










Impacts of climate change on multiple use management of Bureau of Land Management land in the Intermountain West, USA

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Abstract. Although natural resource managers are concerned about climate change, many are unable to adequately incorporate climate change science into their adaptation strategies or management plans, and are not always aware of or do not always employ the most current scientific knowledge. One of the most prominent natural resource management agencies in the United States is the Bureau of Land Management (BLM), which is tasked with managing over 248 million acres (>1 million km²) of public lands for multiple, often conflicting, uses. Climate change will affect the sustainability of many of these land uses and could further increase conflicts between them. As such, the purpose of our study was to determine the extent to which climate change will affect public land uses, and whether the BLM is managing for such predicted effects. To do so, we first conducted a systematic review of peer-reviewed literature that discussed potential impacts of climate change on the multiple land uses the BLM manages in the Intermountain West, USA, and then expanded these results with a synthesis of projected vegetation changes. Finally, we conducted a content analysis of BLM Resource Management Plans in order to determine how climate change is explicitly addressed by BLM managers, and whether such plans reflect changes predicted by the scientific literature. We found that active resource use generally threatens intrinsic values such as conservation and ecosystem services on BLM land, and climate change is expected to exacerbate these threats in numerous ways. Additionally, our synthesis of vegetation modeling suggests substantial changes in vegetation due to climate change. However, BLM plans rarely referred to climate change explicitly and did not reflect the results of the literature review or vegetation model synthesis. Our results suggest there is a disconnect between management of BLM lands and the best available science on climate change. We recommend that the BLM actively integrates such research into on-the-ground management plans and activities, and that researchers studying the effects of climate change make a more robust effort to understand the practices and policies of public land management in order to effectively communicate the management significance of their findings.

Key words: Bureau of Land Management; climate change; ecosystem services; Intermountain West; natural resource management.

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INTRODUCTION

Climate change will impact the health and resilience of ecosystems across the globe (IPCC 2014, 2018, USGCRP 2017, 2018). In the Intermountain West (IMW) region of the United States, climate change poses numerous threats to sustainable management of public lands (Archie et al. 2012). Public land managers in this region are generally aware of and concerned about climate change, but express uncertainty about how to adequately plan for it (Murphy et al. 2015, Wyborn et al. 2015). This is hardly surprising considering that predictions from the scientific community are often provided on spatial and temporal scales that differ from the scales at which public land management policies and procedures are enacted (Wyborn et al. 2015). Furthermore, disconnects between land manager awareness and the most up-to-date academic research (Archie 2014, Carter et al. 2020), as well as institutional constraints and limited resources, make it difficult to plan for climate change (Cheng and Randall-Parker 2017, Morisette et al. 2017). The Bureau of Land Management (BLM) manages more public land in the IMW than any other natural resource management agency (Hardy Vincent et al. 2020). As such, this paper is aimed at examining if these challenges affect BLM through a systematic review of the scientific literature on climate change in the IMW, a synthesis of regional vegetation modeling studies, and a content analysis of BLM Resource Management Plans (RMPs).

As the largest public land management agency in the United States (Skillen 2009), the BLM is tasked with monitoring the condition of all 248 million acres under its supervision while managing for multiple (FLPMA 43 U.S.C. §§1701–1736, 1737–1782, 1976), often conflicting (Danvir 2018), land uses. Based on the Federal Land Policy and Management Act of 1976 (FLPMA), which codifies the structure and priorities of the organization, the BLM is mandated to preserve the multiple uses of public land under its management. Those multiple uses include diverse activities, such as resource extraction, recreation, and

preservation of natural and cultural resources (USDOI BLM 2016). These uses comprise a significant portion of the national economy and provide incalculable non-market value to society (Pederson et al. 2006, Kemp et al. 2015). However, managing for multiple uses is fraught with challenges, including conflicts among uses, an incomplete knowledge of complex and constantly evolving ecosystems, and discordant public, private, and political interests (Skillen 2009, Archie 2014, Veblen et al. 2014, Butler et al. 2015, Wyborn et al. 2015).

Climate change is exacerbating the challenges faced by the BLM and, in some cases, causing non-linear and irreversible transitions in ecosystems managed by this agency (Baron et al. 2009, Joyce et al. 2009, West et al. 2009, Ellenwood et al. 2012, McNeeley et al. 2017, Halofsky et al. 2018). Accordingly, all BLM RMPs completed from 2001 to 2017 (Executive Order 13783 issued on 28 March 2017 withdrew all previous requirements that federal agencies plan for climate change) were mandated to consider climate change in their planning by secretarial order (Kemp et al. 2015). Despite this, the extent to which the BLM is altering their management practices in response to observed and future predicted climate change remains unclear (Kemp et al. 2015). Furthermore, we are unaware of a comprehensive assessment of the myriad impacts of climate change on BLM land uses and ecosystems in the IMW.

To illuminate and fill these gaps, our study analyzes climate change research and BLM plans in the IMW, a highly sensitive region that contains 142 million acres of land managed by the BLM (Fig. 1; Hardy Vincent et al. 2017). The IMW includes some of the hottest and driest areas in North America and contains a wide variety of ecosystems, many of which are water-limited, exhibit low primary productivity, and are prone to disturbances such as fire, erosion, and plant invasion (Maestre et al. 2012). Such sensitivity suggests that climate change may dramatically impact IMW ecosystems, potentially threatening effective management. Furthermore,

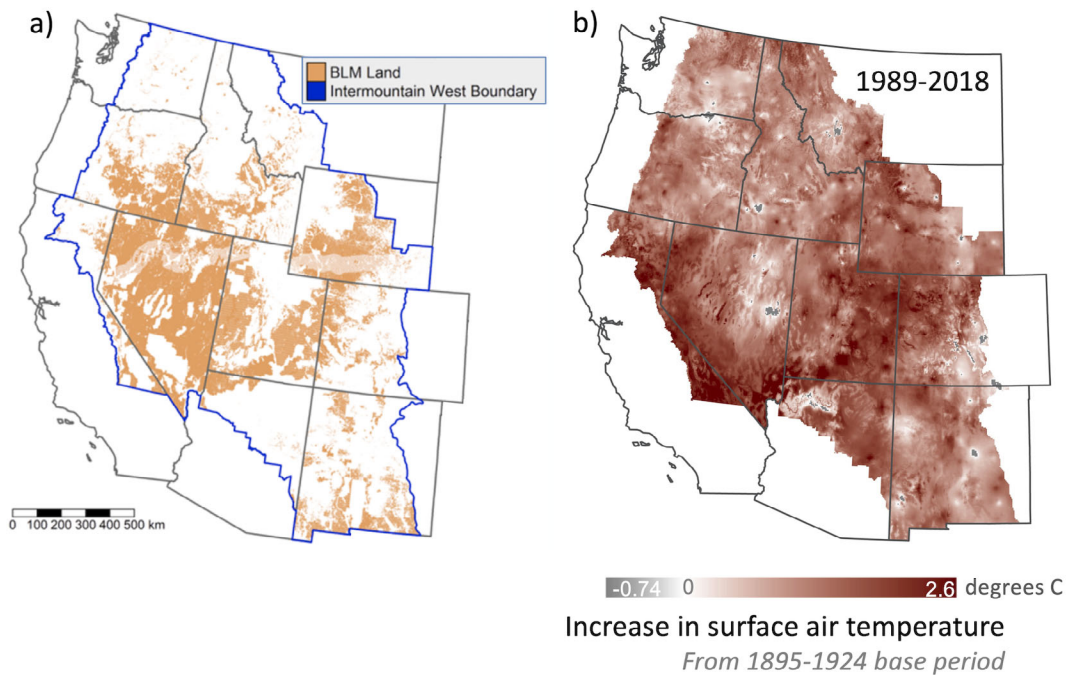


Fig. 1. (a) Our study area includes the Intermountain Western USA (IMW), outlined in blue, and specifically focuses on land managed by the U.S. Bureau of Land Management, highlighted in orange. (b) Observed (interpolated) change in the average surface air temperature (2 meters above surface) between two time periods, comparing 1895–1924 to 1989–2018. Temperature data were synthesized from PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>, Map created 4 June 2019.

as the BLM manages the majority of public land in the IMW (USDOI BLM 2018), a review of their management plans will allow us to determine whether the agency is prepared for and/or capable of adapting to climate change.

With these priorities in mind, our study includes a systematic literature review of peer-reviewed research focused on climate change impacts on land use in the IMW from 2009 to 2018, a synthesis of published models projecting impacts to vegetation in the IMW, and a content analysis of BLM RMPs from field offices throughout the IMW. Specifically, we aim to determine whether the academic literature presents clear implications for land management in the IMW under climate change, and the degree to which BLM offices across the IMW are planning for such expected changes. Our mixed methods analysis addresses the following questions:

1. What climate change impacts on the dominant vegetation types and multiple uses of

BLM land in the IMW are identified in recent peer-reviewed literature?

2. Are climate change and associated impacts explicitly considered in BLM RMPs for the IMW, and do such references match the climate change impacts highlighted in the peer-reviewed literature?

BACKGROUND

Climate change will affect the future sustainability of many of the different uses that the BLM protects and facilitates (Ellenwood et al. 2012), and may increase conflicts over these uses (Halofsky et al. 2018). For example, management of wildlife populations and livestock grazing depends on vegetation composition, which may be affected by climate change (Ziska et al. 2005, Izaurrealde et al. 2011). Such impacts could undermine the sustainability of these land uses, requiring the BLM to adapt management to

continue administering these uses. Furthermore, the inherent uncertainties of predicting localized consequences of climate change (Archie 2014) make it difficult to forecast future challenges with enough precision to be actionable to managers (Kemp et al. 2015).

Climate change in the Intermountain West

The IMW has already experienced considerable warming over the past century. Comparing average temperatures throughout the IMW during the thirty-year period 1989–2018 to the period 1895–1924, land managed by BLM has warmed nearly 0.9°C (Fig. 1). On more local scales, Tang and Arnone (2013) found a similar temperature increase within the Great Basin (1°C increase from 1901 to 2010), and land managed by the BLM in western Colorado, eastern and southern Utah, southern Nevada, and eastern California has experienced particularly significant warming (>2°C). Notably, the BLM also manages land in eastern Nevada, which has cooled slightly during this timeframe, further highlighting the challenges faced in planning for changes in this large and diverse region. Overall, however, climate models are in close agreement that the IMW will experience additional warming under all foreseeable future scenarios (Fig. 2; IPCC 2014, 2018, Frölicher et al. 2014, Palmquist et al. 2016, USGCRP 2017, 2018, Gonzalez et al. 2018).

In addition to temperature, climate models also project changes in water availability. Seasonal snowpack, for instance, provides the vast majority of water for the IMW (Strum et al. 2017, Julander and Clayton 2018), but the projected hotter temperatures will reduce snowpack, the percent of precipitation delivered as snow, and the fraction of snowpack that is converted to streamflow, as well as alter the timing of snowmelt (Cook et al. 2014, Klos et al. 2014, Musselman et al. 2017, Rhoades et al. 2017). Similarly, the probability of decadal to multi-decadal mega-drought increases with hotter temperatures (Ault et al. 2014, 2016, Cook et al. 2015, Prein et al. 2016), and future climate scenarios are predicted to significantly exceed any drought cycles observed in the past millennium throughout the American Southwest (Cook et al. 2015).

Ecosystems in the IMW are also affected by many more nuanced characteristics of the

temperature and water regime, many of which are not well predicted by current climate models (e.g., changes in specific temperature and moisture regimes that serve as critical phenological cues for plants and animals; Bradley et al. 2016, Snyder et al. 2019). The uncertainty associated with such changes will further complicate land management into the future. These complications are even more difficult to address within the current planning rules for the BLM, which makes it difficult for managers to explicitly plan for uncertain climate change effects.

FLPMA, the BLM, and climate change planning from 2001 to 2017

FLPMA (43 U.S.C. §§1701–1736, 1737–1782) established the structure and policy mandate of the BLM to protect a diverse array of uses, which tasks the BLM with balancing the utilization of different resources in a manner that meets the needs of people with different interests (Rose 2016). This multiple use mandate is notoriously challenging due to conflicts between uses and lack of procedural guidance (Ross 2016). Lack of clarity over which land uses to prioritize and vague rules regarding the use of science in planning makes it difficult for the BLM to uphold these numerous policy agendas in their RMPs (Hardy Vincent et al. 2017).

FLPMA requires that the BLM articulates all land management activities and priorities through official plans that are available to the public. The process of writing or significantly overhauling these RMPs requires a period of public comment, where plans can be challenged by stakeholders based on the directive of the U.S. National Environmental Policy Act of 1970 (NEPA 1970, 42 USC §§ 4321–4347). Although the BLM evaluates and amends plans in response to changing environmental, land use, and/or policy conditions, NEPA requires a period of public comment and review if those changes dramatically alter management. As a result, BLM field offices are hesitant to put anything particularly contentious into their plans without clear guidelines (Nave et al. 2020).

As a branch of the U.S. Department of the Interior, the BLM must also follow Secretarial and Executive Orders in a manner that remains consistent with FLPMA (Ross 2006). For instance, in 2001, the Secretary of the Interior signed

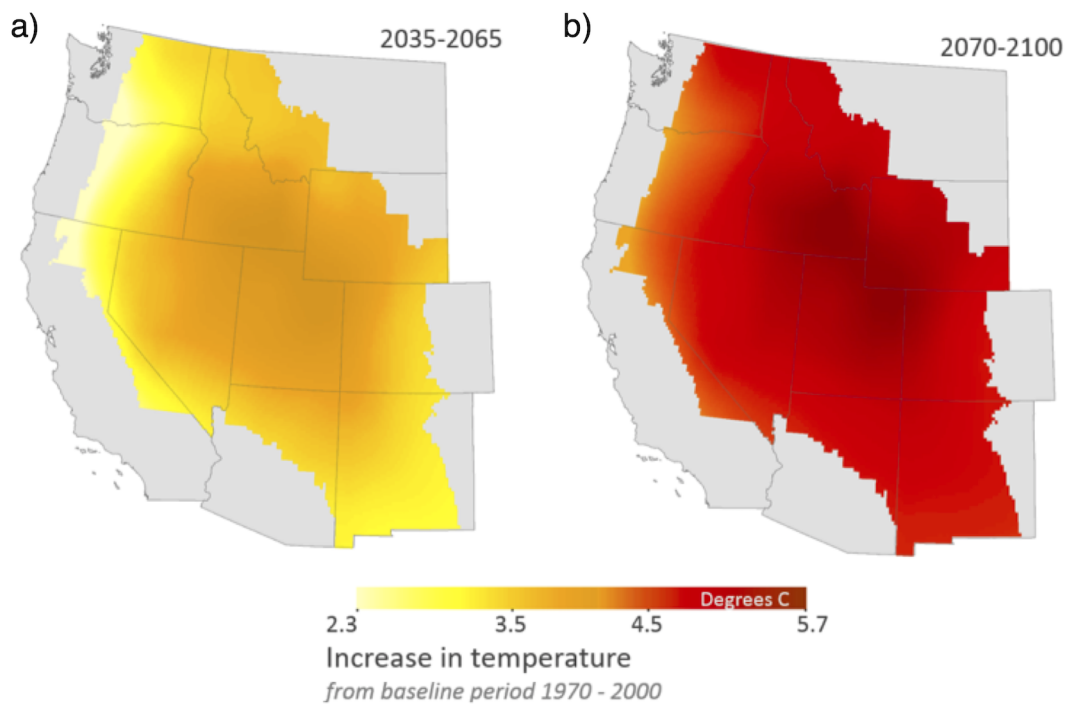


Fig. 2. Future predicted change in mean annual temperature for (a) 2035–2065 and (b) 2070–2100, relative to a 1970–2000 baseline. Data obtained from the World Climate Research Program’s Working Group on Coupled Modelling CMIP5 multi-model ensemble (Maurer et al. 2007) available at: <https://gdo-dcp.ucllnl.org/> (BCSD-CMIP5 Climate Monthly data downloaded for continental U.S.).

Secretarial Order 3226 requiring bureaus, offices, and services within the Department of Interior, to “consider and analyze potential climate change impacts” in planning (SO 3226 2001:1). This order was augmented with numerous Presidential Executive Orders, memoranda, reports, and operational manuals developed between 2013 and 2016 (e.g., EO 13653 of 1 November 2013, “Preparing the United States for the Impacts of Climate Change,” Presidential Memorandum of 3 November 2015, “Mitigating Impacts on Natural Resources from Development and Encouraging Related Private Investment,” Report of the Executive Office of the President of June 2013, “The President’s Climate Action Plan,” and Department of the Interior Departmental Manual Part 523, Chapter 1: Climate Change Policy, dated December 20, 2012).

In an effort to meet such requirements, the BLM released “Advancing Science in the BLM: An Implementation Strategy” in 2015, which asserted that “effective and consistent integration

of the best available science in decision making [sic] is becoming more and more essential for public land management in an era of changing climate. . . and diverse legal challenges” (Kitchell et al. 2015), and more consistent practice throughout the BLM is needed in order to be more effective as an organization (Schadegg 2017). Based on these recommendations (Schadegg 2017), the BLM finalized an attempt to reform their planning process, the Resource Management Planning Rule (43 C.F.R. 1600), in 2016. However, in 2017, President Trump signed a joint resolution overturning the Resource Management Planning Rule, and Interior Secretary Zinke issued a memo to the BLM indicating that the BLM should instead reduce “duplicative and disproportionate [scientific] analyses” (Zinke 2017). Furthermore, the Trump administration overturned Secretarial and Executive Orders to consider climate change (Zinke 2017), and Secretarial Order 3360 rescinded multiple science-based climate change policies (SO 3360, 2017).

Thus, only RMPs written or amended between 2001 and 2017 were required to consider climate change.

METHODS

To answer our research questions, we performed three different analyses. First, we conducted a systematic review of scientific, peer-reviewed literature pertaining to climate change and land use in the IMW. Second, we synthesized the results of models projecting vegetation changes throughout the IMW. Finally, we analyzed the content of RMPs written or revised between 2001 and 2017 within the IMW to determine how the BLM is explicitly managing for climate change. All data and results generated from these analyses are available on HydroShare.

Study area: U.S. Intermountain West (IMW)

The IMW includes areas between the eastern edge of the Rocky Mountains and the eastern edge of the Sierra Nevada and Cascade Mountains, stretching between the borders with Mexico and Canada, and including 140 million acres of land in the states of Washington, Oregon, California, Idaho, Nevada, Utah, Arizona, Montana, Wyoming, Colorado, and New Mexico. We focus our analysis on four ecoregions that encompass the majority of BLM lands in the IMW: The Northern Basin and Range, Central Basin and Range, Wyoming Basin, and Colorado Plateau. These semiarid regions are dominated by sagebrush steppe, pinyon-juniper woodlands, and other shrublands (West and Young 2000).

Systematic literature review

Our systematic literature review was designed to identify recent articles addressing climate change impacts on the various land uses for which the BLM manages. The BLM does not have an official list of these land uses because, under FLMMPA, all uses must be prioritized in management. Based on the most dominant uses managed by the BLM and prior knowledge of their interaction and potential conflicts, we created nine categories: logging/timber, mining, grazing, energy (energy extraction, development, and corridors), recreation, supporting ecosystem services, conservation, historic/cultural values, and wild horse/burro management (Table 1;

USDOI BLM 2016). We recognize that this list is not exhaustive, nor are the categories necessarily exclusive. For instance, conservation is not directly a land use, but rather a land value prioritized in BLM land management. Furthermore, cultural values and recreation are ecosystem services (Millennium Ecosystem Assessment 2005), but we separate them here into their own categories to emphasize their importance outside of the umbrella of ecosystem. The category of supporting ecosystem services refers to the specific recognition of a relationship between ecosystem integrity and various human values rather than a categorization of the full suite of these services, which could refer to all BLM land uses. However, explicit mention of “ecosystem services” in the literature was deemed relevant to our analysis as it recognizes the connection between ecosystem integrity and human benefits (Costanza et al. 2017).

We searched Scopus in February and March 2019 for all articles that contained both a climate change identifier as well as a regional identifier

Table 1. Operational definitions of the land uses analyzed for our systematic literature review.

Land use	Definition
Conservation	Protection of critical habitat, native wildlife and vegetation populations, natural resources, and natural landscapes
Ecosystem services	Direct and indirect contributions of ecosystems to human well-being, including water and air purification, carbon sequestration, and climate regulation
Cultural/historic value	Traditional, spiritual, cultural, and historic values that are tied to natural features or landscapes
Recreation	Outdoor participation on public lands, including camping, hunting, fishing, hiking, boating, cycling, and wildlife viewing
Wild horses & burros	Management and protection of wild horses and burros to ensure healthy populations
Grazing	Domestic livestock (mostly sheep and cattle) use of rangelands
Logging & timber	Harvest of timber for commercial purposes
Energy	Fossil fuel development, extraction, and corridors
Mining	Development and extraction of minerals, including gold, silver, copper, hard rock materials, coal, sand, and gravel

(e.g., climat* AND “*mountain west”; see Appendix S1: Table S1) within the title, abstract, or key words. Our list of climate identifiers was intentionally broad so as to capture all articles that might address climate change impacts, either implicitly or explicitly. After exporting and cleaning the bibliometric data, we searched all abstracts for the nine land uses outlined above and discarded any articles that did not reference at least one of these categories. We also eliminated all articles from 2019, as they only represented two months of publications (January/February) at the time of our analysis, and we felt that our search results would be most readily reproducible if we ended the search with 2018. We also removed articles published prior to 2009 so as to ensure that we captured the most recent climate forecasts, analytical methods, and models. We further winnowed our search by keeping only articles that had a mean annual citation rate of two or more to remove low-impact papers, excluding the 2018 articles, of which we kept all.

We developed a coding protocol to document the focus and relevance of the final set of papers identified in our search, ensuring reliability among coders by checking for consistency and updating our protocol twice. Six different coders determined, based on the body of the text, whether (1) any part of the research took place in the IMW and where, (2) it discussed climate change and its impacts, (3) it discussed management, (4) the BLM was mentioned, (5) any BLM land uses were mentioned, and (6) the paper was relevant to our research questions (see Appendix S2 for coding protocol). After coding the articles, we conducted a thematic analysis by reading each article that included the IMW, mentioned climate change at least once within the body of the text, and mentioned at least one land use ($n = 225$). By reading each article, we were able to go beyond a simple categorization of the literature, and instead present more meaningful insights into the climate change impacts on land use.

Vegetation analysis

As vegetation plays a central role in many BLM activities and concerns, anticipating likely impacts of climate change on vegetation could be crucial for BLM planning. To address this

need, we provide a novel synthesis of recent studies that project vegetation impacts throughout the IMW. We identified studies since 2008 that modeled climate change effects on important vegetation components within the IMW, namely sagebrush (*Artemisia tridentata* Nutt.), cheatgrass (*Bromus tectorum* L.), pinyon-juniper woodlands, and forage production. We only included models which provided spatially explicit results, and addressed lands within the four main ecoregions in the IMW (see *Study area*). If multiple studies reported results from the same model, we only included the original publication of model results (e.g., we only used Schlaepfer et al. 2012 and did not include Schlaepfer et al. 2015) to not double count synonymous results.

These models employ a range of methods and incorporate multiple future emissions scenarios. These disparate inputs may promote variance among model results, potentially limiting their relevance in planning. However, strong agreement between models, despite methodological differences, would increase confidence in their projections and, consequently, their potential to inform management.

To analyze consistency among model projections, we downloaded the highest resolution image showing projected vegetation changes from the selected studies (Appendix S1: Table S2), imported them into ArcMap, and georeferenced them. We used an unsupervised classification in R (R Core Team 2018) to identify pixel groups in these images and then coded these groups based on whether they corresponded to projected decreases, no change, or increases in the original figure. Lastly, we masked these images to only include data from BLM land in the IMW.

We then counted the number of models indicating increases, decreases, or no change at each pixel for each vegetation type, considering only pixels where at least three models made projections. We visualized these counts as RGB images where red intensity was determined by the number of models indicating decreases, green was determined by models indicating increases, and blue was determined by models indicating no change. For more extensive methods and results, see Zimmer et al., unpublished manuscript, at bioRxiv 2020.06.16.154989.

BLM Resource Management Plans

Finally, we systematically analyzed all 44 BLM RMPs from within the IMW published between 2001 and 2017 to determine the extent to which these legally binding plans consider and provide potential adaptation strategies for climate change. We chose this time frame because these are the years when the BLM was explicitly required to consider climate change. We downloaded plans from the BLM National NEPA Register (<https://eplanning.blm.gov/eplanning-ui/home>; Appendix S1: Table S3) and analyzed them in two phases.

First, we used Nvivo to search each plan for the presence of the following keywords: “climate,” “warming,” “extreme,” “weather,” “greenhouse gas,” “global,” “IPCC,” and “GHG” (Appendix S1: Table S4). Keywords were paired down from a longer phrase (e.g., “climate change,” “global warming,” “warming temperature,” or “global extremes.”) and left in the singular form so as not to exclude other variations of these words that refer to climate change. These keywords differ slightly from those used in the literature review because we were searching for explicit recognition of climate change by the BLM in these plans. For instance, although the plans may refer to drought adaptation, these systems experience drought regardless of climate change, and we wanted to ensure that we were only coding explicit and unambiguous references to climate change. Therefore, after first searching for climate change, we then categorized the context (e.g., drought adaptation).

Whenever a climate change keyword was found, the whole paragraph to which it belonged was coded. If the word was found in a table, the whole table was selected, unless the table included paragraphs within it, in which case the relevant paragraph was selected and coded. After the initial coding was complete, we cleaned the data and removed any sections that did not explicitly mention or discuss actual climate change. For instance, global positioning systems are not referencing climate change. Also, simply referring to an arid climate cannot be assumed to refer to climate change.

In the second phase of coding, we read and analyzed the relevant content of the coded selections. We completed a content analysis of all coded sections noting what impacts were

mentioned, if adaptation strategies were listed, and what land uses were affected. We created a table of all mentions of climate change and identified themes. Finally, we compared the references of climate change in BLM RMPs to our synthesis of the literature and vegetation models to determine whether the plans and literature address similar concerns regarding climate change impacts on multiple use management.

RESULTS

Systematic literature review

Our initial Scopus search resulted in 7122 peer-reviewed articles. Of these, 841 mentioned at least one BLM land use in the abstract (Fig. 3). From this subset, we identified 280 articles published from 2009 to 2017 with annual citation rates of 2 or greater, and 74 articles published in 2018, for a total of 354 recent and cited land use articles (Fig. 3). Of these, 253 included study areas within the IMW, and 225 of this subset mentioned climate change in the body of the text. These 225 articles serve as the dataset for our systematic literature review.

The BLM was mentioned in 18% of articles but was only a substantial focus of 1% of the articles. When the BLM was mentioned, it was typically as a data source, or as the managing agency of the study area. Explicit management recommendations were also uncommon. While 80% of articles mentioned management of public lands, it was often only alluded to in a generic sense in a single sentence. For example, “These results will be useful to help direct management decisions and prioritize restoration activities for imperiled [Colorado River Cutthroat Trout] populations in the face of a changing climate” (Roberts et al. 2017:1384). This lack of actionable recommendations in the academic literature reaffirms the oft-reported gap between academic research and on-the-ground land management activities (Davenport and Anderson 2005, de Groot et al. 2010, Leahy and Anderson 2010, Archie et al. 2012).

A few land uses for which the BLM manages attracted considerably more attention than others in the academic literature. Of the 225 papers identified, conservation and grazing were the most frequently mentioned land uses (138 and 85 articles, respectively; Fig. 4). Recreation (55 articles), energy development (44), and logging and

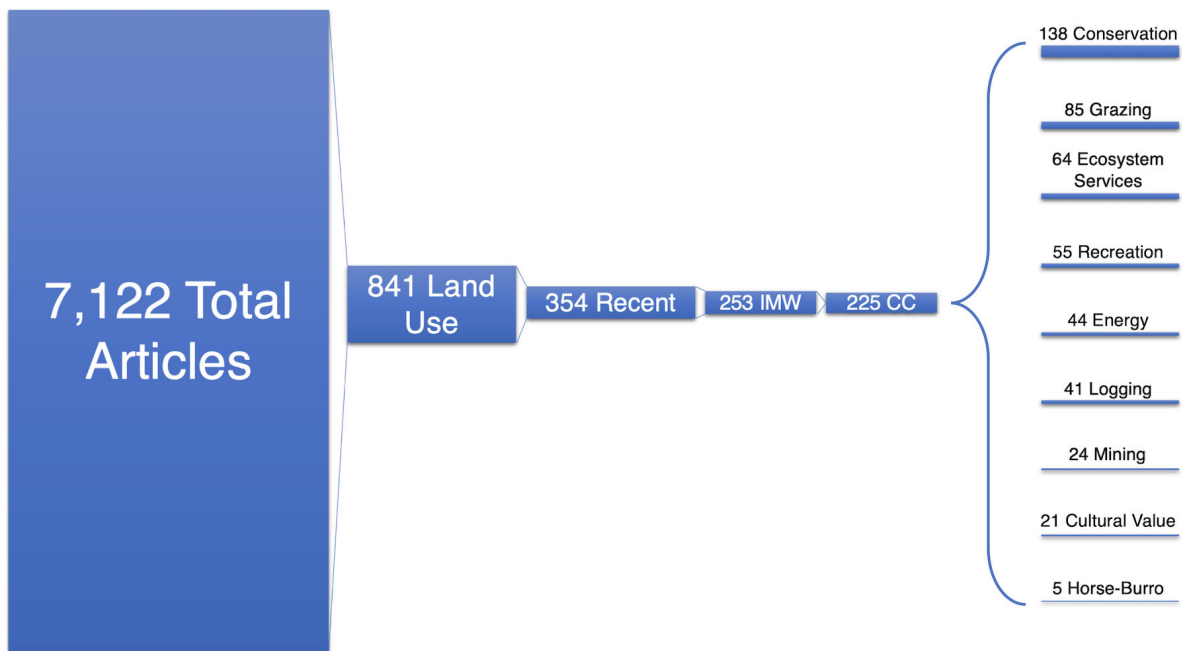


Fig. 3. Flowchart of the article selection process for the systematic literature review. From left to right: all articles produced from the initial Scopus search; articles from the Scopus search with at least one land use in the abstract; articles published between 2009 and 2017 with at least two citations per year and all articles from 2018; articles within the IMW; articles that explicitly mention climate change in the body of the text; number of articles for which each land use appears in the body of the text.

timber (41) were less frequently mentioned, and mining (24), cultural values (21), and wild horses and burros (5) were rarely found within the article text. When discussed, they were often only briefly mentioned, or discussed as a threat to conservation and ecosystem services. Historic value was not found in any article.

The majority of papers focused on one (39% of articles) or two (20%) land uses and avoided addressing the challenges of interacting and potentially conflicting land uses. Of those studies that investigated interactions among multiple uses, the most prominent theme was that direct resource use (e.g., energy development, grazing, recreation) threatened the more intrinsic values (e.g., conservation, ecosystem services, cultural value). For instance, grazing can increase sediment runoff (Warziniack et al. 2018), degrade bird habitat (Friggens and Finch 2015), and promote pinyon–juniper expansion, which negatively impacts small mammal communities (Rowe et al. 2010). Furthermore, the combined impacts of climate change and some land uses

may have significant deleterious effects on ecosystem services and ecological function. For example, combined effects of climate change and recreation have contributed to the decline of the snowy plover, a short-distance migratory bird (Thomas et al. 2012).

In contrast to direct resource use as a threat, a second theme in the literature was that some land uses may actually help sustain others. For instance, grazing was mentioned as a tool to limit wildfire and invasive species, and ultimately preserve biodiversity and ecosystem function (Nafus and Davies 2014, Davies et al. 2016). However, it is difficult to support general conclusions about the effects of grazing on ecosystem services because they are extremely variable at the local scale, depending on grazing intensity and seasonality, and the biotic and edaphic context (Twidwell et al. 2013).

Vegetation analysis

In total, we identified 14 spatially explicit vegetation modeling studies, containing 42 distinct

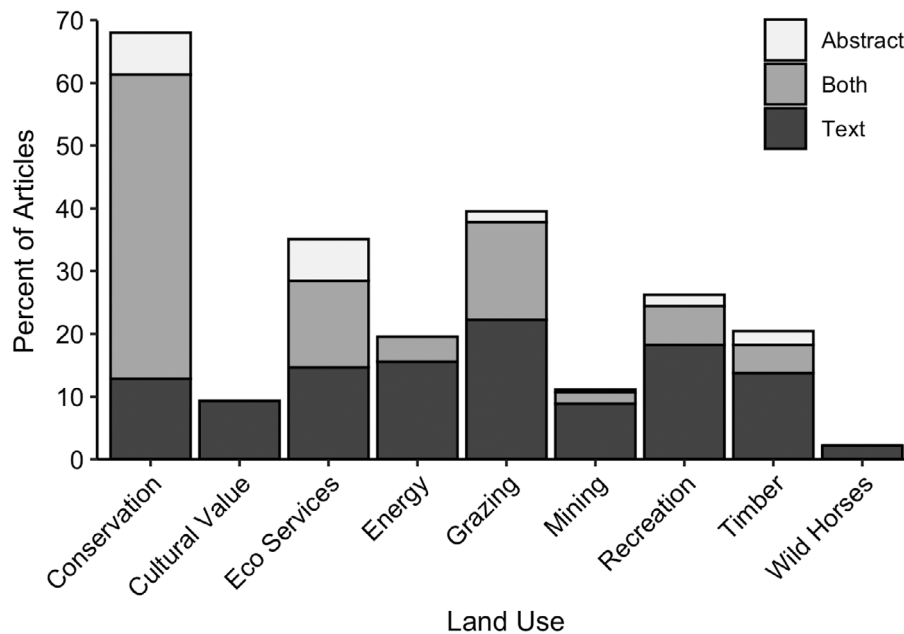


Fig. 4. The percent of articles from the systematic review in which each land use was found. The lightest gray denotes that the land use was only found in the abstract of the paper, the darkest gray denotes that it was only found in the body of the text, and the middle gray means the land use was found in both the abstract and the body of the text.

projections. Overall, these models showed a high degree of consistency in the direction of projected impacts to pinyon–juniper, cheatgrass, sagebrush, and forage production (Fig. 5). Models indicated pinyon–juniper is likely to decline in all ecoregions besides the Wyoming Basin, where results are uncertain. Models mainly projected no climate change impacts to cheatgrass in all regions. For sagebrush, no change was most likely in the Wyoming Basin and Northern Basin and Range, while the Colorado Plateau and Central Basin and Range had uncertain results split between no change and decreases. Models showed forage production is projected to increase in all regions, but increases were slightly more uncertain in southern areas, including the Colorado Plateau. It is important to note that these results do not address the magnitude of change in a region, only the direction of change.

BLM RMP analysis

Of 44 total RMPs, only 17 mentioned climate change in any capacity (Appendix S1: Table S3). In general, references to climate change were

vague, with very few specific predicted impacts or management considerations. There were exceptions, such as plans developed by the Tres Rios, Dominguez-Escalante, Lakeview, Burns, John Day, and Vale offices (Table 2). For example, the Tres Rios RMP directly linked climate change with extreme weather and increased outbreaks of insects and diseases threatening vegetation, habitat loss, aspen decline, threats to riparian vegetation, drought, and biodiversity loss (Table 2).

Plans also rarely examined the impacts of greenhouse gases (GHGs), climate change, or poor air quality, and focus instead on monitoring or minimizing carbon emissions from BLM land uses without explicit rationale. For example, the Tres Rios plan directly links GHGs with energy extraction stating, “Greenhouse gases should not be vented from existing wells and should achieve at least 95% emission reduction” (part 2, pg. 65). However, linking GHGs and resulting climate change with specific land uses is exceptionally rare. While other plans may mention GHGs, they do not typically link

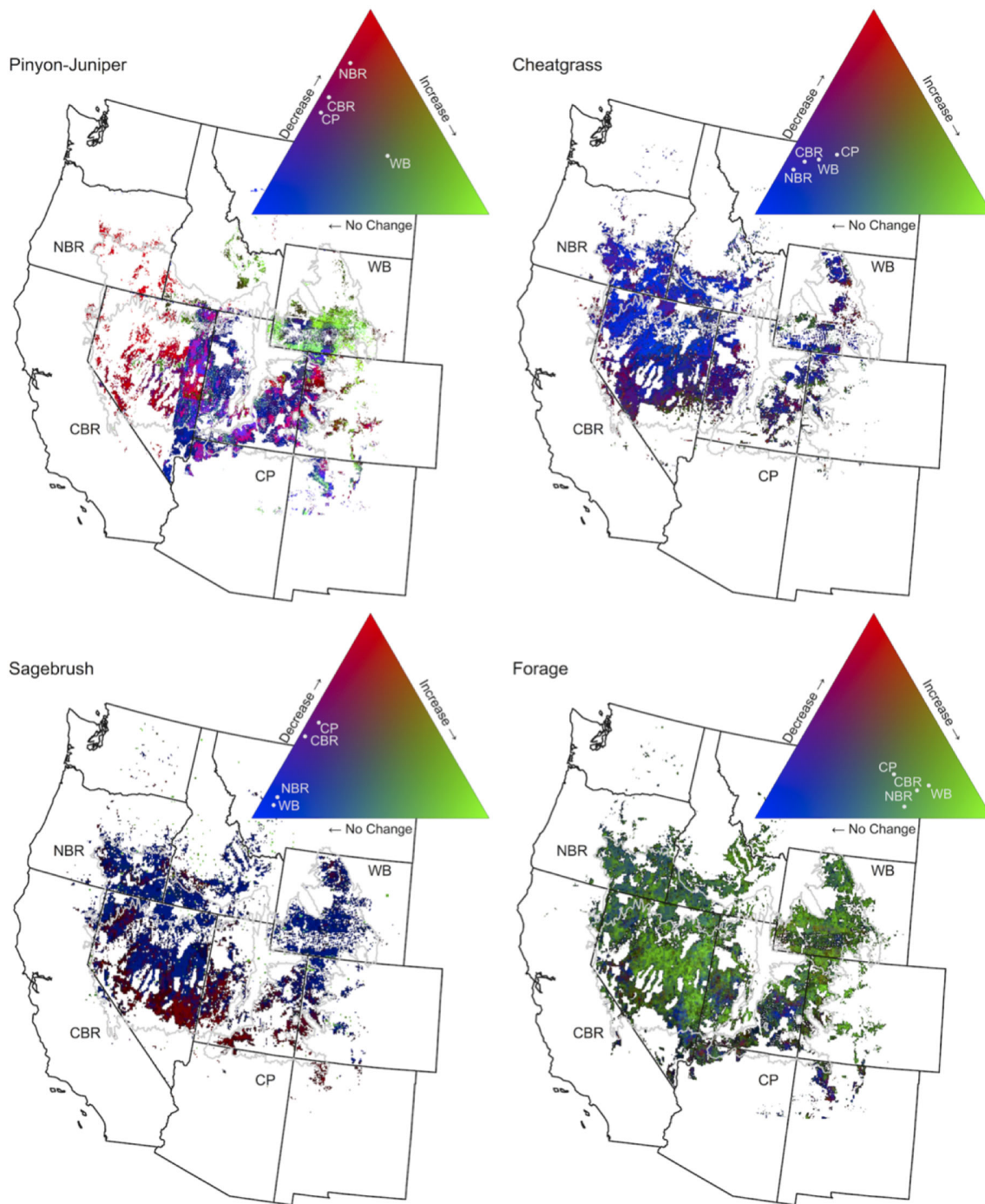


Fig. 5. RGB visualizations showing model projections for all species. Red intensity is determined by the number of models indicating a decrease in vegetation, green is determined by number of models indicating an increase, and blue is determined by number of models indicating no change. Muted colors indicate greater inconsistencies in projected direction of change. Mean pixel values for each ecoregion are shown (white text) within the legends for each vegetation type. CBR, Central Basin and Range; CP, Colorado Plateau; NBR, Northern Basin and Range; and WB, Wyoming Basin.

Table 2. All references to climate change in BLM Resource Management Plans published between 2002 and 2017 for the Intermountain West.

Plan	Year	Reference to climate change
Taos, NM	2012	Identify potential GHG sources and sinks
John Day Basin, OR	2012	Discusses impact of climate change on: changes in wintering elk; sage-grouse population and habitats (and possible listing of sage-grouse); rangeland vegetation. Discusses monitoring and adaptation for sage-grouse and rangeland vegetation
Carson City, NV	2001	Monitoring and adjusting livestock and wild horse numbers to adjust to "trends in . . . climatic data"
Winnemucca District, NV	2015	Monitor forest health/disease (whitebark pine) as early warning to respond to climate change
Socorro, NM	2010	Discusses GHGs and vulnerability of federal land to "wide range of effects from climate change, some of which are already occurring" but does not specify. Says it is impossible to predict "RMP's proposed actions on climate"
Price, UT	2008	Adjust grazing practices due to "extreme climatic conditions"
Vernal, UT	2008	Climate change found in references but not plan
Canyons of the Ancients, CO	2010	Require use of green mobile well completion equipment for oil and gas wells to "prevent venting of saleable gas and other air pollutants"; also in references
Colorado River Valley, CO	2015	Reduce GHG emissions associated with construction and industrial activities
Grand Junction, CO	2015	"Minimize emissions, within the scope of BLM's authority;" protect watershed health impacts from "climate variability"
Tres Rios, CO	2015	Associates climate change with extreme weather, insects/diseases, habitat loss, aspen decline, threats to riparian vegetation, drought, and biodiversity loss. Links GHGs with energy extraction, specifies required reductions
Dominguez-Escalante National Conservation Area	2017	Discusses climate trends as impetus for new RMP; require oil and gas activities to submit comprehensive inventory of anticipated direct and indirect GHG emissions
Lakeview, OR	2003	Mentions "climate-driven stresses" in management objectives of "Late-Successional Reserve," specifically mentioning wildfires and spotted owl recovery
Burns District Office, OR	2005	Climate change has negative effect on soil crusts; also discusses climate change contributing to increasing wildfire severity that threatens riparian vegetation resilient to climate variation
Vale Field Office, OR	2002	Mentions "climatic data" in regards to wild horses and domestic grazing [ten mile seeding project], and vegetation management
Cody, WY	2015	Discusses paleoclimate change; mentions "both natural and anthropogenic" GHGs

Note: NM, New Mexico; OR, Oregon; NV, Nevada; UT, Utah; CO, Colorado; WY, Wyoming.

production of GHGs with specific land uses, nor do they offer explicit rules or regulations. For instance, the Socorro, New Mexico plan mentions GHGs but states, "It is not possible at this time to predict with any certainty the local or regional effects of this RMP's proposed actions on climate," (pg. 10). Although this statement technically complies with the 2001 mandate "to consider" climate change, it completely abstains from taking responsibility for GHG emissions from land uses.

When the plans do mention climate change, the emphasis is often on mitigation rather than adapting to climate change impacts. The John Day field office plan is one of the very few exceptions (Table 2) listing specific actions that could minimize the impact of climate change effects on sage grouse. Of those that do consider the impact

of climate change on BLM lands and uses, the most commonly discussed were wild horses/burros, domestic or wildlife grazing, and energy development and extraction (Table 2). The Price plan, for instance, discusses grazing in relation to climate variation:

"During times when extreme climatic conditions exist, the BLM will manage and adjust grazing practices to maintain and work toward meeting Standards for Rangeland Health for Public Lands in the PFO [Price Field Office], see Appendix R-7". (pg. 99, emphasis added)

However, since extreme climatic conditions exist without anthropogenic climate change, this statement does not necessarily endorse the reality of climate change or the need for climate change-specific adaptation strategies.

DISCUSSION

Climate change impacts on land uses

Our literature review did not return a single paper concluding that climate change does not pose a major threat to BLM ecosystems and the services and products for which those lands are valued, although there were several inconclusive articles. Table 3 summarizes climate change impacts on BLM land uses as well as interactions among land uses, and Table 4 summarizes foreseeable impacts to BLM ecosystem processes, characteristics, and services. Here, we also compare these impacts to BLM RMPs.

Conservation.—The scientific literature as a whole suggests that wildlife and vegetation are threatened by climate change. Several species are classified as being highly threatened by climate change, including pika (Beever et al. 2016), salmonids (cold-water fish; Isaak et al. 2010), sage grouse (Homer et al. 2015), and spotted owl (Peery et al. 2012). Only two RMPs mention potential impacts to these species (see John Day Basin and Lakeview RMPs, Table 2). In contrast, two other RMPs list wild horses as potentially impacted (Carson City and Vale Field Office RMPs; Table 2). Regarding vegetation, whitebark pine (Shanahan et al. 2016), aspen (Rehfeldt et al. 2009), and cold-adapted species (Hansen and Phillips 2015) were commonly found to be threatened by climate change. Common effects include distributions shifting upslope, changes in abundance, greater threats from invasive species, habitat loss, loss of ecosystem engineers, threats to the thermal suitability of many species, and anthropogenic land use exacerbating the effects of climate change (Rowe et al. 2010, Isaak et al. 2010, Muhlfield et al. 2015, Friggens and Finch 2015, e.g., Beever et al. 2016, Mathewson et al. 2017, Roberts et al. 2017, Budy and Gaeta 2017, Behl and Benkman 2018).

The literature describes myriad predicted changes to sagebrush steppe, pinyon-juniper woodlands, and other shrublands, many of which have the potential to negatively impact a wide range of wildlife and plant species that depend on those communities for all or part of their life cycles (Davies et al. 2011, Coates et al. 2016). We further discuss these projected changes in the Vegetation Analysis section below.

Protection of aquatic species on BLM lands in a changing climate is likely to depend on the reliability of water sources and streamflows. Although some climate projections suggest an increase in precipitation, droughts are predicted to be more frequent and last longer (Snyder et al. 2019), increasing the chance that seeps and springs will periodically go dry, with negative consequences for aquatic species. Only two RMPs (Grand Junction and Tre Rio RMPs) mention these impacts of climate change specifically (Table 2). Increased wildfire events and subsequent erosional processes likewise have negative implications for aquatic species conservation (Murphy et al. 2020). Again, only two RMPs mention wildfire in connection with climate change: the Lakeview and Burns District office RMPs (Table 2).

The disconnect between the literature and BLM RMPs is particularly striking since conservation and maintenance of vast areas of intact, unfragmented, roadless habitat is key to the BLM's mission. Dickson et al. (2017) showed that, as the largest land manager in the western USA, the BLM has a key role to play in sustaining movement of organisms and enabling fundamental ecological processes among protected areas and across jurisdictional boundaries. These values are prioritized in BLM planning (FLPMA), and yet there is a stark contrast between the myriad impacts identified in the literature and those planned for in BLM RMPs in the IMW.

Livestock and grazing.—The BLM manages 115 million acres of rangeland, most of which is in the IMW (Warziniack et al. 2018), making grazing management an important component of BLM duties. Determining how the BLM should manage grazing under climate change is hindered by the multitude of environmental factors that influence both livestock themselves and livestock's impact on the environment (Henry et al. 2012, Rojas-Downing et al. 2017). However, only two RMPs mention grazing (the Price and Vale Field Office RMPs), and only the Carson City RMP mentions livestock, in connection with climate change.

Temperature increases are known with the highest certainty, and hence, the direct impacts of warmer temperatures on livestock and forage are especially important. Livestock tend to require considerably more water under warmer

Table 3. Climate change impacts on and interactions between various land uses for which the BLM manages.

Land use	Climate change impacts	Land use interactions
Conservation	<ul style="list-style-type: none"> • Distribution shifts upslope • Changes in abundance • Increased threat of invasive species • Habitat loss 	<ul style="list-style-type: none"> • Grazing negatively impacts small mammal communities and causes habitat degradation • Energy development displaces wildlife • Timber, grazing, mining reduce habitat quality for fish
Ecosystem services	<ul style="list-style-type: none"> • Decreased water availability in summer • Poor air quality due to wildfire and longer pollen seasons • Decreased ability of forests to sequester carbon 	<ul style="list-style-type: none"> • Pressure on water from mining, grazing, and energy development • Grazing can cause loss of streamside vegetation and increased erosion • Oil and gas extraction can contaminate groundwater
Cultural value	<ul style="list-style-type: none"> • Increased disturbances damage historic sites • Traditional practices and knowledge may erode 	<ul style="list-style-type: none"> • Loss of natural characteristics of spiritual and cultural significance due to recreation, oil and gas, and grazing • Threatened by increased recreation (particularly motorized)
Recreation	<ul style="list-style-type: none"> • Overall increase in outdoor recreation participation • Lower elevations become unsuitable for snow-based recreation • Extreme summer temperatures dampen recreation • Sites with highly valued natural characteristics (e.g., glaciers) may have lowered visitation rates if threatened 	<ul style="list-style-type: none"> • Managing for nonmotorized recreation may complement biodiversity and wildlife management, but conflict with timber and mining • Oil and gas extraction diminishes natural qualities valued by visitors • High potential of overlapping in area with oil and gas • Potential increases in motorized recreation may negatively impact other recreational, extractive, and conservation uses through increased dust and damage to biocrusts
Grazing	<ul style="list-style-type: none"> • Overall increased rangeland productivity due to increased temperatures and longer growing seasons • Low-elevation, low-moisture sites may have reduced productivity 	<ul style="list-style-type: none"> • Grazing can reduce fire frequency/severity and invasive species • Negatively affect wildlife • Can damage riparian vegetation and stream quality • High potential of overlapping in area with oil and gas
Wild horses & burros	<ul style="list-style-type: none"> • No information in literature 	<ul style="list-style-type: none"> • Spatial overlap with livestock grazing
Timber & logging	<ul style="list-style-type: none"> • Minimal effects, but overall long-term decline in timber production • Primary sensitivity is to increased incidences of wildfire, insects, and disease associated with climate change • Accelerated root disease 	<ul style="list-style-type: none"> • Can affect stream quality and wildlife habitat • Thinning can reduce wildfire risk, clearcutting can increase wildfire risk
Mining & energy development	<ul style="list-style-type: none"> • Increased mudslides and fires may threaten infrastructure • Will be most affected by policies aiming to reduce GHG emissions 	<ul style="list-style-type: none"> • Can contaminate groundwater • Causes reduced abundance and diversity of native species • Contributes to loss of natural qualities associated with recreation • High potential of overlapping in area with recreation and grazing • Threatens nutrient cycling and sediment transport

conditions (Thornton et al. 2009), and, though highly dependent on species and breed, life stage, and nutritional status, heat stress has been shown to reduce reproduction (Nienaber and Hahn 2007), compromise metabolic and digestive functions (Mader 2003, Bernabucci et al. 2006, King et al. 2006), reduce weight gain (Mitlöhner et al. 2001), and increase mortality (Sirohi and Michaelowa 2007).

The quantity, quality, and location of available forage are also expected to change with increasing temperatures (Neiberger et al. 2018). For example, in some parts of the IMW, primary productivity is expected to increase in the form of non-native annual grasses, such as *Bromus tectorum*, that lose palatability in summer and increase risk of catastrophic wildfire, which reduces local forage availability for several years

Table 4. Commonly documented impacts of climate change across the Intermountain West and examples of references that discuss such impacts.

Category	Impacts	References
Biological soil crust	Change to community structure and function	Washington-Allen et al. (2010), Root et al. (2011), Blay et al. (2017)
	Warm/dry climates host late-successional species and have more nitrogenase activity	Norton et al. (2011), Schwabedissen et al. (2017), Shaw et al. (2019)
Mammals	Distribution shifts poleward or upslope	Rowe et al. (2010), Lynn et al. (2018)
	Decline in some species abundance (e.g., bats, pika, small mammals)	Rowe and Terry (2014), Beever et al. (2016), Hayes and Adams (2017)
	Habitat loss	Malaney and Cook (2013), Beever et al. (2016), Mathewson et al. (2017)
	Chronic heat stress	Mathewson et al. (2017)
	Changes in food sources and animal activity	Butler (2012)
Birds	Decreased recruitment, fecundity, survival, range (e.g., spotted owl, sandhill crane, snowy plover, crossbill, sage grouse)	Peery et al. (2012), Thomas et al. (2012), Blomberg et al. (2014), Gerber et al. (2015), Brown and Bachelet (2017)
	Loss of habitat (e.g., band-tailed pigeons, songbirds, sage grouse)	Schrag et al. (2011), Friggens and Finch (2015), Homer et al. (2015), Coxen et al. (2017), Shirk et al. (2017)
Fish	Decline in cold-water species habitat	Isaak et al. (2015), Young et al. (2016), Roberts et al. (2017)
	Expansion of invasive species (e.g., brown trout)	Budy and Gaeta (2017)
	Hybridization	Young et al. (2016)
	Distribution shifts	Gresswell (2011)
Aquatic ecosystems	Warmer and more variable thermal/hydrologic conditions	Gresswell (2011), Strecker et al. (2011), Isaak et al. (2012), Leppi et al. (2012), Al-Chokhachy et al. (2013), Roberts et al. (2013), Muhlfield et al. (2015)
	Prone to larger, more frequent disturbances	Isaak et al. (2012), Fesenmyer et al. (2018), Rudolfsen et al. (2019)
	Increased wildfire further warms streams	Isaak et al. (2018)
Water availability	Decrease in water availability due to increased evapotranspiration, altered precipitation patterns, reduced snowpack, and changes in timing of spring runoff	van Mantgem et al. (2009), Sanderson et al. (2012), Perry and Praskievicz (2017)
	Decreased ground- and surface water	Formica et al. (2014), Perry and Praskievicz (2017)
	Increased conflict over water	Sanderson et al. (2012)
Dust	Damage to vegetation, reduced snowpack and water supply, increased nutrient loading to aquatic ecosystems, respiratory and cardiovascular impacts on humans and animals	Duniway et al. (2019)
Discordant shifts in phenology	Advanced cheatgrass phenology	Boyte et al. (2016)
	Accelerated flowering dates	Munson and Sher (2015)
	Montane systems may experience more rapid changes in phenology	Munson and Sher (2015)
Wildfire	Increased fire frequency	Embrey et al. (2012), Hurteau et al. (2014), Hansen and Phillips (2015), Palmquist et al. (2018)
	Fuel dries earlier in year, lengthening fire season	Hurteau et al. (2014), Rocca et al. (2014)
	More high severity fires and mega-fires	Hurteau et al. (2014), Davies et al. (2016)

(Blumenthal et al. 2016). The combination of warmer temperatures and the potential for increased variability in forage production could make grazing management more challenging in the future, even if total forage quantities increase (Reeves et al. 2017).

While changes in precipitation regimes are more difficult to predict, future climate scenarios imply a reduction in water availability for livestock grazing on BLM land, and less reliability of water from year to year. Additionally, climate change is also likely to impact livestock grazing

on public lands through degraded air quality (Achakulwisut et al. 2017), increased transmission of diseases (Breshears et al. 2016), and changes in the timing and distributions of pests (Mills et al. 2010).

Recreation.—Research from social and economic sciences has identified several dominant pathways in which climate has, and will continue, to impact outdoor recreation participation and management (Hand et al. 2018). The first of these pathways involves the direct effects of warming temperatures and more variable precipitation on the behaviors of outdoor recreationists themselves. The second pathway involves indirect effects in which outdoor recreationists' behaviors change in response to impacts to the biogeophysical characteristics of outdoor recreation settings including climate change. And yet, none of the RMPs mention recreation in the context of climate change.

For most outdoor recreation activities on BLM lands in the IMW, direct impacts involve rising temperatures, which will increase recreational visits in shoulder seasons previously limited by colder temperatures; this is expected to lead to an increase in outdoor recreation participation. For instance, previous research has shown warming temperatures are correlated with increased visitation to U.S. national parks (Fisichelli et al. 2015, Smith et al. 2019) and national forests (USDA FS 2016, Askew and Bowker 2018). Furthermore, BLM lands facilitate over 65 million outdoor recreation visits per year (Cline and Crowley 2018), with most of those visits occurring in the warm summer months (USDOJ 2019). Rising temperatures extend shoulder seasons earlier into the spring and later into the fall, resulting in more outdoor recreation destinations becoming accessible for longer portions of the year. The demand for warm-weather activities, which include hiking, camping, motorized recreation, and mountain biking, will likely increase on BLM lands in the future (Hand et al. 2018).

BLM lands that have notably arid climates might experience reductions in outdoor recreation participation rates during mid-summer, when temperatures exceed comfortable thermal conditions. Previous research has documented the relationship between outdoor recreation participation levels and temperature switches from positive to negative when mean daily high

temperatures exceed 27°–30°C (Fisichelli et al. 2015, Hewer et al. 2016, Smith et al. 2018). Such declines in participation are likely to occur in the extreme southwestern portions of Utah and southeastern Nevada, as well as the lower-elevation regions of Arizona and New Mexico. However, these regions will still likely experience increasing annual participation as the shoulder seasons expand.

Indirect impacts of climate change on outdoor recreation participation are pervasive, affecting nearly every activity offered on BLM lands. Hunting, fishing, and wildlife viewing opportunities provided by the agency are particularly vulnerable to these indirect impacts. Over half (4.2 million) of all wildlife-associated recreation trips to BLM lands occur in the IMW (Southwick Associates 2018). As the availability and abundance of targeted species change in response to warming temperatures, participation in wildlife-related outdoor recreation may shift accordingly. Previous analyses suggest any reduced participation in hunting, angling, and wildlife viewing attributable to target species being negatively impacted will be outweighed by the direct and positive effects of longer summer seasons (Askew and Bowker 2018).

Although existing research on the impacts of climate change on outdoor recreation opportunities on BLM lands is sparse, the existing literature suggests participation in outdoor recreation on BLM lands will continue to increase for the foreseeable future. BLM lands may experience similar trends as those projected for other federal lands, with warmer temperatures leading to more outdoor recreation for certain geographic regions (notably those at more northern latitudes) and activities (most summer activities; Fisichelli et al. 2015, USDA FS 2016). However, despite this literature, none of these changes or challenges are mentioned in BLM RMPs in the context of climate change.

Cultural and historic uses.—Climate change impacts on cultural and historical values of BLM resources are very seldom discussed in the literature, but the research that does exist notes two main threats: damage to historic sites and alteration of traditional ways of life. First, increased disturbance due to climate change, such as floods and wildfire, has the potential to irreversibly damage historic sites. Second, the lifestyles and

traditions of many Native American communities are likely to be threatened by climate change. For example, traditional foods may be affected by climate change through habitat alterations and changes in the abundance and distribution of species, which often results in the erosion of traditional practices and knowledge (Warziniack et al. 2018). However, none of the BLM RMPs mention cultural or historic values in the context of climate change.

Wild horse management.—Of the 225 articles coded in our systematic literature review, there was no mention of wild horses and burros in relation to climate change. By comparison, two out of the total of 44 BLM RMPs mention wild horses in connection to climate change (the Carson City and Vale Field Office RMPs, Table 2). Despite the lack of peer-reviewed literature on this topic, the effects of climate change on these species may be expected to be similar to that of livestock and grazing. That is, rangeland productivity may increase overall across the IMW, suggesting a potential benefit to wild horses and burros. As these species are largely considered to be nuisances by managers with negative environmental impacts, a potential increase may exacerbate conflicts with other uses, including conservation and livestock permitting, due to competition.

Timber extraction.—While the literature returned in our search seldom explicitly discusses direct linkages between climate change and timber harvest, numerous papers document recent and future predicted shifts in tree species viability (Buma and Wessman 2013, Hansen and Phillips 2015, Iglesias et al. 2015, Yang et al. 2015, Shinneman et al. 2016, Stevens-Rumann et al. 2018), increased wildfire frequency and severity (Wu et al. 2011, Macfarlane et al. 2013), and increased spread of invasive pests and diseases (Embrey et al. 2012, Weed et al. 2013, Shanahan et al. 2016, Halofsky et al. 2017, Warziniack et al. 2018), all of which could decrease harvest. Contrastingly, increases in temperatures and CO₂ could result in increased forest productivity and biomass accumulation, resulting in greater timber productions at higher elevations (Halofsky et al. 2017). However, long-term decreases in moisture availability and increased disturbances will likely reduce forest growth and reproduction at low elevations, and potentially shift the

ranges of important timber species (Halofsky et al. 2017, Parmenter et al. 2018). Similarly, although BLM RMPs mention these aspects (Table 4), none link them with timber extraction.

Oil and gas extraction.—Although oil and gas extraction is infrequently mentioned in the selected literature, it is connected to climate change in 4 of the 44 analyzed BLM RMPs. In the literature, oil and gas extraction comes up as a potential threat to other uses, such as conservation, which is consistent with RMPs. As noted in our analysis of BLM RMPs, some field offices did restrict extraction of fossil fuels, as these activities inevitably contribute to anthropogenic climate change. However, due to the way FLPMA was written, the BLM also has to manage for legacy land uses, including energy extraction (Ellenwood et al. 2012). Any efforts to reduce oil and gas extraction would likely be challenged by beneficiaries of this land use in court (Pendery 2010).

Under current rules, the BLM will continue to permit fossil fuel extraction (Pendery 2010), and yet, of all the land uses the BLM manages for, energy extraction contributes the most directly to anthropogenic climate change. Therefore, the most direct way the BLM can reduce the contribution to climate change from permitted land uses is by reducing permits for energy extraction on BLM land. This reality is reflected by several lawsuits recently brought against the BLM for allowing energy extraction without considering how such actions could contribute to climate change, and thus directly undermine other land uses for which BLM is mandated to manage (Kohler 2019, Passut 2019, Randall 2019). Dealing with these lawsuits is challenging for the BLM, but due to current management guidelines, the BLM may also face lawsuits from oil and gas companies if they restrict energy extraction. Thus, without major rule changes the BLM appears to lack the ability to rectify this issue (McEnaney 2017).

Vegetation analysis

We found that models projected consistent climate change impacts to pinyon-juniper, cheatgrass, sagebrush, and forage production in the IMW. Despite the consistency of the model projections, we did not find evidence in any of the analyzed BLM RMPs that IMW field offices are

planning for these vegetation changes in response to climate change (Table 2).

The BLM has devoted considerable resources for decades to fighting pinyon–juniper encroachment (Redmond et al. 2013). It is tempting to conclude that projected pinyon–juniper declines we found in all ecoregions except the Wyoming Basin might allow the BLM to reduce costly pinyon–juniper management in the future. However, BLM efforts to control pinyon–juniper expansion focus primarily on areas where valuable sagebrush steppe habitat is being lost. The coarse scale of the projections makes it difficult to evaluate the implications for this more targeted concern. Projected increases in forage production may also benefit land management, implying greater capacity of BLM lands to support livestock and wildlife populations. For sagebrush, we found no climate change impacts were projected in most areas, indicating current management can largely continue into the future. However, southern areas of the Colorado Plateau and Central Basin and Range show the potential for declines, suggesting restoration strategies targeting no net loss of sagebrush may be infeasible in these areas.

Models indicated that no climate change impacts to cheatgrass were most likely in all ecoregions, indicating current cheatgrass management will likely need to continue in the future. Even if cheatgrass suitability were to decline, other invasive annual grasses such as medusahead (*Taeniatherum caput-medusae* L.) and red brome (*Bromus madritensis* L. ssp. *Rubens* L.) could potentially fill its niche (Snyder et al. 2019). However, despite a legacy of managing for these vegetation challenges, only four RMPs explicitly mention climate change impacts on these vegetation types (Table 2).

Evaluating (the absence of) climate change in RMPs

For this study, we completed a content analysis of BLM RMPs from 2001 to 2017 from the IMW because these plans are the legally binding documents that should document BLM management under FLPMA. Our analysis revealed very few explicit references to climate change, which is consistent with other research on BLM RMPs (Nave et al. 2020). Despite this finding, it is possible that the BLM is able and planning to adapt to

climate change using the existing management practices described in the plans. For example, field offices generally reserve the ability to increase or decrease grazing densities according to forage availability and conflicts with other uses, both of which may change under future climate regimes (Veblen et al. 2014). It is also possible that the BLM is attempting to adapt management for climate change realities using other mechanisms, such as Rapid Ecoregional Assessments (REAs; USDOI BLM 2019). Given that FLPMA requires management actions to be articulated in official plans, it is unclear if and/or how new management needs that emerge from REAs could be implemented under existing RMPs. In other cases, however, by excluding consideration of climate change in RMPs, the BLM is limiting their ability to adapt to future challenges (Archie 2014).

It is important to acknowledge that the development and approval process for RMPs takes a considerable amount of time, often requiring ~8 yr (Squillace 2018). While the 17-yr time period for which we analyzed plans should have been sufficiently long for most plans to have explicitly included consideration of climate change, some of the plans may have been too far along in the process to be modified when the 2001 mandate was issued and/or were not revised in this timeframe. Regardless, the relative dearth of climate change impact or adaptation consideration in RMPs calls into question whether BLM field offices in the IMW are planning for projected climate change, and if the current planning process can appropriately address these issues.

The difficulty of planning for expected climate change has resulted in lawsuits and litigation against the BLM. For instance, in 2019 the BLM was sued in Wyoming, Colorado, and Utah for failing to incorporate climate change into its oil and gas leasing process (Kohler 2019, Passut 2019, Randall 2019). However, efforts by the BLM to adapt their planning procedure have been stifled (see *Background*; McEnaney 2017). These results suggest that more explicit incorporation of science and better planning protocol is indeed necessary for effective natural resource management in a climate change-affected future (Wyborn et al. 2015). Other federal land management agencies may also be failing to address climate change in their management plans;

however, more research is needed to determine whether this concern applies to other agencies.

The science–management gap identified in our study is problematic (Carter et al. 2020), as our results support previous findings that climate change will likely increase land use conflicts on public land (Johnson and Becker 2015) and that most human land uses and/or values are fundamentally threatened by climate change (Chambers and Wisdom 2009). In particular, intrinsic values, which are identified as threatened by extractive uses in the literature, are under-prioritized by BLM RMPs due to an institutional focus on more active, extractive, and anthropocentric uses (Loomis 2002). Several studies indicate these intrinsic values need greater consideration (Koontz and Bodine 2008). Consistent with these findings, our results suggest that currently, climate change is not adequately considered in BLM RMPs for the IMW region, which may apply to other natural resource agencies, as well.

Improving communications in the science–management–policy nexus

There is a clear disconnect between the scientific understanding of the impacts of climate change on lands managed by the BLM in the IMW and the agency's explicit use of that research in RMPs. This disconnect could, in part, be due to the inaccessibility of much of the literature, as the vast majority of papers we reviewed were published in journals that require a subscription or charge for access. However, in most cases, a free copy of the paper can be obtained by simply contacting one of the authors.

While the U.S. government has thus far failed to develop a comprehensive policy on climate change mitigation or adaptation, public land management agencies acknowledge the imperative of planning for climate change. In a survey of BLM and U.S. Forest Service (USFS) managers, the vast majority of respondents thought climate change science was useful for their work (90%), for future planning efforts (97%), and for specific management projects (80%), and a large majority (80%) agreed strongly that using climate change science is within their job description or responsibilities (Kemp et al. 2015). And yet, our analysis of BLM RMPs revealed limited explicit mention of climate change.

Our research demonstrates a wealth of literature regarding climate change impacts in the IMW in the scientific literature. Yet, the stark disparity between the literature and management plans highlights a disconnect between academics, managers, and policymakers. To bridge this gap, scientists need to make their research more accessible and could make greater efforts to include more explicit and thorough management recommendations (Carter et al. 2020). Increasingly, boundary-spanning organizations have emerged to assist in translating science for land managers (e.g., the U.S. Joint Fire Science Program's fire science exchange network; Kocher et al. 2012). At the same time, managers and policymakers need to make stronger efforts to access and more fully incorporate information from the scientific community (Kitchell et al. 2015). Here, we have provided a synthesis of the science from over 200 articles, which can be used as a starting point for managers to incorporate climate change science into their land management planning. Furthermore, the data collected for this project provide a list of DOIs for all the literature outlined here (available on HydroShare, <https://www.hydroshare.org/resource/5f6249260f5f4f3fa9818a97970886af/>), which can facilitate the incorporation of such science into management practices and plans. However, fundamentally improving communication within the science–management–policy nexus will require realignment of incentives in academia, management agencies, and funding agencies to acknowledge the value of more meaningful interactions.

LIMITATIONS

There are several limitations to our study that must be noted. First, our initial search for literature required that each article contains a word or phrase identifying both climate change and the IMW. We are certain to have missed articles focused on land use if they did not highlight climate change in the title or abstract of their paper. Furthermore, research regarding some land uses may purposefully avoid explicit climate change language and instead refer to a “warmer and drier future,” for example. We also chose to search for 9 land uses categories, which is not a comprehensive list.

Another caveat is that most of the models we reviewed in the vegetation analysis do not consider the effects of future changes in wildfire regimes. Climate change is expected to increase the size, frequency, and severity of fires in the IMW (Liu et al. 2013, Barbero et al. 2015, Abatzoglou and Williams 2016, Murphy et al. 2018, Prudencio et al. 2018). Increases in fire could cause greater declines in pinyon–juniper (Allen et al. 2015, McDowell et al. 2015) than the models predict and could lead to decreases, rather than increases, in sagebrush (Reeves et al. 2018). Conversely, fire might cause greater increases in cheatgrass than shown in our results (Bradley et al. 2018, Larson et al. 2018). Additionally, our results do not address the magnitude or speed of expected vegetation changes, only the direction of such changes. Furthermore, our vegetation analysis had a limited sample size, which could bias our conclusions. As such, the conclusions from the vegetation models should be taken as evidence of climate change not included in the RMPs, rather than results that are immediately useful for management.

Finally, we used BLM RMPs to determine whether the BLM is addressing climate change, but it is possible that they are taking actions beyond those listed in these plans, as these are often intentionally vague (Glicksman and Coggins 2001). Thus, managers' ability to adapt to climate change may be greater than what is represented in these RMPs.

CONCLUSIONS

Through a systematic review of peer-reviewed literature, analysis of vegetation models, and content analysis of BLM RMPs in the IMW, we found that active resource use generally threatens intrinsic values such as conservation and ecosystem services on BLM land, and climate change is expected to exacerbate these threats in numerous ways. Thus, the BLM should aim to consider the interactions of these land uses in the context of climate change. The BLM will also need to consider both how climate change will affect public land, as well as how the management of public land potentially contributes to climate change. These conclusions are consistent with the BLM's own findings (Kitchell et al. 2015). However, our analysis of BLM plans

demonstrates a lack of (1) explicit climate change management in BLM plans; (2) a clear directive of land uses and priorities in land use plans; and (3) science on climate change impacts on land uses. This absence may be due in part to the lack of truly interdisciplinary research on climate change, which may be impeding managers' ability to effectively manage multiple land uses under climate change.

We also recommend researchers studying the effects of climate change make a more robust effort to understand the practices and policies of public land management in order to communicate their findings effectively. To this end, we recommend that editors and reviewers strongly encourage a more explicit description of management implications when accepting articles regarding climate change that pertain to public land managers. We have attempted to disclose some of the challenges currently faced by the BLM in managing for climate change. Currently, the rules and guidelines that dictate how the BLM manages public land do not provide adequate direction on how to manage for climate change. Thus, these results support the BLM's internal attempts to improve their planning to "incorporate[e] best available science" while simultaneously following diverse mandates in a highly nuanced policy framework. However, due to more recent Secretarial and Executive Orders, these issues are unlikely to be resolved without congressional or executive support.

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SUPPORTING INFORMATION

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