying climate-related information needs through a low-cost, efficient tool. If more precision and greater ability to generalize to a population are desired, this technique could easily be expanded to include random samples of populations of interest. Despite these limitations, pairing key end-user needs with a wide range of available biophysical data provides an example of a novel interdisciplinary framework for indicator-focused climate change assessments.

6. Advancing an interdisciplinary assessment framework

With rapid biophysical changes occurring across Idaho and the globe, policy makers and land managers are increasingly seeking to understand the effects of our changing climate. The inherent uncertainty, lack of immediacy, and current paucity of evidence of direct impacts of climate change can impede effective communication between land managers and the public regarding the anticipated changes and potential management options (Moser 2010). Effective action depends on understanding regional and local implications of climate science through an interdisciplinary lens that accounts for the needs of end users, who range from city water managers to wildlife professionals. Thus, we provide this interdisciplinary case example for indicator-focused climate change assessment. We use Idaho-specific climate change science and a survey of end-user needs as a clear and targeted case example that highlights the topics that our intended audience is shown to value and understand (Nisbet and Kotcher 2009), improving the likelihood of both end-user acceptance and use of the science for policy and management decisions.

Using biophysical climate indicators to assess the impacts of climate change is difficult because of their varying levels of control by direct climate metrics (i.e., changes in temperature and precipitation). This level of control, or *biophysical complexity* in relation to climate, reflects the degree to which indicators are mechanistically controlled by, and therefore reflective of, regional climate. When choosing indicators for this local-to-regional scale climate change assessment, the *perceived importance* (i.e., perceived climate change impacts and data needs) of the indicator datasets to eventual end users was considered so as to make the final product (i.e., the regional climate change assessment) as useful as possible. This type of approach—using key informants to screen indicators for their utility—enhances the likelihood that science will inform and improve future resource management.

Our survey results qualitatively indicate differences in the *perceived importance* of certain indicators over others from the perspective of end users (*y* axis of Fig. 11, derived from Fig. 2 and 3), whereas the *biophysical complexity* of an indicator (*x* axis of Fig. 11, derived from Fig. 1) is related to the relative influence of direct climate forcings (e.g., temperature) versus other,

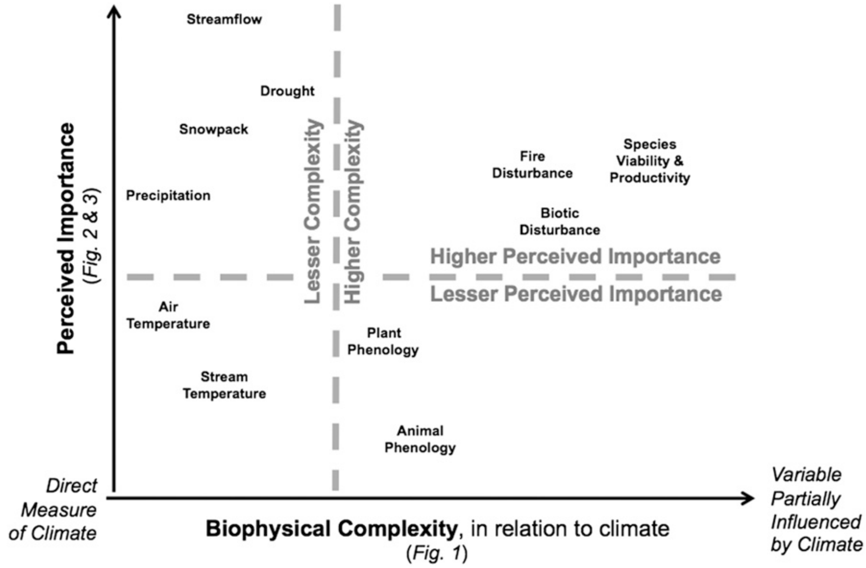

FIG. 11. Conceptual model useful when considering which climate change indicators to focus research and/or outreach efforts upon for local- to-regional-scale assessments. Levels of biophysical complexity and perceived importance are qualitatively derived from differences highlighted in Fig. 1 and Figs. 2 and 3, respectively.

non-climate-related, mechanisms (e.g., ecological competition, human manipulation) controlling the variable. Within this two-dimensional conceptualization, indicators can be delineated into four quadrants that can help others conceptualize social and biophysical trade-offs when evaluating an indicator for possible inclusion in a climate assessment (Fig. 11).

In this case, indicators grouped within the zone of highest perceived importance and lowest biophysical complexity are snowpack, streamflow, drought, and precipitation. These likely rank high in perceived importance because they are linked to water limitations and—since under a warming global climate, water limitation is of much higher concern than energy limitation—these indicators are some of the most important to end users in water-limited regions, such as our Idaho case example. Furthermore, indicators that are low in perceived importance and low in biophysical complexity (e.g., temperature metrics) are biophysical variables that people may have little control to impact locally; although extreme levels of air temperature and stream temperature may be of concern, a general warming trend is of much less perceived importance to end users than issues of water limitation within our case example. However, in other regions (e.g., desert cities with urban heat islands), results of such analysis might reveal temperature increase as being of high perceived importance.

Indicators high in both perceived importance and biophysical complexity (fire and productivity related) are likely of higher perceived importance to people because they are tangibly visible and potentially harmful (e.g., destruction of land/property or loss of food). In addition, on account of the high level of biophysical complexity these types of indicators are some of the greatest challenges for the research community to assess in relation to climate. Therefore, more research effort needs to be devoted to understanding how they are likely to be impacted by climate change, while also considering other controls beyond climate (e.g., fuel loading, land management, global economics, ecological drivers).

This basic framework developed through our Idaho case example, along with national-scale insights (USGCRP 2011a), will help others as they decide how to create local- to-regional-scale climate change assessments that overlap social importance with biophysical changes. By surveying the relevant end users, the types of variables available and most pertinent to them can be considered in conjunction with their level of complexity connecting the biophysical variable to climate. With the use of such a framework and engagement of end users from the onset, local- to regional-scale climate change assessments worldwide can strongly increase the likelihood that they are applied by the people making critical decisions that shape and prepare their landscapes for the future.

Acknowledgments. We are sincerely grateful to Al Larson for collecting and providing the mountain bluebird dataset. Lilac data were provided by the USA National Phenology Network through Joseph M. Caprio and Mark D. Schwartz. Jeff Hicke provided valuable analysis support and improvements to the manuscript. Additionally, we are grateful for the following funding: J. Blades, J. Holbrook, K. Kemp, Z. Klos, R. Niemeyer, and A. Suazo were funded by the National Science Foundation's (NSF) Integrative Graduate Education and Research Traineeship (0903479); V. Jansen was supported by a National Aeronautics and Space Administration Grant (NNX10AT77A); T. Magney was supported by the USDA-NIFA (2011-637003-3034); Z. Klos was also supported by the NSF's Graduate Research Fellowship Program (2010100816); C. Walsh was supported by USDA-NIFA (2011-68002-30191); and T. Link was supported by NSF CBET (0854553). Fire-related research was supported in part by USFS (04-JV-11222048021), the USDA/USDI Joint Fire Science Program (03-1-1-07), and the University of Idaho. This publication was also made possible by the NSF Idaho EPSCoR Program (IIA-1301792) and by the National Science Foundation (EPS-0814387).

REFERENCES

Abatzoglou, J. T., 2011: Influence of the PNA on declining mountain snowpack in the western United States. *Int. J. Climatol.,* **31,** 1135–1142, doi:10.1002/joc.2137.

——, R. Barbero, J. W. Wolf, and Z. Holden, 2014a: Tracking interannual streamflow variability with drought indices in the U.S. Pacific Northwest. *J. Hydrometeor.,* **15,** 1900–1912, doi:10.1175/JHM-D-13-0167.1.

——, D. E. Rupp, and P. W. Mote, 2014b: Seasonal climate variability and change in the Pacific Northwest of the United States. *J. Climate,* **27,** 2125–2142, doi:10.1175/JCLI-D-13-00218.1.

Berndtson, K., and Coauthors, 2007: Grand challenges in global health: Ethical, social, and cultural issues based on key informant perspectives. *PLoS Med.,* **4** (9), e268, doi:10.1371/journal.pmed.0040268.

Betts, A. K., 2011: Vermont climate change indicators. *Wea. Climate Soc.,* **3,** 106–115, doi:10.1175/2011WCAS1096.1.

Blunden, J., and D. S. Arndt, Eds., 2013: State of the Climate in 2012. *Bull. Amer. Meteor. Soc.,* **94,** S1–S258.

Caissie, D., 2006: The thermal regime of rivers: A review. *Freshwater Biol.,* **51,** 1389–1406, doi:10.1111/j.1365-2427.2006.01597.x.

Cayan, D. R., S. A. Kammerdiener, M. D. Dettinger, J. M. Caprio, and D. H. Peterson, 2001: Changes in the onset of spring in the western United States. *Bull. Amer. Meteor. Soc.,* **82,** 399–415, doi:10.1175/1520-0477(2001)082<0399:CITOOS>2.3.CO;2.

Clark, G. M., 2010: Changes in patterns of streamflow from unregulated watersheds in Idaho, western Wyoming, and northern Nevada. *J. Amer. Water Resour. Assoc.,* **46,** 486–497.

Cohen, S. J., 1997: Scientist–stakeholder collaboration in integrated assessment of climate change: Lessons from a case study of northwest Canada. *Environ. Model. Assess.,* **2,** 281–293, doi:10.1023/A:1019077814917.

Collins, B. M., P. N. Omi, and P. L. Chapman, 2006: Regional relationships between climate and wildfire-burned area in the Interior West, USA. *Can. J. For. Res.,* **36,** 699–709, doi:10.1139/x05-264.

Coyne, I. T., 1997: Sampling in qualitative research. Purposeful and theoretical sampling; merging or clear boundaries? *J. Adv. Nurs.,* **26,** 623–630, doi:10.1046/j.1365-2648.1997.t01-25-00999.x.

Craghan, M., 2012: Climate ready estuaries: 2012 progress report. U.S. Environmental Protection Agency, EPA-842-R-13-002, 24 pp. [Available online at http://www2.epa.gov/cre/climate-ready-estuaries-progress-reports.]

Creswell, J. W., 2009: *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 3rd ed. Sage Publications, 296 pp.

Crozier, L. G., and R. W. Zabel, 2006: Climate impacts at multiple scales: Evidence for differential population responses in juvenile Chinook salmon. *J. Anim. Ecol.,* **75,** 1100–1109, doi:10.1111/j.1365-2656.2006.01130.x.

Diggle, P. J., P. Heagerty, K. Y. Liang, and S. L. Zeger, 2002: *Analysis of Longitudinal Data*. 2nd ed. Oxford University Press, 379 pp.

Dilling, L., and M. C. Lemos, 2011: Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environ. Change,* **21,** 680–689, doi:10.1016/j.gloenvcha.2010.11.006.

Dillman, D. A., J. D. Smyth, and L. M. Christian, 2009: *Internet, Mail, and Mixed-Mode Surveys: The Tailored Design Method*. 3rd ed. John Wiley and Sons, 499 pp.

Dolenec, Z., and P. Dolenec, 2011: Influence of the local spring warming on the breeding phenology in blackcap (*Sylvia atricapilla*) in Croatia. *J. Environ. Biol.,* **32,** 625–627.

——, ——, and A. P. Møller, 2011: Warmer springs, laying date and clutch size of tree sparrows, *Passer montanus,* in Croatia. *Curr. Zool.,* **57,** 414–418.

Dunn, P. O., and D. W. Winkler, 1999: Climate change has affected the breeding date of tree swallows throughout North America. *Proc. Roy. Soc. London,* **266,** 2487–2490, doi:10.1098/rspb.1999.0950.

Easterling, D. R., 2002: Recent changes in frost days and the frost-free season in the United States. *Bull. Amer. Meteor. Soc.,* **83,** 1327–1332, doi:10.1175/1520-0477(2002)083<1327:RCIFDA>2.3.CO;2.

EPA, 2010: Climate change indicators in the United States. U.S. Environmental Protection Agency Rep. EPA-430-R-10-007, 80 pp. [Available online at http://www.epa.gov/climatechange/science/indicators/.]

Gavin, D. G., A. C. G. Henderson, K. S. Westover, S. C. Fritz, I. R. Walker, M. J. Leng, and F. S. Hu, 2011: Abrupt Holocene climate change and potential response to solar forcing in western Canada. *Quat. Sci. Rev.,* **30,** 1243–1255, doi:10.1016/j.quascirev.2011.03.003.

Gorte, R. W., C. H. Vincent, L. A. Hanson, and M. R. Rosenblum, 2012: Federal land ownership: Overview and data. Congressional Research Service, 24 pp. [Available online at https://fas.org/sgp/crs/misc/R42346.pdf.]

Gotelli, N. J., and A. M. Ellison, 2004: *The Analysis of Multivariate Data: A Primer of Ecological Statistics.* 1st ed. Sinauer, 510 pp.

Hayhoe, K., and Coauthors, 2007: Past and future changes in climate and hydrological indicators in the US northeast. *Climate Dyn.,* **28,** 381–407, doi:10.1007/s00382-006-0187-8.

Hulme, M., and J. Turnpenny, 2004: Understanding and managing climate change: The UK experience. *Geogr. J.,* **170,** 105–115, doi:10.1111/j.0016-7398.2004.00112.x.

IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Cambridge University Press, 1132 pp. [Available online at http://www.

ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-PartA_FINAL.pdf.]

Isaak, D. J., S. Wollrab, D. Horan, and G. Chandler, 2012: Climate change effects on stream and river temperatures across the northwest U.S. from 1980–2009 and implications for salmonid fishes. *Climatic Change,* **113,** 499–524, doi:10.1007/s10584-011-0326-z.

Karl, T. R., and R. W. Knight, 1998: Secular trends of precipitation amount, frequency, and intensity in the United States. *Bull. Amer. Meteor. Soc.,* **79,** 231–241, doi:10.1175/1520-0477(1998)079<0231:STOPAF>2.0.CO;2.

Kiem, A. S., and E. K. Austin, 2013: Disconnect between science and end-users as a barrier to climate change adaptation. *Climate Res.,* **58,** 29–41, doi:10.3354/cr01181.

Knowles, N., M. D. Dettinger, and D. R. Cayan, 2006: Trends in snowfall versus rainfall in the western United States. *J. Climate,* **19,** 4545–4559, doi:10.1175/JCLI3850.1.

Lean, J. L., 2010: Cycles and trends in solar irradiance and climate. *Wiley Interdiscip. Rev.: Climate Change,* **1,** 111–122, doi:10.1002/wcc.18.

Leiserowitz, A. A., 2005: American risk perceptions: Is climate change dangerous? *Risk Anal.,* **25,** 1433–1442, doi:10.1111/j.1540-6261.2005.00690.x.

——, and N. Smith, 2010: Knowledge of climate change across global warming's six Americas. Yale Project on Climate Change Communication, 81 pp. [Available online at http://environment.yale.edu/climate-communication/article/knowledge-of-climate-change-across-global-warmings-six-americas1.]

——, E. Maibach, C. Roser-Renouf, and N. Smith, 2011: Global warming's six Americas in May 2011. Yale Project on Climate Change Communication, 57 pp. [Available online at http://environment.yale.edu/climate-communication/article/SixAmericasMay2011.]

Lubell, M., A. Vedlitz, S. Zahran, and L. T. Alston, 2006: Collective action, environmental activism, and air quality policy. *Political Res. Quart.,* **59,** 149–160, doi:10.1177/106591290605900113.

Luce, C. H., and Z. A. Holden, 2009: Declining annual streamflow distributions in the Pacific Northwest United States, 1948–2006. *Geophys. Res. Lett.,* **36,** L16401, doi:10.1029/2009GL039407.

——, J. T. Abatzoglou, and Z. A. Holden, 2013: The missing mountain water: Slower westerlies decrease orographic enhancement in the Pacific Northwest USA. *Science,* **342,** 1360–1364, doi:10.1126/science.1242335.

Mackun, P., and S. Wilson, 2011: Population distribution and change: 2000 to 2010. U.S. Census Bureau. [Available online at http://blogs.census.gov/2011/03/24/population-distribution-and-change-2000-to-2010/.]

McCullough, D. A., 1999: A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. U.S. Environmental Protection Agency Rep. EPA-910-R-99-010, 279 pp.

McKenna, S. A., and D. S. Main, 2013: The role and influence of key informants in community-engaged research: A critical perspective. *Action Res.,* **11,** 113–124, doi:10.1177/1476750312473342.

Melillo, J. M., T. C. Richmond, and G. W. Yohe, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 841 pp.

Menne, M. J., C. N. Williams, and R. S. Vose, 2009: The U.S. Historical Climatology Network monthly temperature data, version 2. *Bull. Amer. Meteor. Soc.,* **90,** 993–1007, doi:10.1175/2008BAMS2613.1.

Meyer, R., 2012: Finding the true value of US climate science. *Nature,* **482,** 133, doi:10.1038/482133a.

Morgan, P., E. K. Heyerdahl, and C. E. Gibson, 2008: Multi-season climate synchronized forest fires throughout the 20th century, northern Rockies, USA. *Ecology,* **89,** 717–728, doi:10.1890/06-2049.1.

Moser, S. C., 2010: Communicating climate change: History, challenges, process and future directions. *Wiley Interdiscip. Rev.: Climate Change,* **1,** 31–53, doi:10.1002/wcc.11.

Moss, R., and Coauthors, 2014: Decision support: Connecting science, risk perception, and decisions. *Climate Change Impacts in the United States: The Third National Climate Assessment,* J. M. Melillo, T. C. Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 620–647.

Mote, P. W., 2006: Climate-driven variability and trends in mountain snowpack in western North America. *J. Climate,* **19,** 6209–6220, doi:10.1175/JCLI3971.1.

——, A. F. Hamlet, M. P. Clark, and D. P. Lettenmaier, 2005: Declining mountain snowpack in western North America. *Bull. Amer. Meteor. Soc.,* **86,** 39–49, doi:10.1175/BAMS-86-1-39.

National Research Council, 2010: *Monitoring Climate Change Impacts: Metrics at the Intersection of the Human and Earth Systems.* National Academies Press, 110 pp.

Nayak, A., D. Marks, D. G. Chandler, and M. Seyfried, 2010: Long-term snow, climate, and streamflow trends at the Reynolds Creek Experimental Watershed, Owyhee Mountains, Idaho, United States. *Water Resour. Res.,* **46,** W06519, doi:10.1029/2008WR007525.

Nisbet, M. C., and J. E. Kotcher, 2009: A two-step flow of influence? Opinion-leader campaigns on climate change. *Sci. Commun.,* **30,** 328–354, doi:10.1177/1075547008328797.

Osborn, T. J., M. Hulme, P. D. Jones, and T. A. Basnett, 2000: Observed trends in the daily intensity of United Kingdom precipitation. *Int. J. Climatol.,* **20,** 347–364, doi:10.1002/(SICI)1097-0088(20000330)20:4<347::AID-JOC475>3.0.CO;2-C.

Patton, M. Q., 1990: *Qualitative Evaluation and Research Methods*. 2nd ed. Sage, 532 pp.

Pederson, G. T., L. J. Graumlich, D. B. Fagre, T. Kipfer, and C. C. Muhlfeld, 2010: A century of climate and ecosystem change in western Montana: What do temperature trends portend? *Climatic Change,* **98,** 133–154, doi:10.1007/s10584-009-9642-y.

Power, H. W., 1966: Biology of the mountain bluebird in Montana. *Condor,* **68,** 351–371.

——, and M. P. Lombardo, 1996: Mountain bluebird (*Sialia currucoides*). The birds of North America online, A. Poole, Ed., Cornell Lab of Ornithology, accessed 15 March 2012. [Available online at http://bna.birds.cornell.edu/bna/species/222.]

Ritchie, J., J. Lewis, and E. Gillian, 2003: Designing and selecting samples. *Qualitative Research Practice: A Guide for Social Science Students and Researchers,* Sage, 77–108.

Salancik, G. R., 1984: On priming, consistency, and order effects in job attitude assessment: With a note on current research. *J. Manage.,* **10,** 250–254.

Sandelowski, M., 1995: Sample size in qualitative research. *Res. Nurs. Health,* **18,** 179–183, doi:10.1002/nur.4770180211.

Sarewitz, D., and R. A. Pielke Jr., 2007: The neglected heart of science policy: Reconciling supply of and demand for science. *Environ. Sci. Policy,* **10,** 5–16, doi:10.1016/j.envsci.2006.10.001.

Schwartz, M. D., and J. M. Caprio, 2003: North American first leaf and first bloom lilac phenology data. IGBP PAGES, World Data Center for Paleoclimatology Data, Contribution Series 2003-078, NOAA/NGDC Paleoclimatology Program, accessed 15 February 2012. [Available online at ftp://ftp.ncdc.noaa.gov/pub/data/paleo/phenology/north_america_lilac.txt.]

——, R. Ahas, and A. Aasa, 2006: Onset of spring starting earlier across the Northern Hemisphere. *Global Change Biol.,* **12,** 343–351, doi:10.1111/j.1365-2486.2005.01097.x.

Slack, J. R., and J. M. Landwehr, 1992: Hydro-climatic data network: U.S. Geological Survey streamflow dataset for the United States for the study of climate variations, 1874–1988. U.S. Geological Survey, Open-file Rep. 92-129, 193 pp. [Available online at http://pubs.er.usgs.gov/publication/ofr92129.]

Stoutenborough, J. W., S. G. Sturgess, and A. Vedlitz, 2013: Knowledge, risk, and policy support: Public perceptions of nuclear power. *Energy Policy,* **62,** 176–184, doi:10.1016/j.enpol.2013.06.098.

USGCRP, 2011a: Monitoring climate change and its impacts: Physical climate indicators. National Climate Assessment Report Series, Vol. 5B, U.S. Global Change Research Program, 30 pp.

——, 2011b: Ecosystem responses to climate change: Selecting indicators and integrating observational networks. National Climate Assessment Report Series, Vol. 5A, U.S. Global Change Research Program, 32 pp.

——, 2012: Societal indicators for the National Climate Assessment. National Climate Assessment Report Series, Vol. 5C, U.S. Global Change Research Program, 120 pp.

Vera, C., and Coauthors, 2010: Needs assessment for climate information on decadal timescales and longer. *Procedia Environ. Sci.,* **1,** 275–286, doi:10.1016/j.proenv.2010.09.017.

Vose, R. S., D. R. Easterling, and B. Gleason, 2005: Maximum and minimum temperature trends for the globe: An update through 2004. *Geophys. Res. Lett.,* **32,** L23822, doi:10.1029/2005GL024379.

Williams, A. N., and Coauthors, 2001: Global climate change: Implications of extreme events for soil conservation strategies and crop production in the Midwestern United States. *Proc. 2001 Int. Soil Conservation Organization Meeting,* West Lafayette, IN, ISCO, 509–515.

Wolter, K., and M. S. Timlin, 1993: Monitoring ENSO in COADS with a seasonally adjusted principal component index. *Proc. 17th Climate Diagnostics Workshop,* Norman, OK, NOAA, 52–57.