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## The American West as a social-ecological region: Drivers, dynamics and implications for nested social-ecological systems

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### Abstract (200 words)

The American West exists in the popular imagination as a distinct region, and policies and politics often suggest that both the challenges and the opportunities for land management and human well-being across the region are relatively homogeneous. In this paper, we argue that there *are* key characteristics that define the West as a social-ecological region, and also that there are myriad social-ecological systems (SESs) within the region that require diverse and dynamic approaches to managing change over time. We first conceptualize aridity, topography, and a unique political economy of land as exogenous factors that persist over time and space to define the American West as a contiguous social-ecological region. We then identify a second set of characteristics that show high degrees of variation across SESs within the American West. Finally, we operationalize the relationships between regional characteristics and local dynamics through a set of case studies that exemplify specific types of SESs in the region. The results of these empirical representations of the regional and intra-regional social-ecological dynamics of the contemporary American West highlight the implications for research and management of taking a cross-scale integrated approach to address pressing social-ecological opportunities and challenges in complex adaptive systems.

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## 1. Introduction

There are few regions as evocative and symbolically powerful as the American West (hereafter, ‘the West’). As the setting to countless cinematic morality tales and home to some of the world’s most recognizable dryland and alpine landscapes, the West possesses a strong and enduring regional identity (Keske et al. 2017). The West is also diverse, and includes rural ranching communities in grassland ecosystems, high-tech micro-urban centers in Rocky Mountain valley bottoms, extraction-dominated landscapes across the high desert, Tribal nations managing natural resources within and across sovereign borders, myriad outdoor recreation destinations from alpine to riverine, and many other centers of human-environment interactions. Contemporary popular imagination has at times contrasted an ‘old west’ identity, focused on natural resource extraction, with a ‘new west,’ one of amenity destinations, recreational economies and increasing urbanization (Otterstrom and Shumway 2003; Winkler et al. 2007). The reality, of course, is more complicated; characteristics that define the region emphasize a strong link to social-ecological legacies as well as reveal the impact of contemporary environmental and demographic change (Limerick 1987; Smith and Krannich 2000; Robbins et al. 2009).

There is a substantial body of human-environment research embedded within the often-taken-for-granted bounds of the West, historically thought of as lands west of the 100th meridian (Wilkinson 1993; Seagar et al. 2018; for a few research examples, see Brick, Snow and Van de Wetering 2001; Robbins et al. 2009; Altaweel et al. 2016). Various prior research efforts that have attempted to define the West as a distinct region have focused on factors such as water appropriation law, lack of demographic diversity, rurality, or presence of iconic animal species (Nugent 1992; Berry et al. 2000; Robbins et al., 2009; McKinney and Thorson 2015). Despite these efforts, there has been relatively little effort to analytically demarcate and define the West as a region with consistent social and ecological characteristics, organized by a common set of system variables, and marked by diverse sets of nested dynamics. The potential of such an approach is worth considering. As Walker (2003: 7) notes when suggesting a regional political ecology of the West, “regional approaches can retain the greatest strengths of [interdisciplinary scholarship] in revealing the importance of local-scale social dynamics while situating these dynamics within broader scales of regional (and global) processes.” In the context of coupled social-ecological systems (SES) science (e.g. Liu et al. 2007, Ostrom 2009, Martín-López et al. 2017), clearly defining geographic regions can provide researchers and managers with a common framework from which to analyze, compare and learn from the relationships among nested systems responding to similar challenges and potential impacts of global environmental change (for one example, see Ellis and Ramankutty 2008).

The purpose of this paper is to analytically define and visualize the West as a social-ecological region, and to highlight the variation that characterizes the SESs nested within the region. Based on expert discussion held during a May 2018 workshop in Boise, Idaho (HES 2018), as well as past scholarly work on the drivers of diverse SESs and their challenges within the region, we define and delineate the region using a common set of characteristics that show

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3 strong continuities over space and time, and serve as consistent exogenous (to any specific SES  
4 within the region) drivers of SES characteristics and dynamics. We then identify several fast  
5 variables (those that change quickly over space and time) that demonstrate wide variation within  
6 the region, and contribute to system dynamics across SESs in the West. The variables and  
7 specific systems analyzed in this paper are not exhaustive, but they provide empirical evidence  
8 and examples that highlight the multi-scalar nature of SES dynamics in the West as a region (for  
9 a similar community-scale example, see Altaweel et al. 2016). To further our definition and  
10 operationalization of the West, we present four vignettes (with full case studies in Supplementary  
11 Material) that demonstrate the interplay between the regional variables exogenous to a given  
12 SES and the fast variables that are emblematic of characteristics of the specific SESs. With an  
13 empirically based definition of the West as a social-ecological region, the analytical synthesis  
14 and research agenda we present is driven by an interest in advancing the conceptualization and  
15 investigation of SES dynamics within the West, particularly as regional political and climate  
16 pressures (among many others) have the potential to dominate discourse about management and  
17 decision-making (Ragsdale 2016; Schoenagel et al. 2017).  
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## 24 **2. Social-ecological characteristics of the American West**

### 25 *2.1 Conceptualizing the West as a social-ecological region with nested social-ecological systems*

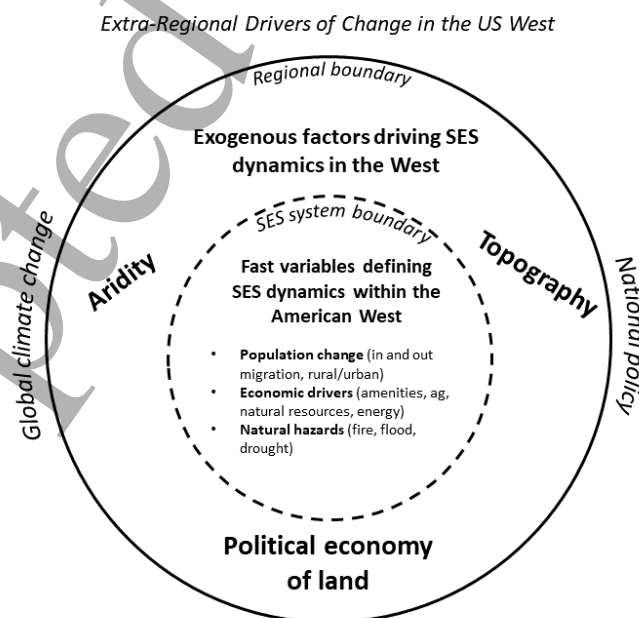
26 The concept of SESs is not new generally (Marsh 1864), nor to research on the American  
27 West specifically (for one example, see Ingram 1990). In the past two decades, however, there  
28 has been an upswell of scholarship aimed at building a more explicit recognition of the linkages  
29 between social and ecological systems both conceptually and empirically as a means of  
30 establishing a common framework from which to work toward global sustainability goals (Folke  
31 et al. 2005; Ostrom 2009; Fischer et al. 2015). Despite the increase in SES analyses, spatially  
32 explicit approaches for delineating, characterizing and analyzing SESs are still relatively rare  
33 (for a few examples, see Ellis and Ramankutty 2008; Martín-López et al. 2017). Here we attempt  
34 to address to this gap, by characterizing the West as a social-ecological region, thereby providing  
35 a consistent place from which to further analyze and compare the intra- and inter-system  
36 dynamics of SESs nested within the region. In this conceptualization, there are many specific  
37 SESs nested within a region organized by a critical set of variables and influenced by cross-scale  
38 interactions (including with forces operating at much larger scales, like global climate variability  
39 and economic structures) (Gunderson and Holling 2002; Walker and Salt 2006).  
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46 To operationalize the West as a social-ecological region, we draw on definitions from  
47 Chapin et al. (2009) to define three types parameters that characterize SES dynamics over space  
48 and time: exogenous factors, slow variables, and fast variables. Exogenous factors are those that  
49 “remain relatively constant over long time periods and across broad regions and are not strongly  
50 influenced by short-term, small-scale dynamics” (Chapin et al. 2009: 5). Exogenous factors,  
51 when taken together, set the parameters for a social-ecological region and provide a foundation  
52 for understanding dynamics within varying types of embedded SESs (Metzger et al. 2010; Leslie  
53 et al. 2015). Fast variables refer to aspects of SESs that change rapidly over space or time, and  
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generally show much greater variation or instability than do slow variables. Major changes in fast variables can also be thought of as internal perturbations within an SES, which have as much potential to alter the state of the system as do external perturbations (e.g., unanticipated climate disturbances). Slow variables are those that remain relatively constant over years to decades, (often what are referred to in ecology as ‘state’ variables), and we thus engage with slow variables only to describe consistent characteristics of specific SESs.

We conceptualize the West as a social-ecological region defined principally by three key exogenous factors that differentiate it from other regions of the United States: aridity, topography, and a unique political economy of land ownership, tenure and management (Figure 1). We also highlight several fast variables that are associated with contemporary SES dynamics within the West, including changes in population density, economic activity, and natural hazards such as wildfire and drought. Figure 1 presents a conceptual visualization of the nested nature of social-ecological regions and SESs, and their multi-scalar dynamics. In addition to the regional exogenous factors that drive SES dynamics in the West, we recognize that there are extra-regional, macro-scale drivers of change (e.g. climatic change, global markets) that influence the West in specific ways and that interact with the exogenous factors and fast and slow variables. We define and discuss these macro-scale drivers throughout the rest of this paper as appropriate and highlight how they condition the characteristics of both the region and the specific SESs nested within the West.

Figure 1. Conceptualizing the West as a social-ecological region with embedded social-ecological systems



## 2.2 Defining the West as a social-ecological region

Using publicly available data, we identify indicators of each exogenous variable that we hypothesize defines the West, and then employ cluster analysis to explore the co-occurrence of average ‘levels’ of each variable. We are testing the hypothesis that the West as it is understood in the popular imagination is in fact a region that can be characterized as more arid, more topographically complex, and with more public land than other regions of the country. As an indicator of aridity, we use climate water balance data (Dobrowski et al. 2013) and a measure of water deficit (in mm). As an indicator of topography, we use WorldClim Global Climate Data V1 (Hijmans et al. 2005), and refactor the elevation data to create an index of topographic complexity, calculated the range of elevation in a moving window around each gridcell and transformed that range into a 0-1 index (with values approaching 0 indicating more complexity or variation). Finally, as an indicator of the political economy of land, we use a measure of the proportion of land per county that is owned by the federal government using the Gap Analysis Program Protected Areas Database v 10.3 (Gergeley and McKerrow 2013). The political economy of land tenure and management in the West includes federal policies that reserved large expanses of surface and subsurface resources for state ownership and management, and privileged a particular set of beneficiaries while dispossessing Native communities of their land and associated resources (White 1991; Wilkinson 1993; Robbins 1999; Gaido 2002; Hixson 2013; Bonds and Inwood 2016). Political economy cannot be measured directly, and so we use the proxy of federal land ownership to represent the “footprint” of this legacy on the West (Spence 1999; Vincent, Hanson and Argueta 2017).

At the top of Figure 2 we present the distribution of each of the three variables separately, as they are originally measured. We then refactor those measures to the county level to conduct cluster analysis. Cluster analysis was performed using the k-means algorithm, since all three variables are continuous measures. We used multiple fit statistics to guide our decision about the best-fitting number of clusters (Martín-López et al. 2017). We chose to interpret three clusters based on average silhouette method, which is a measure of cohesion across all three variables among cases (counties) within each cluster. Average silhouette width of the three-cluster solution presented here is roughly .57, which is generally considered a reasonable fit (for an overview of cluster analysis methods, see Chatfield and Collins 2018). Details of multiple fit statistics, cluster averages and boxplots to show the distribution of each variable within each cluster are provided in the Supplementary Material. All analysis was conducted in R (R Core Team 2019) using the cluster (R version 2.0.9) (Maechler et al. 2019) and factoextra (R version 1.0.5) (Kassambara and Mundt 2017) packages. Map visualizations were done in ArcGIS Desktop (version 10.7) software.

Figure 2: Distributions of three exogenous variables and final cluster results that characterize the West

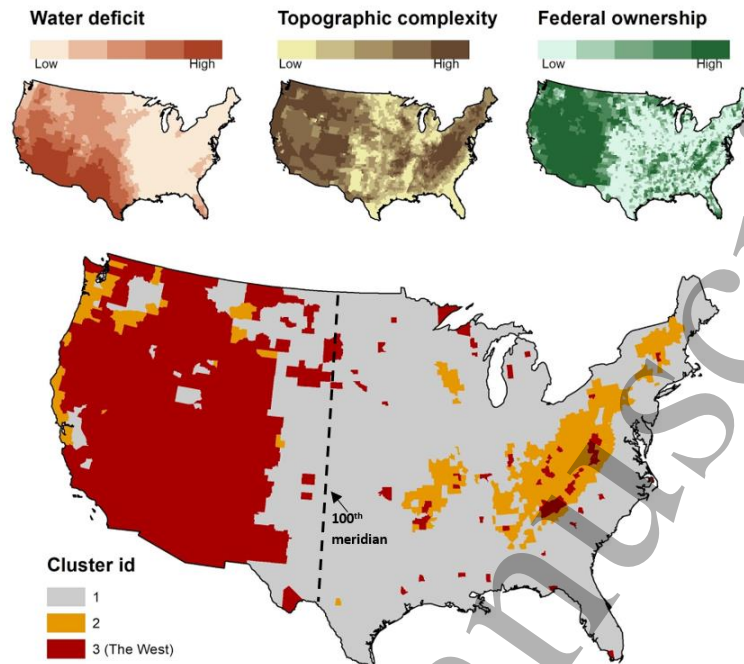


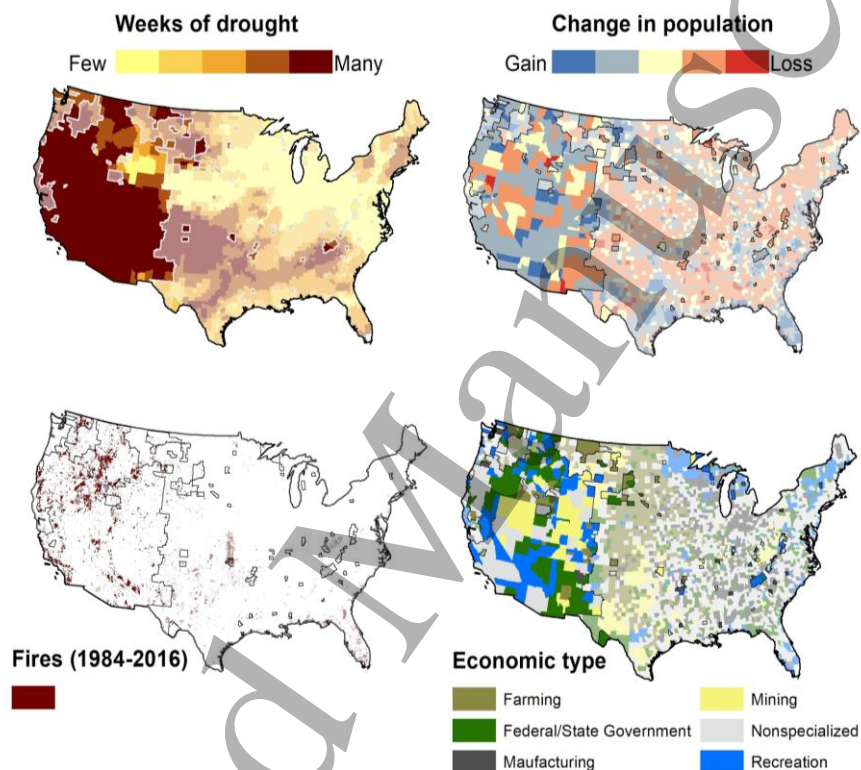
Figure 2 shows the distribution by county of the three cluster classes that operationalize the three key exogenous variables which, we hypothesize, together define the American West. The red counties (Cluster ID 3) are those with high aridity, high topographic complexity, and a large proportion of federally owned land. As can be seen from the map, this cluster of counties largely aligns with both popular conceptions and past research that defines the West as a contiguous geographic region that lies west of the 100th meridian. However, there are also counties that have more water than is the norm (Cluster ID 2) - largely those areas along the Pacific Coast - and counties having more water, less topography and less federal land (Cluster ID 1). The results in Figure 2 also demonstrate that there are places elsewhere in the United States characterized by the presence of high topographic relief, high aridity and high proportions of federal ownership (Cluster ID 3), largely in Appalachia and areas around the Great Lakes. What makes the West a region then, is a set of exogenous variables that co-vary across a large contiguous area - a social-ecological region.

### 2.3 Defining variation and commonality in SES dynamics within the West

Within the West, as defined analytically and presented visually in Figure 2, there are many fast variables that create highly heterogeneous conditions across the region and are conditioned by the exogenous factors identified above. In this section, we explore and describe variation social and ecological variables reflective of dominant narratives about the new and old West, and the natural hazards pressures facing the region (Otterstrom and Shumway 2003; Winkler et al. 2007; Schoenagel et al. 2017; Anderson et al. 2018). We select two social and two ecological variables: population change over the past eight years (2010-2017 (US Census Bureau

2017)), dominant economic activity as of 2015 (ERS 2017), large fire activity from 1984-2016 (USGS and USFS 2016), and total number of weeks in which drought occurred from January 2015 to January 2019 (NDMC, USDA and NOAA 2019). Population change, economic activity and drought data are at the county level, whereas data on large fire activity are polygons representing the perimeters of the fire.

Figure 3. Distribution and variation of fast variables within the West



The maps in Figure 3 demonstrate that fast variables vary within and across the West (maps include a mask that highlights areas that fall in the West as defined in the cluster analysis and map in Figure 2). The maps in Figure 3 show that on the ecological side, drought is a consistent characteristic of the region, with most of the region experiencing drought for almost half of the total period measured. Fire activity is more variable, with a much higher density and total area of fire sites in the northern Rocky Mountains and the extreme southwest. On the social side, Figure 3 shows pockets of relatively high population gain, a few specific places of high population loss, and many counties with moderate gain or loss. Importantly, population gain and loss occurs in a patchwork fashion, in contrast to other parts of the country with large contiguous areas of population loss and small pockets of gain. A similar patchwork exists for dominant economic activity, with recreation scattered along the Rocky Mountain front, mining existing in the Intermountain interior, and very little manufacturing anywhere in the region.



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Taken together, the maps in Figure 3 provide a starting point for understanding where there is potential variation in some key SES dynamics across the West. For example, population change is highly variable from county to county within the region, and many counties have remained relatively stable in terms of population (challenging the rapid urbanization narrative). Dominant economic activity within the West is much more varied than in other parts of the country and provides one representation of the existence of both the old and new West, side by side (see also Winkler et al. 2007). On the ecological side, drought (the impact on human systems of aridity) is a consistent characteristic of most of the region and represents the extreme operationalization of aridity, which as an exogenous variable has shaped the biophysical landscape over longer time horizons. Drought ebbs and flows on an annual basis, and has consequences for agricultural and recreational livelihoods, while aridity is a consistent feature of the region to which SESs have adapted over time. Large fire activity, increasing in severity and driving human decision-making in the West, appears to also cluster in certain parts of the region more than others, making it an acute driver in specific locations but not necessarily a key management concern across the entire region (Anderson et al. 2018).

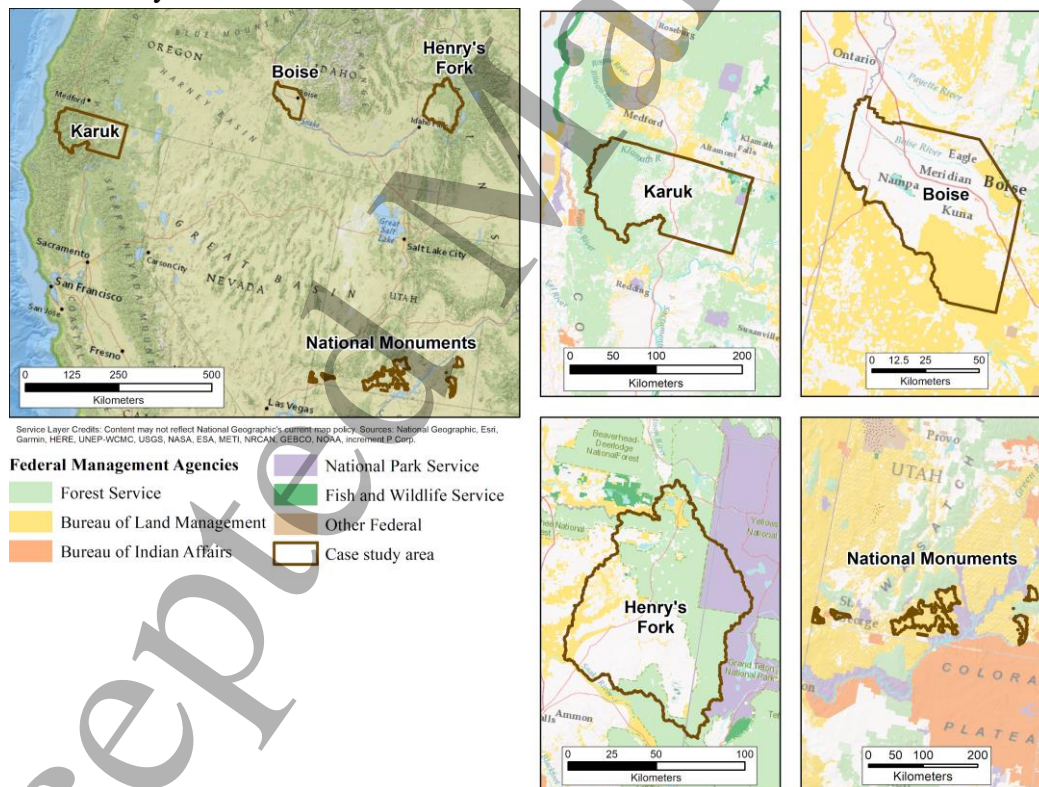
### 3. Examples of SES challenges and dynamics within the American West

In this section, we present four short case study vignettes describing SESs conditioned by the regional context. In Table 1, we characterize each SES using the fast variables described in Figure 3, and highlight how dynamic systems interact with the characteristics of the region that are exogenous to any given SES (as presented in Figure 2). Full case studies of each location summarized here can be found in Supplementary Material. Figure 4 depicts the geography of these SESs.

Table 1. Comparative summary of case studies

Example SESs	Exogenous variables	Fast variables
<b>Boise metro area</b>	Aridity Topography	Population growth High-tech activity
<b>Southern UT</b>	Topography Political economy of land	Amenity-based economic activity Stable population
<b>Karuk Tribe</b>	Political economy of land Aridity	High-intensity fire activity Drought
<b>Henry's Fork</b>	Aridity Political economy of land	Population growth Drought

Figure 4. Case study SES locations within the West



### 3.1 Urbanization, agriculture and private lands in the Boise metro area

Agriculture is an important component of historical and contemporary cultural identity of the West, and in some areas of the West that have the highest population growth in the U.S., urban development is taking place directly on top of limited agricultural land. In Boise, Idaho,

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3 the seventh-fastest growing metropolitan region in the US, urban land area has increased by 10%  
4 in just ten years (Narducci et. al 2019). Urbanization is driven in large part by population influx  
5 from other regions of the country because of this region's affordability and high quality of life  
6 (Sharf 2018). At the same time, agriculture and food processing generates 21% of Idaho's total  
7 economic output, and the Boise metro area has some of the state's best agricultural land.  
8 Research indicates that most people in the Boise area are worried about the rate of farmland loss  
9 (Som Castellano et al., 2017). However, the ability of communities to adapt, by implementing  
10 zoning, easements, or smart-growth, is constrained by a predominant conservative political  
11 ideology of limited government and private property rights. This ideology stems from antipathy  
12 to the one of the defining features of the West – federal land ownership – as 62% of the state of  
13 Idaho is owned by the federal government. With declines in agriculture and no complementary  
14 increase in conservation planning, ecosystem services provisioning is also shifting (for example,  
15 groundwater levels can drop with increased exurban residential water consumption as compared  
16 to that of agriculture) (Narducci et al. 2019; Quintas-Soriano et al. 2019).  
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### 23 *3.2 Overlapping land jurisdictions, livelihoods strategies and values in Grand Staircase-* 24 *Escalante and Bears Ears National Monuments*

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26 Conflicts over how to manage vast portions of the West have dominated regional  
27 discourse since the late 19th century. More recent vacillations over federal monument  
28 designation in southern Utah – specifically the creation and subsequent reduction in size of  
29 Grand Staircase Escalante (GSENM) and Bears Ears National Monuments (BENM) – serve to  
30 illustrate key ongoing tensions that define the West generally. These include vast public land  
31 ownership and management versus local autonomy, environmental protection versus extraction,  
32 and changing economic opportunities versus cultural desire to maintain early colonialist  
33 economic activities—all set against a backdrop of sensitive ecosystems and a legacy of Native  
34 dispossession by federal and state governments (Spence 1999; Petzelka and Marquart-Pyatt  
35 2012) . At their inception, GSENM and BENM were large protected area designations overlaid  
36 on federal lands previously managed for multiple use values (timber, mining, recreation, range,  
37 and ecological value such as wildlife habitat). Presidents designated the monuments (Clinton  
38 1996; Obama 2016) to protect unique desert ecosystems and geologic features as well as Native  
39 cultural heritage. The National Monument boundaries are overlaid on a rural landscape with a  
40 strong history of extraction as the dominant livelihood. Today, the economy of some parts of the  
41 region is dominated by a service industry that caters to amenity migration and tourism, but recent  
42 reductions in monument size and scope by President Trump represent an attempt to reinvigorate  
43 an extractive industry (Headwaters Economics 2017).  
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### 51 *3.3 Collaborative water management in the Henry's Fork Watershed*

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53 Water management in the West often requires balancing diverse economic, ecological  
54 and cultural values with priorities for what is most often a scarce resource. The Henry's Fork of  
55 the Snake River sustains angling and agriculture, the two main industries in the region, as well as  
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ecosystem health (Lawson 2012; Auerbach et al. 2015). The regional economy is strongly tied to water resources, which annually produces approximately \$2 billion (USD) in agriculture production and over \$30 million (USD) from angling (Loomis, 2006). Stakeholders within the Henry's Fork watershed have taken a collaborative approach to managing a scarce resource (IDEQ 2017; Van Kirk 2011; Van Kirk and Griffin, 1997; Van Kirk et al. (2019)). Political, cultural and economic differences among those who use the watershed for agriculture, recreation and conservation could generate conflict. However, a shared cultural identity around the unique location and long history of angling in the river has provided a constructive starting point for collaborative decision-making in the watershed. Local non-profit organizations such as the Henry's Fork Foundation and the Friends of the Teton River dedicate their mission to preserving, protecting, and sustaining the biodiversity found in the river (Van Kirk et al. 2019). These civil society groups have worked very closely with irrigation groups such as the Idaho Water Resource Board and the Henry's Fork Watershed Council to preserve the multifunctionality of the river. Consequently, ecological and agricultural groups and tourism industry have learned the best ways to share water resources so that all watershed stakeholders receive the benefits the Henry's Fork River provides (Van Kirk et al. 2019).

### *3.4 Karuk traditional knowledge, prescribed fire and a changing climate*

The West is characterized by a history of colonial dispossession of indigenous lands, much of which has been incorporated into federal land management systems (Spence, 1999). The loss of these lands has often led to the disenfranchisement of tribal and indigenous communities in setting goals for their shared management across jurisdictional boundaries. The Karuk Tribe, located in the Mid-Klamath region of California, is working to integrate traditional knowledge systems for managing forest ecosystems, including the use of prescribed fire to manage forest health, into priorities and partnerships with the US Forest Service and state agencies. Managing forest health using traditional practices also have the future-looking goal of reducing climate vulnerabilities associated with more frequent high intensity fires expected for the region (Norgaard 2016). This effort to maintain the viability of forest ecosystems and the non-timber forest products that are culturally and economically important provides an example of the social-ecological complexity associated with the political economy of tribal governance and public forest land management in the West. Global climate variability as an extra-regional driver of change in the Klamath region is expected to increase the severity of forest fires in the region and thus exacerbate coordination challenges across jurisdictions (Westerling et al. 2006). It remains to be seen whether the traditional knowledge systems of the Karuk Tribe will be adequately integrated into future cross-jurisdictional approaches to forest and fire management and whether they are employed to reduce present and future vulnerabilities.

#### 4. Connecting SES dynamics to the regional context of the American West: Implications for research and management

The power of a multilevel approach to SES research and management at a regional and system-specific scale is it recognizes the broad, consistent context within which much variation is present. Both exogenous variables and fast variables shape how specific SESs evolve over time, what management needs arise, and which possible futures exist for the human and ecological communities that comprise them. For researchers, discerning the relevant variables within the system that might seem far afield from a given question requires thinking across scales, domains and variability (Turner et al. 2016). For example, if changing federal policies limit the fire management practices currently used by the Karuk, and thus lead to an increase in fuels for high-intensity fires (themselves further fueled by climate change), many aspects of Karuk physical, spiritual and economic well-being could be at risk (Norgaard 2016; see also the Supplementary Material). From a management point of view, Chaffin et al. (2016) argue for a transformative governance approach in complex systems that can both respond to and in some cases instigate change in specific SESs situated in a broader context. This might look, for example, like the Henry's Fork watershed, where the topography and increasing incidence of drought led to land and water management changes that are adapting to regional aridity and improving recreational opportunities (see also Kepner et al. 2000). Collaborative management approaches that can engage with regional dynamics and institutions in ways that are place-specific have proven effective in some locations, and can be challenging in contexts where the regional exogenous variables, especially the political economy of land, dominate SES dynamics (Singleton 2002; Huber-Stearns and Cheng 2017).

This analysis is intended to provide initial direction for continued investigation of SES dynamics in the West, and the systematic assessment of cross-scale characteristics lends itself to the use of existing frameworks to address management needs and outcomes (for example, Ostrom (2009)). Taken together, the analysis and interpretation presented in this paper demonstrates that regional characteristics provide important continuities across space and time, and that SES dynamics in the West are therefore distinct from those in other regions. In contrast to analyses that define the West purely in geographic or cultural terms, this approach foregrounds the importance of a small number of unique, intersecting variables that set the stage for social-ecological interactions within specific places. This suggests that descriptions of regional demographic and ecological change, like those encapsulated in the 'old West' and 'new West,' may be defined as much by their similarities as by their differences, and points researchers to consider the interaction among multiple scales of space and time in analyses of western dynamics. As the American West confronts looming issues of climatic, demographic, and economic change, these drivers and their interactions are likely to remain as important as ever in shaping both conflicts and avenues for constructive adaptation.

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