Idaho Climate-Economy Impacts Assessment
Rangelands Report

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Key takeaways: anticipated changes to climate, risks, and implications for rangelands-dependent sectors

Anticipated changes

Precipitation: Idaho is projected to have more year-to-year variation in the timing and amount of precipitation, with more frequent extreme precipitation events. With more precipitation falling as rain than snow, spring snowpack is less than historical averages. The timing of when water moves out of watersheds is happening earlier in the year and minimum streamflows have been observed to be lower than historical average minimums.

Temperature: Warmer temperatures in all seasons are anticipated. Summers are expected to be warmer and drier, with increased frequency of extreme heat days and longer frost-free periods. Along with an expected increase in summer temperatures will be a slight decrease in summer precipitation and more frequent occurrences of drought, creating the potential for decreased native vegetation growth during warm seasons in water-limited places.

Risks

Drought: Higher summer air temperatures and slightly less precipitation falling in summer lead to longer and more severe droughts. Warming air temperatures increase evapotranspiration; dry air can hold more water and remove more moisture from the soil. These effects combined lead to greater plant stress.

Wildfire: Wildfire seasons are anticipated to continue to lengthen across rangelands in Idaho, resulting in more frequent and larger wildfires.

Invasive species: Warming air temperatures, drought, and increased risk of wildfire are favoring and will continue to favor invasive species, including annual grasses, over native perennials.

Terrestrial habitat degradation: Drought, wildfire, and invasive species spread all work together to alter microbial and plant communities, reducing habitat quality for wildlife and livestock.

Streamflow and aquatic habitat: Warmer air temperatures and more precipitation falling as rain than snow implies less snowpack and earlier snowmelt, reducing streamflow and increasing water temperatures.

Implications for rangeland-dependent sectors

Implications for livestock production: Wet winters and warmer, drier summers may decrease forage available during summer months, resulting in the need to adjust turnout dates. Feed crops harvested for later use, such as hay or alfalfa, may also suffer declines due to hotter, drier growing conditions and reduced water availability. Warmer temperatures may cause animal heat stress and require additional resources, such as shipping water. Both wildfire and annual grasses can impact yearly livestock grazing rotations, stocking rates, and rangeland management due to restoration and conservation of threatened wildlife species. Increasing inter-annual variability of precipitation and temperature can increase costs for livestock operations and limit their viability (for examples, see Ritten et al., 2010 and Briske et al., 2021).

Implications for rangeland managers: The consequences of drought and wildfire will continue to pose challenges. Converting degraded rangelands and croplands back to productive native rangelands with healthy perennial grasses has the potential to sequester atmospheric carbon. Managers can aim to keep rangelands productive, limit conversion to other land use types, and look for opportunities to restore degraded rangelands back to their potential.

Implications for recreation: Changes in temperature and precipitation may alter demand for recreational usage on rangelands. These changes will test the capacity of public lands, infrastructure, and staff to accommodate shifting recreational demands. Earlier snowmelt could increase shoulder season usage and ecological stress. Drought and wildfire may impact the availability of wildlife habitat, affecting bird and wildlife viewing and hunting. Wildfires, restoration efforts, and loss of species habitat may mean area closures to recreational use. Warmer stream temperatures and lower summer flow rates may negatively impact recreational cold-water fisheries while improving warmer-water fisheries.

1. Background: Idaho's rangelands and climate

Rangeland ecosystems are defined by their vegetation – shrubs and grasses are the dominant plant cover, and include sagebrush steppe, bunchgrass, and grass-filled meadows. In Idaho, rangelands occupy 54% of the land area – nearly 28.8 million acres in the southern part of the state. Federal government manages most of the acreage defined as rangelands (69%), followed by private ownership (25%), and state management units (6%) (Figure 1a). Idaho's rangelands cover most of southern Idaho and overlap significantly with where the majority of Idaho's residents reside. Rangelands provide many benefits for Idahoans, in the forms of livestock grazing, habitat for wildlife, and places to recreate.

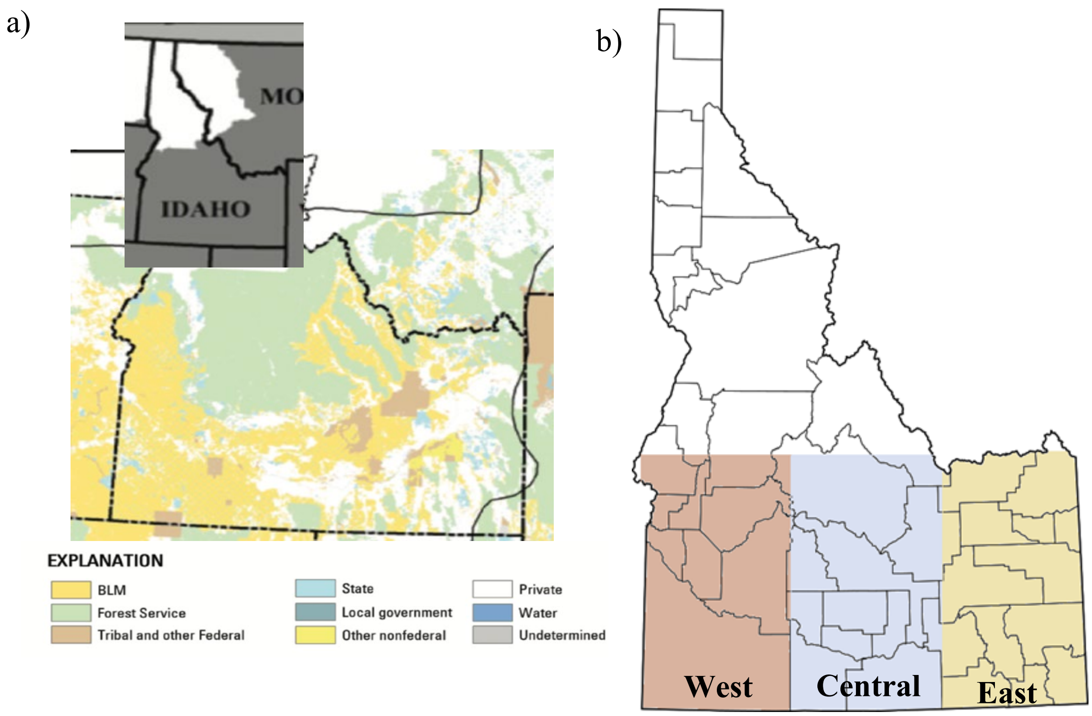

Figure 1. a) Rangeland management in Idaho and b) geographic division of rangelands in Idaho (data source: (a) Inside Idaho, Idaho Surface Management Agency and (b) University of Idaho Extension Regions).

How has climate change affected Idaho's rangelands?

From 1895 to 2019, the average annual temperature across rangelands in the intermountain west region of the United States increased by 1-3°F[1] (Climate Toolbox). Further, twenty of the warmest 21 years have occurred since 2000 (see the assessment's Climate Report). The warming trend is causing more winter precipitation to fall as rain instead of snow.[2] Though precipitation trends across the northwestern U.S. vary by location and time period considered, the strongest trend observed is an increase in spring precipitation, falling as rain (Chambers et al., 2008). While summer precipitation is variable, it is slightly declining. Changes in climate have already significantly impacted water availability, primary production, invasive species abundance, and wildfire size and frequency. These changes will continue and perhaps intensify, assuming future climate realizations follow trends and projections.

Though increased precipitation is generally considered a benefit for rangelands, slight increases in spring precipitation have occurred alongside higher spring temperatures, resulting in increasing aridity or dryness of the region (Dai, 2013). These more arid conditions have led to a greater loss of water from plants and from the land surface, resulting in less available soil moisture during the growing season (Dai, 2013; Abatzoglou et al., 2014; Snyder et al., 2019).

[1]Hegewisch, K.C and Abatzoglou, J. T., 'Historical Climate Tracker' web tool. Climate Toolbox (https://climatetoolbox.org/)

Hotter, drier conditions create stressors for native flora and fauna, increasing risk of invasive species spread and wildfire.

The warmer temperatures being experienced in rangelands lengthened the growing season by about four days per decade between 1975 and 2010 (Klos et al., 2015) or by about two weeks across the last 40 years (Figure 2) (Abatzoglou et al., 2014). Warmer temperatures are also lengthening the frost-free season (Abatzoglou et al., 2014). Multiple studies have predicted earlier and longer growing seasons across the northwest, leading to earlier green-up and greater early season forage production by the end of the century (Hufkens et al., 2016; Reeves et al., 2017).

Will climate in Idaho's rangelands continue to change?

Due to regional variation in climate, the southern part of Idaho has been divided into three regions of rangelands – west, central, and east (Figure 1b). Three main climate metrics that may have the greatest ecological and economic consequences for users of Idaho's rangelands have been identified: change in spring precipitation, number of "high" wildfire risk days, and days exceeding 100°F.

Average regional projections for early century (2010-2039) and mid-century (2040-2069) are presented in Figure 2. Projections are produced using the Climate Toolbox (Hegewisch et al., 2021) for regions demarcated using the borders displayed in Figure 1b. Following the rest of this technical report, estimates were performed for RCP4.5 and RCP8.5 scenarios, following the Climate Report.[2]

Projections are presented in Figure 2 as deviations from the 30-year average (1970-2000). Overall, each region will receive greater March-May precipitation, with the eastern region projected to have the largest increase in spring precipitation and the largest year-to-year variance. All regions are anticipated to experience an increase in days over 100°F, with the western region seeing the largest increase. All regions will likely experience an increase in heat stress days (days over 100°F), with the western region seeing the largest increase: +11 days between present and 2039 (RCP8.5) and an additional 27 heat stress days between 2040 and 2069 (RCP8.5). "High" wildfire risk days are also expected to increase by five days across the three regions between present and 2039 (RCP 8.5). Between 2040 and 2069, the "high" wildfire risk days are expected to increase further, with the largest increase (17 days) in eastern Idaho (RCP8.5).

[2] Two emission scenarios are used for this report to project future change, RCP4.5 (moderate-warming) and RCP8.5 (high-warming).RCP4.5 is a moderate-warming scenario and RCP8.5 is a high-warming scenario. Mid-century projections are less sensitive to choice of RCP; differences between RCP4.5 and RCP8.5 are most important for late century projections. More detail about RCP is provided in the assessment's Climate Report.

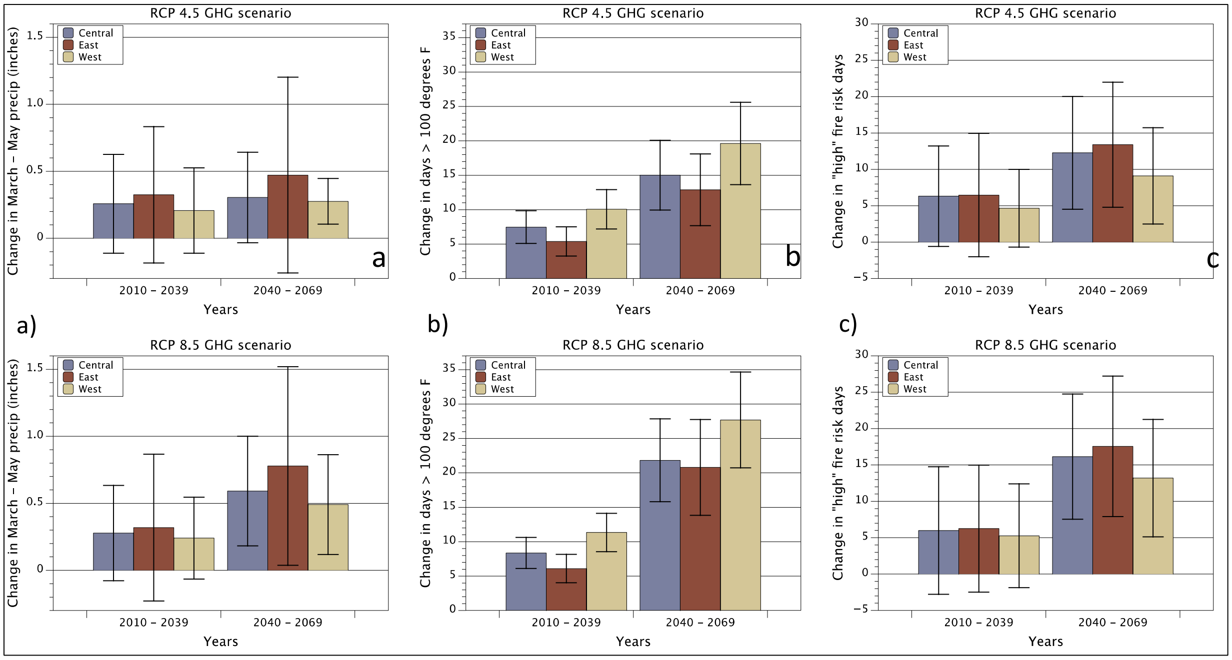

Figure 2. Projected increases in a) spring precipitation, b) heat stress days, and c) "high" wildfire risk days for three regions that comprise Idaho's rangelands, for early and mid-century time periods, as compared to the 30-year average (1970-2000) under RCP4.5 and RCP8.5 climate scenarios (data source: Climate Toolbox (Hegewisch et al., 2021)).

2. What are the ecological implications of a changing climate on Idaho's rangelands?

In resource-dependent sectors specifically, changes to ecosystems and the environment can have significant impacts on regional economies. Below is a discussion of how climate change may influence environmental and ecological factors that, in turn, create growing challenges to sectors that operate in Idaho's rangelands. While there are myriad ecological impacts that climate change will bring, the focus of this report is on anticipated changes to primary productivity and forage production, water availability, invasive species, and wildfire. It is important to point out that while ecological impacts are discussed separately, they are interrelated; for example, warmer, drier summers will impact forage availability and an earlier spring favors spread of annual invasive grasses over native vegetation, which, in turn, influences wildfire frequency and severity. It is worth noting the complexity of ecological changes and the potential for feedback loops between production and management decisions and the natural system. These feedbacks loops are opportunities for future discussion and research.

Primary productivity and forage production

Precipitation is the most important factor in rangeland plant primary productivity, which includes native vegetation and forage. Earlier snowmelt and an increase in spring precipitation in the form of rain rather than snow implies that plant growth will begin earlier in the year and end earlier in the summer (Neibergs et al., 2018). Greater variability in precipitation, including longer drought periods and deluge events, implies that soil water content is expected to exacerbate plant stress levels more often. Lower soil moisture has the potential to limit forage nutritional quality and productivity during summer months, especially during periods when summer precipitation may be less than normal (Polley et al., 2013; Polley et al., 2017). It is unclear how projected changes in both precipitation and temperature will influence forage production in rangeland ecosystems. There are few long-term datasets on plant biomass and production specific to Idaho and the intermountain west. Therefore, there is a significant knowledge gap in the understanding of how historic climate influences vegetative production. Larger scale models predict forage productivity to increase across northern grasslands in the U.S. by the end of the century due to increased growing season length (Reeves et al., 2014; Hufkens et al., 2016; Polley et al., 2017).

Year-to-year variation and shifting timing of seasonal precipitation and temperature will alter the growth and amount of forage on rangelands that is critical in the diet of herbivores, including livestock, ungulates, and threatened species, such as the greater sage-grouse. Wildlife managers and livestock producers are accustomed to uncertainty and variability in annual precipitation. However, changes to the timing of forage availability and drought duration suggest increasing variability for which current management approaches to balance forage supply and demand may no longer fit (Briske et al., 2021). Common adaptive approaches, including de-stocking during extreme droughts and re-stocking during years of surplus, may not be economically viable for regions experiencing long-term loss of forage production. Adaptive management and novel rules of thumb may be necessary to sustain livestock operations and maintain wildlife populations. These changes may include livestock turnout dates, grazing rotations, and stocking rates, as well as wildlife conservation strategies. Failure to consider how climate change will impact forage production in rangeland systems will have economic and management implications for livestock producers, wildlife conservation, hunting, and wildlife viewing.

Water availability
Less precipitation falling as snow is reducing spring snowpack, changing the timing of when water moves out of watersheds, and lowering minimum streamflow. These changes impact water available for livestock, irrigation, and wildlife.

While total amount of precipitation falling in a year has not changed much in the face of climate change, the timing of when that precipitation falls during the year and in what form (rain instead of snow) is changing. With increasing temperatures, Idaho is experiencing less snow (Chambers et al., 2008) and a reduced spring snowpack (Holden et al., 2018; Mote et al., 2018).

Fewer but larger and more intense precipitation events reduce soil moisture and increase water losses to surface runoff and percolation to groundwater (Schreiner-McGraw et al., 2019). Earlier snowmelt and drought are anticipated to reduce streamflow and production in riparian systems.

Invasive annual grass abundance
Climate change is expected to alter the current geographic distributions of invasive species and, in particular, invasive annual grasses. Warmer winters and increased wildfire frequency will benefit annual invasive grasses, such as cheatgrass (*Bromus tectorum)*, medusahead (*Taeniatherum caput-medusae*), and red brome (*Bromus madritensis*), which have expanded in mid- to low-elevation shrublands and woodlands in the last 50 years (Figure 3) (Chambers et al., 2008). In general, the earlier and longer growing seasons, as well as warmer temperatures, are creating conditions that favor annual grasses over native vegetation. Cheatgrass is expected to

benefit, with warmer summers and decreased precipitation due to reduced competition from native plants and increased likelihood of wildfires (Bradley et al., 2009). Sites with sparse perennial grass cover are most susceptible to invasion by these annual grasses. In a changing climate, annual invasive grass species are likely to become more abundant at higher elevations (Chambers et al., 2008; Bansal et al., 2016).

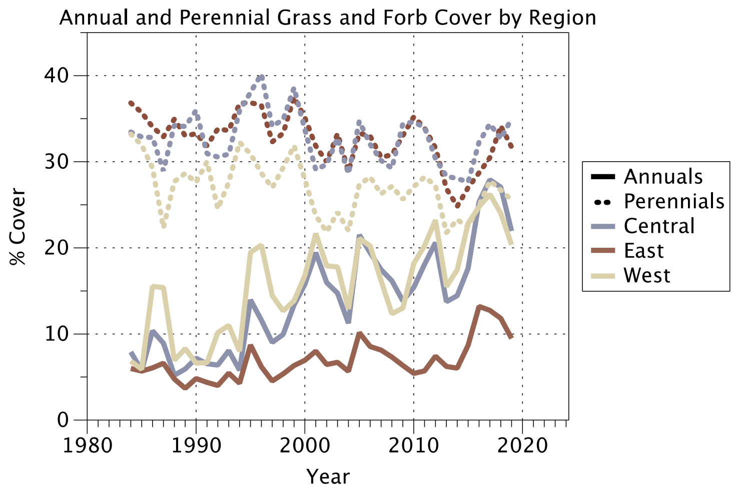

Figure 3. Estimated annual percent cover for Idaho's rangelands by region (data source: Rangeland Analysis Platform).

While many projections forecast cheatgrass range expansion in the northern latitudes and higher elevations, at lower latitudes cheatgrass is expected to contract where drier winters are projected (Abatzoglou et al., 2011) due to limited moisture and subsequent plant establishment and growth (Bradley et al., 2016). Unfortunately, the contraction of cheatgrass in its southern range may benefit another annual invasive grass, red brome, which can tolerate drier conditions (Bradley et al., 2016).

Wildfire

Across the Pacific Northwest, annual wildfire season length and annual burned areas continue to increase (Klos et al., 2015). In the Snake River Plain and the Columbia Plateau ecoregions, large wildfires are becoming more frequent (Dennison et al., 2014). The number, frequency, and size of wildfires are dictated by multiple variables: climate, vegetation type, and fuel bed characteristics of natural and human ignitions (Chambers et al., 2019).

Much of the increased wildfire frequency and area burned across the sagebrush steppe region has been attributed to an increase in invasive annual grasses (Balch et al., 2013; Pilliod et al., 2017). Invasive annual grasses, such as cheatgrass, create a continuous fuel bed in places that historically had native perennial bunchgrasses and shrubs, which results in a more patchy and limited fuel bed compared to cheatgrass (Chambers et al., 2019). In these locations, the amount of accumulated litter from invasive annual grasses, which is tied to increased precipitation in the prior year(s) (Pilliod et al., 2017), influences wildfire frequency and size (Balch et al., 2013). Historically, the wildfire return interval was 30 to 72 years in sagebrush systems and is now reduced to less than 5 years in heavily invaded locations (Brooks et al., 2004).

Increased temperatures and lower humidity during spring and summer create conditions advantageous for wildland fire (Abatzoglou et al., 2011). Plant composition can be impacted by increasing wildfire frequency, leading to a replacement of wildfire-sensitive with wildfire-tolerant plants, such as invasive annual grasses. This increased wildfire frequency and area burned benefit invasive annual grasses that can invade areas where perennial plants are set back by intense and/or frequent wildfire. Invasive annual grasses are linked in a positive feedback loop with wildfire across the sagebrush steppe rangelands, meaning with more wildfire comes more invasive annual grasses, and more invasive annual grasses promote more wildfires (Synder et al., 2019).

3. Economic implications of a changing climate in Idaho's rangelands

Quantifying the economic impacts of climate change is limited by uncertainty about future climate, complexity in how ecosystems will be impacted by these changes, and uncertainty about future market conditions. Further, the economics of sectors and agencies that are connected to rangeland ecosystems in the western U.S. are data-limited and understudied, so assessment of the economic impacts is largely unknown. Based on the summary of the anticipated impacts of temperature and precipitation on ecological factors, including net primary productivity and forage production, water availability, invasive species abundance, and wildfire severity and frequency, presented below are anticipated impacts of these ecological changes on three economic sectors that heavily utilize rangeland ecosystems—livestock production, wildlife management, and recreation. When possible, case studies summarize existing assessments of the economic impacts resulting from changes to these environmental factors on livestock production, wildlife management, and recreation.

Livestock production

Much of Idaho's livestock industry relies on rangeland ecosystems for summer grazing and feed crops. In 2019, cattle and calf production ranked second in magnitude of statewide agricultural commodities in cash receipts (Table 1). Idaho's average annual beef cattle and calf inventory exceeds one million head (USDA National Agricultural Statistics Service (NASS)). Idaho's beef cattle industry is predominantly based in Idaho's rangelands (southern Idaho). In 2019, Idaho's top beef producing counties were Owyhee, Bingham, Cassia, Twin Falls, and Lemhi (USDA NASS).

Commodity	2019 Cash Receipts (in $ millions)	Average Share of Total Idaho Cash Receipts for 2015-2019
Dairy	$2,854	33.3%
Cattle and calves	$1,736	23.4%
Potatoes	$953	12.1%
Hay	$468	5.5%

Table 1. Estimates of 2019 cash receipts for the top four commodities produced in Idaho (USDA NASS).

Rangeland ecosystems play an important role in livestock production, both through their use for grazing and the production of hay and alfalfa feed crops. Many producers lease federal, state, or private lands for livestock grazing during the growing season. Over 1.5 million head of cattle, sheep, and horses graze on Idaho's public rangelands, which are managed by the Bureau of Land Management (BLM) and U.S. Forest Service (USFS) annually, amounting to over 2.05 million animal unit months (AUMs) of forage (Table 2).

Managing Agency	Cattle (head)	Sheep (head)	Cattle (AUMs)	Sheep (AUMs)
BLM	534,869	615,829	1,123,800	175,872
USFS	128,888	217,540	606,864	147,966
Combined	663,757	833,369	1,730,664	323,838

Table 2. Summary of current livestock grazing authorizations on federal lands in Idaho (sources: BLM and USFS use schedules).

Potential impacts to livestock production

Availability and quality of forage and feed crops

Overall, is unclear how changes in temperature and precipitation will impact forage production on rangelands. Warmer winters and earlier, wetter springs may result in greater forage production during these times, while hotter, drier summers may reduce forage availability during seasons that rangelands have typically been relied upon for forage. Changes to forage production, including increasing year-to-year variability, may require livestock producers to derive novel grazing rotations or alter timing and intensity of grazing.

Case study: Economic impacts of drought on a ranching operation in south-central Idaho

Wold et al. (2021) combine forage production estimates using remotely sensed imagery and historic climate data with an economic model of a representative ranch in south-central Idaho. Forage projections are used as constraints in an economic model to determine optimal production decisions and quantify the economic impact of changes in forage production for a livestock producer in response to short-term severe and long-term moderate droughts on a representative ranch. Economic impacts:

- The forage reductions caused by a 5-year severe drought resulted in a 10% reduction in herd size. A 10-year moderate drought resulted in a 4% reduction in herd size, both of which persist for up to 10 years after the end of the drought.
- For a 300-head operation, a 10-year moderate drought resulted in a 16% reduction in average annual ranch income (an annual loss of ~$14,000 during the drought).
- For a 300-head operation, a 5-year severe drought resulted in a 28% reduction in average annual ranch income (an annual loss of ~$23,000 during the drought).

Water availability
Less water available on rangelands will influence the livestock sector, which uses surface water and groundwater for animal consumption, feed crop irrigation, and animal cooling. Higher summer temperatures may increase animal water consumption by a factor of two (Nardone et al., 2010). Irrigation water curtailments and water price increases may increase the cost of growing and purchasing feed crops or cause irrigated pastures used for hay or alfalfa to be cost-ineffective in production.

Case study: Economic implications of investing in off-stream water sources for livestock

Livestock utilization of riparian areas is often relied upon by ranchers for late summer forage, cooling, and water. Stillings et al. (2003) developed a bioeconomic model for southwestern Idaho and northeastern Oregon (the Blue Mountains region) that tracks the ecological and economic impacts of a 15% reduction in utilization of riparian areas by providing off-stream water and minerals. While this study does not consider reductions in surface water availability, its conclusions can inform the impacts of adapting to such a change. Economic implications:

- Reduced utilization of riparian areas resulted in a reduction in herd size of 10%.
- By restricting access to riparian areas, upland forage and off-stream pastures were more heavily utilized, resulting in additional availability of animal units. Greater usage of pasture with supplementation also resulted in higher sale weights.
- Larger sale weights and herd size resulted in an increase in annual returns to the ranching operation of $4,500 to $11,000 per year, with the variation depending on annual precipitation and cattle prices.

Heat stress has been cited as a major cause of reduced productivity in the beef industry. In cattle, heat stress impairs animal growth, pregnancy rates, and disease susceptibility. St-Pierre et al. (2003) found that heat stress causes an annual loss of $1.69-2.36 billion to the livestock industry. The same study found that annual heat stress created a total of $1.035 million in losses to Idaho's beef cattle industry per year.

Warmer summer temperatures and reduced water availability may require that livestock producers alter grazing rotations to mitigate heat stress and ensure water is available. Providing supplemental water for animals may be necessary.

Invasive species
The spread of invasive plant species in rangelands reduces forage availability for livestock operations. Producers may choose to control invasive species, using chemical or mechanical methods, but this comes at a cost. Producers must weigh the tradeoffs of lost forage production and control costs in range management decisions.

Case study: Economic impacts of yellow starthistle to Idaho's agricultural industry

Infestation of yellow starthistle (*Centaurea solsitialis* L.) outcompetes native vegetation, reducing forage availability for livestock and wildlife. Julia et al. (2007) used an input-output model to determine the costs of reduced forage availability due to the yellow starthistle invasion in Idaho. Assuming an infestation of 266,000 acres:

- The yellow starthistle invasion reduced available forage for livestock by 221,858 AUMs per year.
- The direct and secondary (induced) economic impacts of the infestation to the agricultural sector were $10,124,000 per year (in 2005 USD).

Wildfire

Increasing frequency and severity of wildfire events on rangeland ecosystems can create short- and long-term reductions in the quantity of forage available. Following a wildfire, public grazing allotments are closed for several years, meaning summer forage must come from an alternate source. Establishment of invasive annual grasses and the replacement of native vegetation with noxious weeds after a wildfire event can further reduce forage availability in the long-term. While livestock find cheatgrass palatable in winter and early spring months, utilizing stands for forage may require modifications to grazing rotations and/or grazing permits.

Case study: Economic impacts of wildfire on a ranching operation in western Idaho

Maher et al. (2013) simulated the economic impacts to a representative livestock producer from shortened wildfire return intervals and wildfire occurrence on a public grazing allotment. Economic impacts:

- After a wildfire, herd size is reduced by up to 40% due to reduced forage availability.
- In the years just after a wildfire event, ranch income is reduced by up to $60,000 and often requires short-term borrowing of up to $20,000.
- The likelihood of bankruptcy after a wildfire event on a grazing allotment is 22%, assuming average beef prices.
- The economic impact of annual grasses and wildfires can be reduced if ranchers factor risk into their production decisions and identify alternative early-season forage sources or diversify to off-ranch income streams.

Wildlife and habitat management

The 28.8 million acres of rangelands in Idaho are managed by a combination of public land management agencies and private landowners (Table 3). Over half of the acreage is managed by federal agencies – primarily the BLM and the U.S. Forest Service. Rangeland managers are in a unique position in that they are charged with managing lands that are used to support ranching and herding, recreation, and critical habitat for many terrestrial and aquatic wildlife species, including salmonids, migratory ungulates, and the greater sage-grouse.

As such, maintaining rangelands as working landscapes and conservation of sagebrush steppe ecosystems is one of the most difficult and pressing concerns for land management in the western U.S. Rangeland management agencies are charged with setting and enforcing harvest restrictions (including forage utilization by livestock) and conserving wildlife species by preserving their populations and habitats. Faced with limited budgets and the need to spend public resources cost-effectively, managers need to determine activities that meet their mandated objectives, as well as objectives desired by the public, at least cost. Management decisions include allocating resources to permitting livestock grazing, mitigating the spread of invasive species and wildfire risk, restoring habitat, managing recreation, overseeing extractive industries and energy development, and conserving species. The stresses created by climate change are expected to increase the difficulty of managing these multi-use landscapes.

Management Authority	Acres of Rangeland	Percent of Total Rangeland
Bureau of Land Management	10,961,030	38.1
U.S. Forest Service	7,443,706	25.9
Private	6,827,264	23.7
Idaho Department of Lands	1,505,797	5.2
Other Federal	1,382,443	4.8
Tribal	504,853	1.8
Other State	148,879	0.5

Table 3: Acres of rangeland in Idaho (data source: Multi-Resolution Land Characteristics Consortium (MRLC), 2016, accessed September 2018).

Potential impacts to wildlife and habitat management

Ungulates and big game species

For ungulates, climatic changes can have both positive and negative implications. For deer, elk, pronghorn, and moose, the winter season has the highest mortality rates and changes in snow density and hardness from freeze-thaw or rain-on-snow events can limit forage availability (Christianson and Creel, 2007; Hurley et al., 2015; Kautz et al., 2019). Movement through snow is also energetically demanding and can limit the ability to evade predators (Parker et al., 1984; Telfer and Kelsall, 1984; Mech et al., 2001). If climate change leads to a reduction in snow cover and depth, habitat for ungulates may expand, as they have a preference for areas with shallower snowpack (Jenkins, 2007; Weiskopof, 2019; Deb, 2020). (See the assessment's Ungulate Report by K. Strickfaden for more information.)

Forage may become available earlier in the spring due to increasing temperatures and can lead to higher survival rates of fawns (Hurley et al., 2014). This may also result in increased prevalence of tick- and mosquito-borne diseases and lead to an increase in mortality rates (Sonenshine, 2018; Ludwig et al., 2019). Other environmental stressors, such as longer periods of drought and high temperatures, increased wildfire frequency and severity, and more frequent soil freezing events, will place additional stress on vegetation communities and limit nutritional quality of forage available to ungulates (Christenson et al., 2014). Vegetation with low nutritional quality prevents ungulates from putting on the fat they need to survive the winter. Furthermore, a female in poor body condition may give birth to smaller offspring or breed and give birth later in the year, both of which will increase her offspring's susceptibility to predation. Females may even choose not to breed at all. Because of this lag effect, the impacts of poor foraging conditions on population dynamics may not become apparent until the next year when recruitment or reproductive rates are low (Horne et al., 2019). (See the assessment's Ungulate Report by K. Strickfaden for more information.)

A threatened species – greater sage-grouse

Greater sage-grouse populations are declining throughout most of their habitat range. Population decline is a complex issue, with likely many causal factors, including changes to rangeland climate. Critical habitat includes perennial bunchgrasses and shrubs for nesting habitat, forbs and insects for feeding, and riparian habitat for foraging during dry summer months. Increased wildfire return intervals and subsequent annual grass invasions and juniper encroachment have resulted in loss of nesting habitat for the bird. The greater sage-grouse was considered for listing in 2010 under the Endangered Species Act (ESA), but found to be "warranted, but not precluded." Listing was reconsidered in 2015; again, the species was found to warrant protection, but other species were found to be higher priority. With further decline of greater sage-grouse populations due to changes in climate and other anthropogenic change within their habitat range, potential listing as endangered continues to be a possibility. Much of the remaining greater sage-grouse habitat overlaps with BLM-managed lands and private lands (Table 4), implying any conservation policy will have implications for numerous jurisdictions and managers across rangelands.

Management Authority	Percent of Greater Sage-Grouse Habitat
Bureau of Land Management	63
Private	19
State of Idaho	7
U.S. Forest Service	5
Other Federal	6
Tribal	1

Table 4: Percent of greater sage-grouse habitat in Idaho by land management (data source: Gillian et al., 2017).

As such, greater sage-grouse protection is written into many federal and state rangeland management plans, as well as mandates for private lands. While figures on expenditures toward greater sage-grouse conservation are vague, in 2019, the Idaho state legislature committed almost $1 million toward greater sage-grouse conservation. In 2020, federal appropriations for the greater sage-grouse across the western U.S. amounted to $66 million (H.R.133 - 116th Congress, 2019-2020). Further population declines and listing of the species would have impacts to economic sectors in addition to the conservation requirements from the listing itself.

Taylor et al. (2019) summarized the findings of several studies that estimate the economic impact of greater sage-grouse conservation, in terms of lost AUMs for grazing. They quantify the total reductions in earnings over a 40-year operating horizon to livestock producers for three possible scenarios for Idaho and southwest Montana– reduction of 1 month of AUMs for spring grazing ($60.5 million loss), reduction of 1 month of AUMs for fall grazing ($61 million loss), and reduction of 1 month of AUMs for both spring and fall grazing ($122.5 million loss). This analysis also used an input-output regional economic modeling framework to estimate the direct, indirect, and induced impacts of the same conservation policies and found the total impacts to be $1 billion, $1 billion, and $2 billion, respectively, for the same 40-year time horizon.[3]

Invasive species management
Annual invasive grasses, such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*) are two of the most impactful stressors to rangeland ecosystems in Idaho. These annual invasive grasses have massive seed production capacity and once introduced, quickly spread across a landscape to create near monocultures, on both public and private lands. These annual invasive grasses outcompete native forage species, impact wildlife habitat quality, and change wildfire regimes. Currently, the estimated losses from weeds in pasture and rangeland systems exceed $2 billion annually in the U.S. (Pimental et al., 2005), which is a greater loss than all other pests combined.

In 2018, the estimated direct damages (including fighting wildfire) to the state of Idaho from existence of all noxious and invasive plants exceeded $300 million annually. In the same year, Idaho invested $30 million in the control and management of weeds.

Case study: Controlling invasive species in complex social landscapes

Epanchin-Niell et al. (2010) summarized the complexities that resource managers face when deciding how to address biological invasions and provided several recommendations for successful control.

- Control across land-use "mosaics" (public and private lands in various uses) requires collective effort and coordination to reduce costs and support effective action.
- Lack of action by any one stakeholder can reduce nearby stakeholders' incentives by increasing costs of control.
- Top-down (federal-level) or middle-out (state-level) action should include education, incentives, and communication amongst stakeholders to facilitate coordination.

Wildfire
While wildfire is a natural part of rangeland ecosystems, the increasing size and frequency of wildfire can lead to reduction in native grass and forb production, as well as degradation in habitat. Reduction in cover of sagebrush from frequent wildfire can reduce habitat suitable to the greater sage-grouse (BLM, Northern Great Basin Ecoregion: Rapid Ecoregional Assessment). More frequent wildfires and warmer temperatures also contribute to an increase in cover of invasive species, such as annual invasive grasses like cheatgrass, which can lead to a positive feedback cycle (Balch et al., 2013; Bradley et al., 2018). Lower-elevation sagebrush sites are at greater risk of conversion to invasive annual grass-dominated sites (Suring et al., 2005).

[3]For more detailed information, see: https://www.wyoextension.org/agpubs/pubs/b-1258A_sagegrouse_economics-web.pdf

Recreation [4]

Fishing, hunting, and wildlife viewing are long-standing traditions in Idaho. In 2016, BLM land in Idaho alone saw 466,100 fishermen, 296,500 hunters, and 193,500 wildlife watchers. The total expenditures related to these economic activities in 2016 were $295 million, supporting 2,559 jobs and $85 million in salaries and wages. Recreational use on BLM land also generated $33 million in federal, state, and local taxes (Pew Fact Sheet, 2018).

About 5% of Idahoans participate in hunting; big game hunting is the most popular type of hunting in the state (USFWS, 2016). On average, nearly 65,000 deer tags and 35,000 elk hunting tags are issued in wildlife management units in southern Idaho annually (Idaho Department of Fish and Game, 2021). Participation in deer and elk hunting on Idaho's rangelands has increased slightly over the last 20 years throughout central, eastern, and western Idaho (Figure 4).

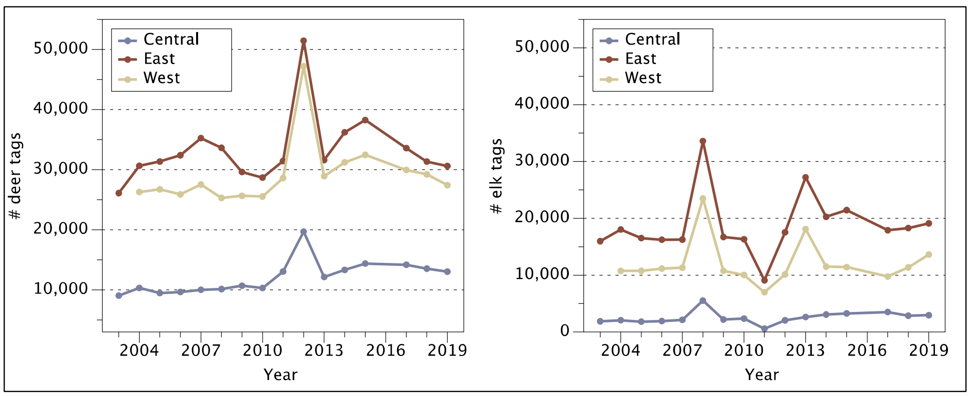

Figure 4. Annual issuance of deer and elk hunting tags in central, eastern, and western regions of Idaho (data source: Idaho Department of Fish and Game, 2021).

Idaho's rangelands contain some of the state's most prized rivers for recreational fishing, including the Henry's Fork, Big Wood, and Boise rivers. In 2016, over 465,000 fishing trips were taken in Idaho. Recreational fishers spend, on average, $438 million per year (USFWS, 2016). Using a survey and demand analysis, McKean et al. (2016) estimated that the willingness to pay for a fishing day trip in central Idaho to be $35, with an annual value per angler of $236. In 2016, the University of Idaho Policy Analysis Group found that the recreational fishery in the Big Wood River Valley contributed $2.5 million in value-added (a combination of output and wages) to Blaine County's economy (Cook and Becker, 2016). Fifteen percent of Idahoans participated in recreational fishing (USFWS, 2016).

Potential impacts to recreation

Water availability

Changes in water availability and streamflow may have impacts on watersports (boating) and fishing across rangelands. Stream temperatures impact the distribution and abundance of aquatic organisms, including coldwater salmonids, such as salmon and trout. These species are valuable sport fishing species and are also culturally important to Native Americans. Altered timing of

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[4] See the assessment's Recreation and Tourism Report for more information.

seasonal precipitation and warmer air temperatures can affect stream temperatures and streamflow and reduce the amount of habitat available to these fish species. Simultaneously, warmer water temperatures are favorable to other sport fish, such as bass (see the assessment's Fish Report by C. Caudill et al. for more information). As discussed above, changes to surface water may also impact terrestrial wildlife populations, creating implications for big game hunting.

Isaak et al. (2017) created a stream temperature database across Idaho and also modeled whether a particular species could occupy a given location under future climate change scenarios. The native salmonids of Idaho have particular stream temperature tolerances; if these are exceeded, individual fish within a location may experience difficulty migrating, declines in reproductivity, or even die-offs. At the same time, non-native fish species may move into those areas, and cold-water salmonids may find other areas of a stream that are currently too cold shift towards their temperature tolerance, but this depends on streamflow and channel characteristics. The assessment's Fish Report suggests that under climate projections, the stream areas suitable for bull trout and cutthroat trout will decline 46% and 11%, respectively, as temperatures in larger rivers exceed their tolerance. Further, the stream areas suitable for spring/summer Chinook salmon will not experience a net loss due to compensating gains in smaller streams. However, mortality for spring/summer Chinook salmon will grow as difficulty in migrating to spawning areas increases. Suitable areas for smallmouth bass, a predator of juvenile salmonids, is predicted to nearly double in size (see the assessment's Fish Report by C. Caudill et al. for more information).

Invasive species
Heavier usage of rangeland ecosystems by recreationists may increase the introduction and spread of existing invasive species, as well as introduce novel non-native species to Idaho's rangelands.

Case study: Economic impacts of invasive species on outdoor recreation

Eiswerth et al. (2005) used economic data in combination with the national recreational survey to estimate the impacts of invasive plants on outdoor recreation in western states. Key takeaways:

- The total economic loss resulting from invasive species spread was estimated to be between $5.9 and $12.4 million per year.
- Total economic losses depend on the rate of annual infestation expansion (5%: $30 million; 20%: $41 million).
- Out-of-state recreational expenditures were estimated to be reduced by $4.47 million (5%) and $17 million (20%), respectively.

Wildfire
The frequency and severity of wildfires are anticipated to increase on rangelands and can impact recreation. During years in which federal agency budgets for firefighting are exceeded, agencies borrow from other accounts, including funds allocated for brush removal and recreation-related programs. Further, agency staff can be diverted to fight wildfires, leaving trail maintenance and

other recreation-related duties unattended. In 2015, the Okanagan-Wenatchee National Forest in Washington state closed access because of the lack of personnel and financial resources needed to keep the forest open to the public. Diversion of overall resources to firefighting can lengthen area closures and delay site restoration. Wildfires also have direct impacts to recreational demand by keeping in-state and out-of-state visitors away due to danger, destruction, and smoke.

4. Knowledge gaps

Idaho's rangelands will be shaped by forces that include climate change and management decisions. The interactions between these two factors are complex and still under investigation. Currently, assessments of how climate will influence future forage production on rangelands hold other values constant, including the assumption that management rules of thumb also are not changing simultaneously. While rangeland managers are developing new tools to adapt to observed changes in climate and mitigate the consequences of climate change, which management practices result in sustainable use and maximize economic potential (or minimize consequences) are very context dependent and not one-size-fits-all. This makes it difficult to predict how specific actions may impact the environment or related economy or provide specific recommendations.

5. Conclusions

Climate change is one of many factors that influence the current and future state of rangeland ecosystems. This report was intended to discuss the anticipated environmental changes and potential economic impacts of climate change for rangeland-dependent sectors in Idaho. In summary, the environmental changes of greatest concern are related to warmer temperatures and timing of precipitation. Some of the expected changes, such as warmer winters and springs, will lengthen the growing season and promote forage growth during these times, benefitting livestock and wildlife. Other expected changes, including hotter, drier summers, will create new challenges for maintaining healthy rangelands and dependent economies, including animal heat stress, surface water availability, and invasive species and wildfire risk.

To complicate matters further, the risks mentioned above are also linked to anthropogenic land use and management decisions made on rangelands. Development in critical wildlife habitat areas, heavy recreational use during shoulder seasons, and chronic overgrazing can exacerbate some of the risks brought on by climate change. These interactions should be considered when developing future rangeland management plans.

Shifts in the ecology of Idaho's rangelands will have consequences for Idaho's wildlife and economy. Under these changing conditions, adaptive management strategies and proactive management decisions will be necessary to improve rangeland sustainability and resilience.

References

Abatzoglou, J. T., Rupp, D. E., Mote, P. W. 2014. Seasonal Climate Variability and Change in the Pacific Northwest of the U.S. *American Meteorolgical Society,* **27**, 2125–2143.

Abatzoglou, J. T. and Kolden, C. A. 2011. Climate Change in Western US Deserts: Potential for Increased Wildfire and Invasive Annual Grasses. *Rangeland Ecology Managment.* **64**, 471–478.

Balch, J. K., Bradley, B. A., D'Antonio, C. M., Gomez-Dans, J. 2013. Introduced Annual Grass Increases Regional Fire Activity Across the Arid Western USA (1980 – 2009). *Global Change Biology,* **19**, 173–183. https://doi.org/10.1111/gcb.12046

Bansal, S. and Sheley, R. L. 2016. Annual Grass Invasion in Sagebrush Steppe: The Relative Importance of Climate, Soil Properties and Biotic Interactions. *Oecologia,* **181**, 543–557.

BLM, Northern Great Basin Ecoregion: Rapid Ecoregional Assessment. U.S. Department of the Interior. https://landscape.blm.gov/geoportal/catalog/REAs/REAs.page

Bradley, B. A. 2009. Regional Analysis of the Impacts of Climate Change on Cheatgrass Invasion Shows Potential Risk and Opportunity. *Global Change Biology,* **15**, 196–208.

Bradley, B. A., Curtis, C. A., Chambers, J. C. 2016. Exotic Brome-Grasses in Arid and Semiarid Ecosystems of the Western US. *Exotic Brome-Grasses in Arid and Semiarid Ecosystems of the Western US,* 257–274. doi:10.1007/978-3-319-24930-8

Brooks, M. L., DíAntonio, C. M., Richardson, D. M., Grace, J. B., Kelley, J. E., Ditomaso, J. M., Hobbs, R. J., Pellant, M., Pyke, D. A. 2004. Effects of Invasive Alien Plants on Fire Regimes. *Bioscience*, **54**, 677-688

Briske, D. D., Ritten, J. P., Campbell, A. R., Klemm, T., King, A. E. 2021. Future Climate Variability Will Challenge Rangeland Beef Cattle Production in the Great Plains. *Rangelands*, **43**(1), 29-36.

Caudill, C., Masingale, J., Seaborn, T., Hora, D., Isaak, D. 2021. Sensitivity of Idaho Fishes to Climate Change. *Idaho Climate-Economy Impacts Assessment*. James A. & Louise McClure Center for Public Policy Research, University of Idaho. Boise, ID.

Chambers, J. C. and Pellant, M. 2008. Climate Change Impacts on Northwestern and Intermountain U.S. Rangelands. *Rangelands,* **30**, 29–33.

Chambers, J. C., Brooks, M. L., Germino, M. J., Maestas, J. D., Board, D. I., Jones, M. O., Allred, B. W. 2019. Operationalizing Resilience and Resistance Concepts to Address Invasive Grass-Fire Cycles. *Frontiers in. Ecology and Evolution,* **7**.

Christianson, D. A. and Creel, S. 2007. A Review of Environmental Factors Affecting Elk Winter Diets. *Journal of Wildlife Management,* **71**(1), 164-176.

Christenson, L. M., Mitchell, M. J., Groffman, P. M., Lovett, G. M. 2014. Cascading Effects of Climate Change on Forest Ecosystems: Biogeochemical Links Between Trees and Moose in the Northeast USA. *Ecosystems,* **17**, 442-457.

H.R.133 - 116th Congress (2019-2020): Consolidated Appropriations Act, 2021. (2020, December 27). https://www.congress.gov/bill/116th-congress/house-bill/133/text

Cook, P. and Becker, D. 2016. Preliminary Estimates of the Economic Effect of Stream Restoration on the Big Wood River Valley, Idaho. Policy Analysis Group Issue Brief No 18.

Dai, A. 2013. Increasing Drought Under Global Warming in Observations and Models. *Nature Climate Chang,* **3**, 52–58.

Deb, J. C., G. Forbes, MacLean, D.A. 2020. Modelling the Spatial Distribution of Selected North American Woodland Mammals Under Future Climate Scenarios. *Mammal Review* **50**, 440–452.

Dennison, P. E., Brewer, S. D., Arnold, J. D., Moritz, M. A. 2014. Large Wildfire Trends in the Western U.S., 1984–2011. *Geophysical Research Letters,* **41**, 2928–2933.

Eiswerth, M. E., Darden, T. D., Johnson, W. S., Agapoff, J., Harris, T. R. 2005. Input-output Modeling, Outdoor Recreation, and the Economic Impacts of Weeds. *Weed Science*, 130-137.

Epanchin-Niell, R. S. and Hastings, A. 2010. Controlling Established Invaders: Integrating Economics and Spread Dynamics to Determine Optimal Management. *Ecology Letters*, **13**(4), 528-541.

Gillan, J. K., Strand, E. K., Johnson, T. J. 2017. Sage-grouse Habitat in Idaho: A Practical Guide for Land Owners and Managers. Contribution Number 1048 of the Idaho Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow (v2).

Hegewisch, K. C., Abatzoglou, J. T., Chegwidden, O., Nijssen, B. 'Climate Mapper' web tool. Climate Toolbox dataset (https://climatetoolbox.org/) accessed 6 March 2021

Holden, Z. A., Swanson, A., Luce, C. H., Jolly, W. M., Maneta, M., Oyler, J. W., Warren, D. A., Parsons, R., Affleck, D. 2018. Decreasing Fire Season Precipitation Increased Recent Western US Forest Wildfire Activity. *Proceedings of National Academy Sciences,* **115**, E8349–E8357.

Horne, J. S., Hurley, M. A., White, C. J., Rachael, J. 2019. Effects of Wolf Pack Size and Winter Conditions on Elk Mortality. *Journal of Wildlife Management*, **83**(5), 1103–1116. doi:10.1002/jwmg.21689.

Hufkens, K., Keenan, T., Flanagan, L., *et al.* 2016. Productivity of North American Grasslands is Increased Under Future Climate Scenarios Despite Rising Aridity. *Nature Climate Change,* **6**, 710–714.

Hurley, M. A., Hebblewhite, M., Gaillard, J. M., Dray, S., Taylor, K. A., Smith, W. K., Zager, P., Bonenfant, P. 2014. Functional Analysis of Normalized Difference Vegetation Index Curves Reveals Overwinter Mule Deer Survival is Driven by Both Spring and Autumn Phenology. *Philosophical Transactions of the Royal Society* B 369, 20130196. http://dx.doi.org/10.1098/rstb.2013.0196.

Idaho Department of Fish and Game (IDFG). 2021. Harvest Statistics. https://idfg.idaho.gov/ifwis/huntplanner/stats/

Inside Idaho. Idaho Surface Management Agency. https://www.insideidaho.org/

Isaak, D. J., Wenger, S. J., Young, M. K. 2017. Big Biology Meets Microclimatology: Defining Thermal Niches of Ectotherms at Landscape Scales for Conservation Planning. *Ecological Applications*, **27**(3), 977-990.

Jenkins, D. A., Schaefer, J. A. Rosatte, R., Bellhouse, T., Hamr, J., Mallory, F. F. 2007. Winter Resource Selection of Reintroduced Elk and Sympatric White-Tailed Deer at Multiple Spatial Scales. *Journal of Mammalogy,* **88**(3), 614–624.

Julia, R., Holland, D. W., Guenthner, J. 2007. Assessing the Economic Impact of Invasive Species: The Case of Yellow Starthistle (Centaurea solsitialis L.) in the Rangelands of Idaho, USA. *Journal of Environmental Management*, **85**(4), 876-882.

Kautz, T. M., Belant, J. L., Beyer, D. E., Strickland, B. K., Duquette, D. K. 2020. Influence of Body Mass and Environmental Conditions on Winter Mortality Risk of a Northern

Ungulate: Evidence for a Late-Winter Survival Bottleneck. *Ecology and Evolution* **10**, 1666-1677.

Klos, Z., J .Abatzoglou, J. Blades, M. Clark, M. Dodd, T. Hall, A. Haruch, P. Higuera, J. Holbrook, V. Jansen, K. Kemp, A. Lamar, A. Lankford, T. Link, T. Magney, A. Meddens, L. Mitchell, B. Moore, P. Morgan, B. Newingham, R. Niemeyer, B. Soderquist, A. S, C. W. 2015. Indicators of Climate Change in Idaho : An Assessment Framework for Coupling Biophysical Change and Social Perception. *Weather, Climate and Society,* **7**, 238–254.

Ludwig, A., Zheng, H., Vrbova, L., Drebot, M. A., Iranpour, M., Lindsay, L. R. 2019. Increased Risk of Endemic Mosquito-Borne Diseases in Canada Due to Climate Change. Candian Communicable Diseases Report, **45**(4), 91-97. doi: 10.14745/ccdr.v45i04a03.

Maher, A. T., Tanaka, J. A. and Rimbey, N. 2013. Economic Risks of Cheatgrass Invasion on a Simulated Eastern Oregon Ranch. *Rangeland Ecology & Management*, ***66***(3), 356-363.

McKean, J. R. and Taylor, R. G. 2000. *Outdoor Recreation Use and Value: Snake River Basin of Central Idaho*. Moscow, ID. Agricultural Experiment Station, University of Idaho.

Mote, P. W., Li, S., Lettenmaier, D. P., Xiao, M., Engel, R. 2018. Dramatic Seclines in Snowpack in theWwestern US. *NPJ Climate and Atmosphereic Science,* **1**.

Multi-Resolution Land Characteristics Consortium (MRLC). 2016. National Land Cover Database. https://www.mrlc.gov/national-land-cover-database-nlcd-2016

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S. and Bernabucci, U. 2010. Effects of Climate Changes on Animal Production and Sustainability of Livestock Systems. *Livestock Science*, **130**(1-3), 57-69.

Neibergs, J. S., Hudson, T. D., Kruger, C. E., Hamel-Rieken, K. 2018. Estimating Climate Change Effects on Grazing Management and Beef Cattle Production in the Pacific Northwest. *Climate Change,* **146**, 5–17.

Parker, K. L., Robbins, C. T., Hanley, T. A. 1984. Energy Expenditures for Locomotion by Mule Deer and Elk. *Journal of Wildlife Management*, **48**(2), 474-488.

Pew Charitable Trust Fact Sheet. 2018. The Economic Contribution of Hunting, Fishing, Wildlife Watching on BLM Lands. https://www.pewtrusts.org/ /media/assets/2018/09/economiccontributionsrecreationblm_idaho_v1.pdf

Pilliod, D. S., Welty, J. L., Arkle, R. S. 2017. Refining the Cheatgrass – Fire Cycle in the Great Basin : Precipitation Timing and Fine Fuel Composition Predict Wildfire Trends. *Ecology and Evolution*, **7**(19), 8126–8151. doi:10.1002/ece3.3414

Pimentel, D., Zuniga, R., Morrison, D. 2005. Update on the Environmental and Economic Costs Associated with Alien-invasive Species in the United States. *Ecological Economics*, **52**(3), 273-288.

Polley, H. W., Briske, D. D., Morgan, J. A., Wolter, K., Bailey, D. W., Brown, J. R. 2013. Climate Change and North American Rangelands: Trends, Projections, and Implications. *Rangeland Ecology and Management.,* **66**, 493–511.

Polley, H. W., Bailey, D. W., Nowak, R. S., Stafford-Smith, M. 2017. Ecological Consequences of Climate Change on Rangelands. In Briske, D. D. (Ed.), Rangeland Systems: Processes, Management and Challenges (pp. 229–260). Cham: Springer International Publishing. https://doi. org/10.1007/978-3-319-46709-2

Reeves, M. C., Moreno, A. L., Bagne, K. E., Running, S. W. 2014. Estimating Climate Change Effects on Net Primary Production of Rangelands in the U.S.. *Climate Change,* **126***,* 429–442. doi:10.1007/s10584-014-1235-8

Reeves, M. C., Bagne, K. E., Tanaka, J. 2017. Potential Climate Change Impacts on Four Biophysical Indicators of Cattle Production from Western US Rangelands. *Rangeland Ecology and Management,* **70**, 529–539.
Ritten, J. P, Frasier, W. M., Bastian, C. T., Gray, S. T. 2010. Optimal Rangeland Stocking Decisions under Stochastic and Climate Impacted Weather. *American Journal of Agricultural Economics,* **92**, 1242–1255.
Safeeq, M., Shukla, S., Arimendi, I., Grant, G. E., Lewis, S. L., Nolin, A. 2016. Influence of Winter Season Climate Variability on Snow–Precipitation Ratio in the Western U.S. *International Journal of Climatology,* **36**, 3175–3190.
Schreiner-McGraw, A. P., Hoori, A., Vivoni, E. 2019. Extreme Weather Events and Transmission Losses in Arid Streams. *Environmental Research*, **14**(8).
Snyder, K. A., Evers, L., Chambers, J. C., Dunham, J., Bradford, J. B., Loik, M. E. 2019. Effects of Changing Climate on the Hydrological Cycle in Cold Desert Ecosystems of the Great Basin and Columbia Plateau. *Rangeland Ecology and Management,* **72**, 1–12.
Sonenshine, D. E. 2018. Range Expansion of Tick Disease Vectors in North America: Implications for Spread of Tick-borne Disease. *International Journal of Environmental Research and Public Health*, **15**, 478-487. doi:10.3390/ijerph15030478.
Stillings, A. M., Tanaka, J. A., Rimbey, N. R., Delcurto, T., Momont, P. A. and Porath, M. L. 2003. Economic Implications of Off-stream Water Developments to Improve Riparian Grazing. *Rangeland Ecology and Management/Journal of Range Management Archives*, **56**(5), 418-424.
St-Pierre, N. R., Cobanov, B., Schnitkey, G. 2003. Economic Losses from Heat Stress by US Livestock Industries. *Journal of Dairy Science*, **86**, E52-E77.
Strickfaden, K. 2021. Climate Effects on Ungulates. *Idaho Climate-Economy Impacts* Assessment. James A. & Louise McClure Center for Public Policy Research, University of Idaho. Boise, ID.
Suring, L. H., Wisdom, M. J., Tausch, R. J., Miller, R. F., Rowland, M. M., Schueck, L., Meinke, C. W. 2005. Modeling Threats to Sagebrush and Other Shrubland Communities. In Wisdom, J. J., Rowland, M. M., Suring, L. H. (Ed.), Habitat Threats in the Sagebrush Ecosystem: Methods of Regional Assessment and Applications in the Great Basin (114-149). Alliance Communications Group. Lawrence, KS.
Taylor, D. T., Rimbey, N. R., Tanaka, J. A. 2019. Economic Impact of Sage Grouse Management on Livestock Grazing in the Western United States. *In Western Economics Forum*, **17**(837-2019-950), 98-113.
Telfer, E. S. and Kelsall, J. P. 1984. Adaptation of Some Large North American Mammals for Survival in Snow. *Ecology*, **65**(6):1828-1834.
USDA NASS. National Agriculture Statistics Service. U.S. Department of Agriculture. https://www.nass.usda.gov/
(USFWS) U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2016. National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.
Weiskopf, S. R., Ledee, O. E., Thompson, L. M. 2019. Climate Change Effects on Deer and Moose in the Midwest. *Journal of Wildlife Management*, **83(**4):769–781.
Wold, A. 2021. Quantifying the Effects of Climate on Rangeland Vegetation Productivity and Economic Consequences at a Ranch Level (M.S. Thesis, Washington State University).