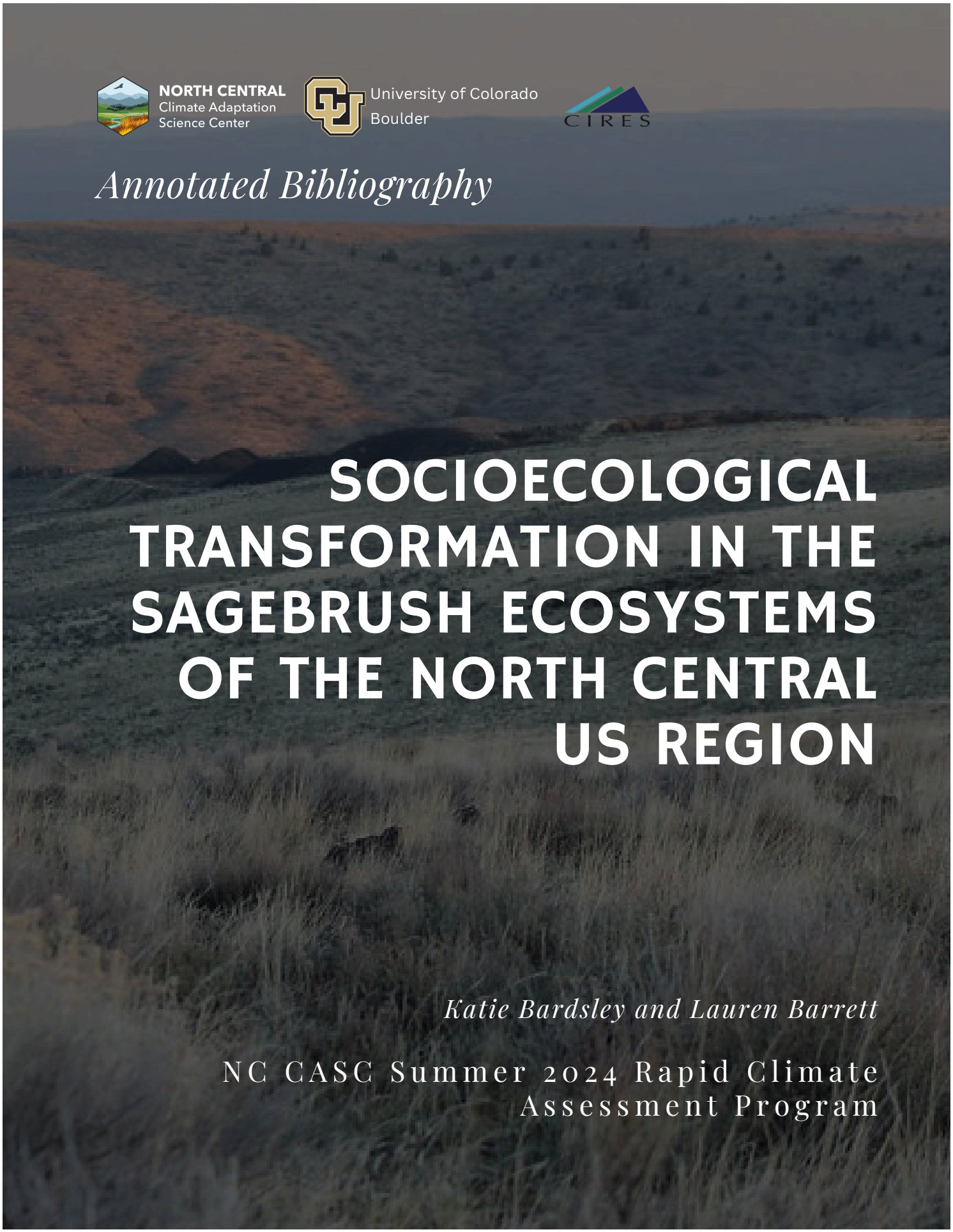


NORTH CENTRAL Climate Adaptation Science Center

University of Colorado Boulder

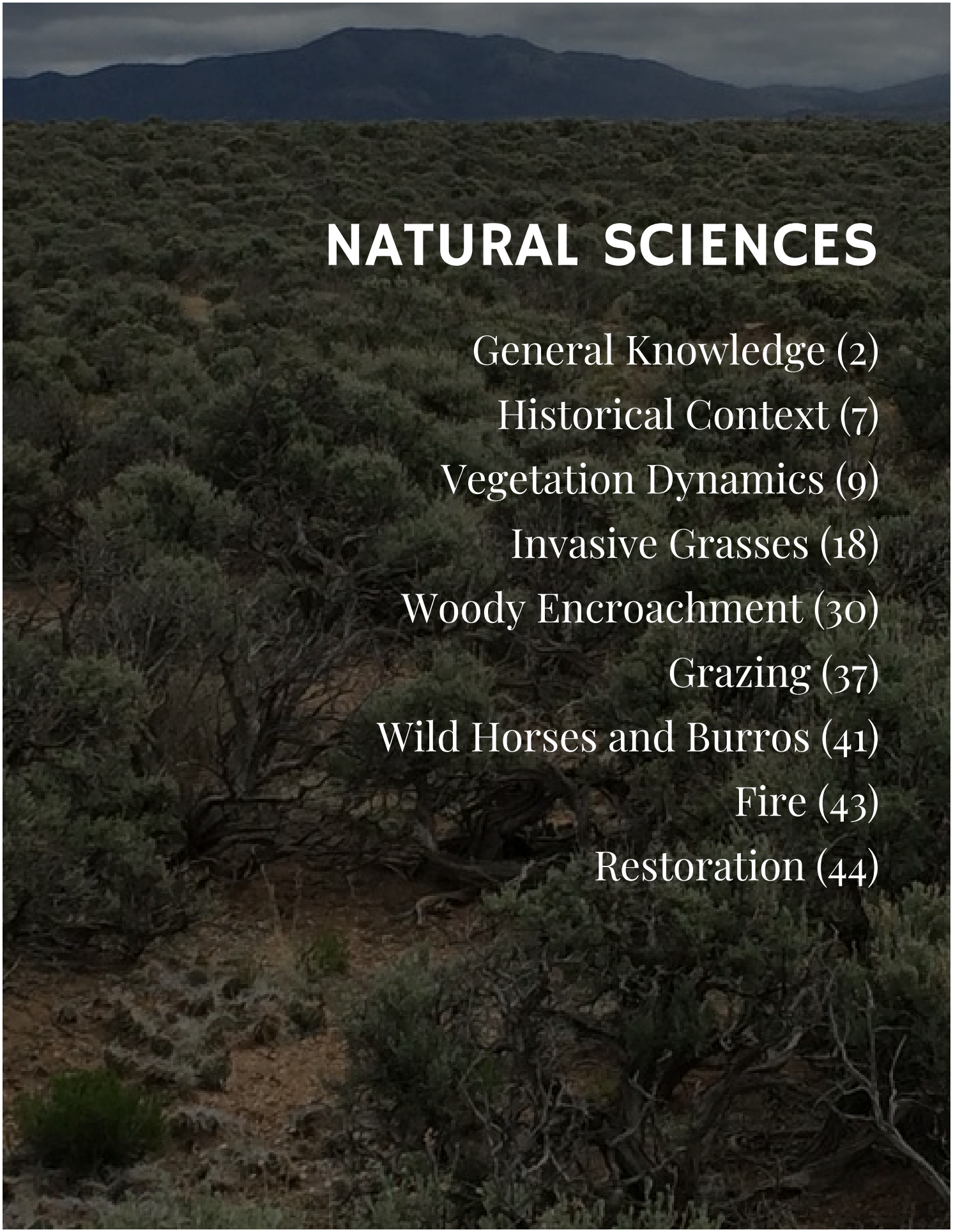
CIRES

Annotated Bibliography

SOCIOECOLOGICAL TRANSFORMATION IN THE SAGEBRUSH ECOSYSTEMS OF THE NORTH CENTRAL US REGION

Katie Bardsley and Lauren Barrett

NC CASC Summer 2024 Rapid Climate Assessment Program



NATURAL SCIENCES

General Knowledge

Natural Sciences

Photo: Alex York, Unsplash

Cahill, M. (2022). The range has changed: My viewpoint on living in the Sagebrush Sea in the new normal of invasives and wildfire. *Rangelands*, *44*(3), 242–247.

https://doi.org/10.1016/j.rala.2022.01.004

- Cahill's perspective piece advocates for the Defend the Core framework, but acknowledges that loss cannot be reversed everywhere or all at once.
- Geography: Oregon, the Northern Great Basin, and sagebrush ecosystems across the west
- Key points:
  - Defend the Core framework:
    - Defend the core - where ecosystem function remains with minor threats
    - Grow the core - where ecosystem function is being lost with rising threats
    - Minimize (or mitigate) risks - where threats are dominant
  - "shore up the core margins with improved management, while being proactive but pragmatic with the rest."
  - "Recovering ecosystem function is expensive and fraught, making protection of what core remains our best option."
  - Grow the Core is where our active and adaptive management is needed most
    - Prioritization of place - "management grows out from existing core landscapes, buffering them from wildfire impacts and building larger intact landscapes"
    - "To Grow the Core, we need more grazing in the dormant season to reduce fine fuels and attenuate wildfire risks and less grazing in the growing season to provide rest for stressed bunchgrasses to recover."
  - "Minimizing Risk means organizing management to reduce the likelihood of threats worsening, especially the frequency and severity of wildfire. ...for now we are Defending the Core by focusing on abating the worst outcomes of wildfire."
  - "Defend the Core from further decline, Grow the Core by reversing threats surrounding the core, and Minimizing the Risks of catastrophe on the greater landscape but accepting we cannot reverse loss everywhere, or all at once."
- Gaps/limitations:
  - None mentioned

Chambers, J. C., Brown, J. L., Bradford, J. B., Doherty, K. E., Crist, M. R., Schlaepfer, D. R., Urza, A. K., & Short, K. C. (2023). Combining resilience and resistance with threat-based approaches for prioritizing management actions in sagebrush ecosystems. *Conservation Science and Practice*, *5*(11), e13021. https://doi.org/10.1111/csp2.13021

- Use a threat-based model alongside a model of resilience and resistance to prioritize management actions, finding consistency and complementarity between indicators.
- Geography: most of sagebrush biome
- Key points:
  - "Sagebrush Ecological Integrity (SEI) areas provided info on extent of intact vs. degraded sagebrush areas and magnitude of predominant threats."
  - "Resilience & Resistance indicators provided info on recovery potential of SEI areas (to both disturbances and conservation and restoration management actions)"
  - "Consistent yet complementary nature of two spatially explicit info sources indicates that they can be integrated and used together to better inform landscape prioritization of conservation and restoration investments."
- Gaps/limitations:
  - Not specifically discussed.

Crist, M. R., Belger, R., Davies, K. W., Davis, D. M., Meldrum, J. R., Shinneman, D. J., Remington, T. E., Welty, J., & Mayer, K. E. (2023). Trends, Impacts, and Cost of Catastrophic and Frequent Wildfires in the Sagebrush Biome. *Rangeland Ecology & Management*, *89*, 3–19. https://doi.org/10.1016/j.rama.2023.03.003

- Synthesize wildfire trends and the impacts of novel fire regimes on plant communities, wildlife, costs, and ecosystem services, finding that the greatest impact is conversion to non-native ecosystems.
- Geography: full sagebrush biome (but fires currently more relevant to the western part/Great Basin)
- Key points:
  - "The greatest impact of uncharacteristically frequent fire is the transition from native sagebrush-perennial grass communities to invasive, non-native, annual grasslands" but "sagebrush ecosystems in the eastern part of the sagebrush biome are less prone to fire ignition depending on the timing of summer or monsoonal precipitation"
  - "Natural sagebrush recovery times cannot keep up with the expanding invasive annual grass/fire cycle, and some areas may have crossed thresholds of no return."
  - "fire-suppression costs and other costs associated with wildfire impacts will likely continue to increase."
  - "Where feasible, enhancing efforts to manage invasive annual grasses and wildland fire may help to break the invasive grass/wildfire cycle"

- Gaps/limitations:
  - “Increased flexibility and better prioritization of management activities based on ecological needs, including commitment to long-term prefire and postfire management, are needed to achieve notable reductions in uncharacteristic wildfire activity and associated negative impacts.”
  - Unknown how long it takes the sagebrush seedbank to disperse and establish into the interiors of large burned areas

Davies, K. W., Boyd, C. S., Beck, J. L., Bates, J. D., Svejcar, T. J., & Gregg, M. A. (2011). Saving the sagebrush sea: An ecosystem conservation plan for big sagebrush plant communities. ***Biological Conservation*****, *144*(11), 2573–2584.** https://doi.org/10.1016/j.biocon.2011.07.016

- This review emphasizes the importance of a coordinated ecosystem conservation plan for future sustainability of sagebrush ecosystems.
- Geography: Full sagebrush biome
- Key points:
  - "To conserve sagebrush plant communities land managers and policy makers need to:
    - (1) prevent undesirable vegetation shifts from occurring [manage grazing, minimize disturbance, etc.],
    - (2) restore communities invaded by exotic annual grass or encroached by conifers [sagebrush restoration research needs], and
    - (3) reduce and mitigate anthropogenic development [and keeping ranchers on their land, energy development, etc.]."
- Gaps/limitations:
  - (from 2011, so interpret accordingly)
  - Restoration of exotic annual invaded areas
  - Seedling establishment research and precision technologies that adjust for environmental factors
  - Re-evaluation of restoration practices based on global changes
  - Research on invasibility

Schlaepfer, D. R., Bradford, J. B., Lauenroth, W. K., & Shriver, R. K. (2021). Understanding the future of big sagebrush regeneration: Challenges of projecting complex ecological processes. ***Ecosphere*****, *12*(8), e03695.** https://doi.org/10.1002/ecs2.3695

- Use two complementary models to explore spatial and temporal relationships in big sagebrush regeneration, finding that uncertainty may be driven more by invasion and wildfire than climate projections.
- Geography: model 1 - range-wide; model 2 - Great Basin and Snake River Plains (main focus Great Basin and Snake River Plains)
- Key points:

- Two complementary models to explore spatial and temporal relationships in big sagebrush regeneration:
  - 1 - range-wide big sagebrush regeneration responses in natural vegetation (process-based)
    - Suggested substantial geographic variation in long-term regeneration trajectories
      - Central and northern areas - remain climatically suitable
      - Marginal and southern areas - less suitable
  - 2 - big sagebrush restoration seeding outcomes following fire in Great Basin and Snake River Plains (regression-based model)
    - Restoration seeding may become increasingly more difficult
    - “challenge of promoting sagebrush establishment after wildfire in invaded landscapes”
- “results suggest that sustaining big sagebrush on the landscape... may climatically be feasible for many areas and that uncertainty about the long-term sustainability of big sagebrush may be driven more by dynamics of biological invasions and wildfire than by uncertainty in climate change projections.”
  - “In the northern Great Basin and Snake River Plains, big sagebrush persistence will be influenced more by fire-invasive annual grass interactions” - sustenance hinges on solving this problem
  - “solutions may be found by promoting conditions similar to those found in undisturbed environments.”
- Focus on general patterns, not exact conditions needed for restoration

- Gaps/limitations:
  - "Divergent projections... encourage further study to evaluate potential benefits of recreating conditions of uninvaded, unburned natural big sagebrush vegetation for post-fire restoration seeding, such as seeding in multiple years [or directly planting seedlings to help with lack of facilitation by adult shrubs] and, for at least much of the northern Great Basin and Snake River Plains, the control of the fire-invasive annual grass cycle."

Shinneman, D. J. (2020). North American Sagebrush Steppe and Shrubland. In M. I. Goldstein & D. A. DellaSala (Eds.), *Encyclopedia of the World’s Biomes* (pp. 505–515). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.11982-7

- Part of an encyclopedia of the world’s biomes - provides an overview of the North American Sagebrush Steppe and Shrubland as an ecological system and some of its current threats.
- Geography: North American sagebrush steppe and shrublands
- Key points:
  - Sagebrush typically where winters are long and cool or cold and summers are hot and dry. The composition and structure vary along “broadly-defined bioclimatic gradients” and “vary abruptly with changes in topography, geology, elevation, and soils (available water)”
  - Sagebrush ecosystems provide habitat for at least 350 species of conservation concern.
  - "~45% of the historical area of sagebrush steppe and sagebrush shrublands lost"
  - - "Altered wildfire regimes coupled with the spread of invasive plant species pose a major threat" - especially in drier western portion
  - "seasonal interactions between shifts in temperature and precipitation may increase aridity and reduce plant available soil water, resulting in possible elevational or latitudinal range shifts, or

possibly an overall loss in climatically suitable habitat." Renwick et al. 2018: cooler and more mesic locations might actually benefit; warmer locations likely to decline.
    - No easy conservation solutions
- Gaps/limitations:
    - "complex, long-term future interactions between climate, fire, and vegetation remain difficult to predict with great certainty... Ongoing research and observations are needed to better address this uncertainty and to facilitate management adaptation to changing conditions."
    - Need better understanding of land use and management effects and estimation of future potential risks
    - Need greater cooperation among stakeholders
- Other comments:
    - Includes useful table summarizing threats, graphic on the invasive plant-fire regime cycle, and discussion of predicted changes in climate and hypothesized effects.

Historical Context

Natural Sciences

Photo: Bureau of Land Management Oregon and Washington, Flickr

Bement, R. E. (1993). Colorado Rangelands: A Land Manager's Historical Perspective. *Rangelands*, *15*(5), 208–210.

- A Colorado land manager's historical perspective and personal stories.
- Likely not the most relevant in the context of ecological transformation.

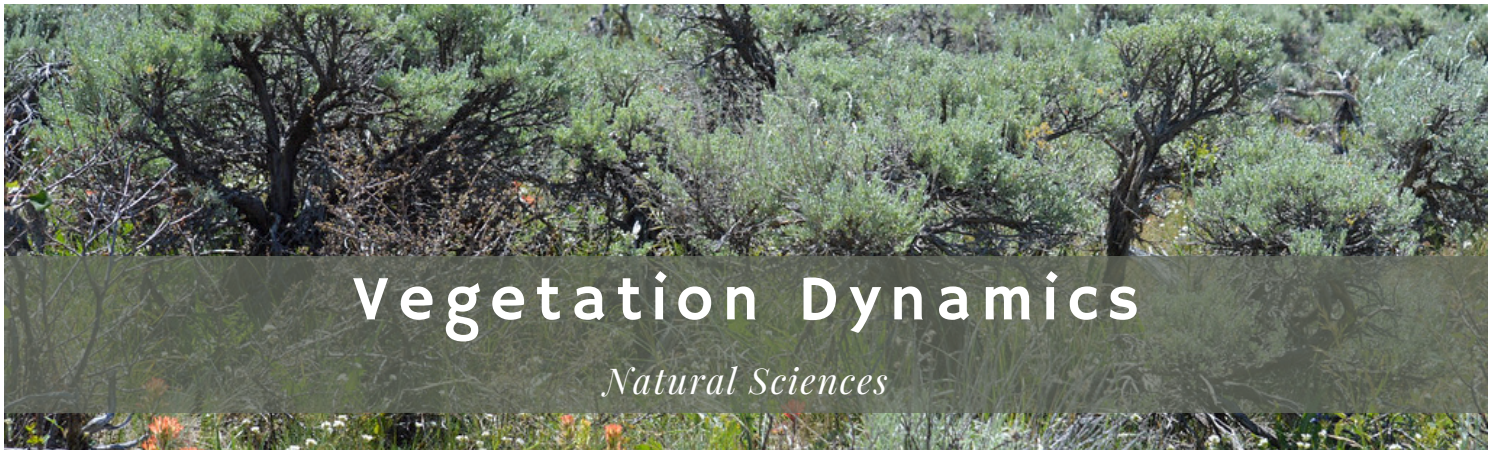
Harris, T., Johnson, D. D., & O'Connor, R. C. (2024). A brief history of sagebrush management in the Great Basin: From removal to reduction and beyond. *Rangelands*, *46*(3), 63–71. https://doi.org/10.1016/j.rala.2024.01.002

- Provides history of the sagebrush system within the Great Basin.
- Geography: focus on Great Basin, but most of range mentioned
- Key points:
  - After overgrazing with little to no management in late 1800s, early 1900s - management shifted to focus on "eradication of sagebrush to promote forage production from WWII to the 1970s"
  - 1970s to present: paradigm shift, emphasis on keeping sagebrush intact for wildlife
  - "However, neither management paradigm has yielded an ideal outcome"
  - "Combination of new and old restoration methods needed" -"we propose that a new management paradigm is imperative—one that bolsters biotic resistance to invasion and resilience to disturbance by promoting the growth of native perennial bunchgrasses interspersed among a healthy overstory of big sagebrush."
- Gaps/limitations:
  - "Further research is critical to understanding the effectiveness of various thinning and seeding methods in high canopy cover Wyoming big sagebrush communities."
  - "Multiple studies have demonstrated successful thinning in mountain big sagebrush sites where higher precipitation and cooler temperatures provide an environment conducive to herbaceous growth... The challenge moving forward will be.... Wyoming big sagebrush environments, where warm, dry conditions prevail, and where resilience and resistance are inherently lower."

- Other comments:
  - Includes notes on the importance of sagebrush in terms of ecosystem benefits, habitat, and invasion defense.
  - History of removal efforts, overgrazing, policy.
  - Strong stance that fire should not be used to control sagebrush.
  - Helpful reminder that too much sagebrush (or the hands off approach) also has its own issues.

Ross, J. V. H. (1984). Managing the Public Range Lands: 50 Years Since the Taylor Grazing Act. *Rangelands*, *6*(4), 147–151.

- Overview of grazing legislation, the BLM, and challenges of managing public lands.
- Maybe less relevant in the context of ecological issues, but good to have as a reference.



Vegetation Dynamics

Natural Sciences

Photo: USFWS Mountain-Prairie, Flickr

Holdrege, M. C., Kulmatiski, A., Beard, K. H., & Palmquist, K. A. (2023). Precipitation Intensification Increases Shrub Dominance in Arid, Not Mesic, Ecosystems. *Ecosystems*, *26*(3), 568–584. https://doi.org/10.1007/s10021-022-00778-1

- Uses STEPWAT2 model from Palmquist et al. 2021 to model how larger but less frequent precipitation events influence vegetation dynamics.
- Geography: big sagebrush ecosystems of the western US
- Key findings:
  - In arid/semi-arid ecosystems, larger precipitation events pushed water into shrub root zones and there was less evaporation, resulting in increased biomass. In mesic ecosystems, water was pushed below shrub root zones, leading to no change in biomass.
  - Increased precipitation intensity led to a competitive advantage for shrubs where arid/semi-arid. There was no consistent response for grasses/forbs.
  - Warming led to a decrease in biomass for all functional groups except for C4 grasses and a decrease in the shrub-to-C3 perennial grass ratio.
  - The combined effect of increased precipitation intensity and warming led to an increase in shrub relative abundance in arid/semi-arid sites.
  - Important to consider interactions between warming, precipitation intensity, and plant functional type.
- Gaps/limitations:
  - All simulations included light grazing and no fire
  - Assumed flat ground
  - Increased precip intensity may have different effects not considered (changes in nutrient availability/cycling, fire frequency, erosion, runoff, etc.)
- Other comments:
  - C3 perennial grasses typically make up most of the understory biomass, C4 grasses more present in the southern and eastern parts of the biome.
  - More sites expected to be suitable for C4 grasses under simulated future climate.

Jordan, S. E., Palmquist, K. A., Bradford, J. B., & Lauenroth, W. K. (2020). Soil water availability shapes species richness in mid-latitude shrub steppe plant communities. ***Journal of Vegetation Science*****,** ***31*****(4), 646–657.** https://doi.org/10.1111/jvs.12874

- Investigated the relationships between ecohydrological, macroclimatic, and biotic variables and plant richness, demonstrating the importance of soil water availability, and ecohydrological variables more broadly, as critical predictors.
- Geography: sagebrush-dominated sites across Wyoming
- Key points:
  - "Species and functional type richness were related to both macroclimate and ecohydrology, but ecohydrology explained slightly more variation than climate."
  - Species richness was most closely related to soil water availability, particularly in the top soil layers (and during the non-growing season)
  - "Variability in precipitation was negatively related to grass richness."
  - "Suggests that fine-textured soils often support greater species richness than coarse-textured soils"
  - Weak support for the ""more-individuals"" hypothesis
  - No biotic variables were predictors of richness.
  - Highlights the value of including direct estimates of soil water availability in addition to climate and vegetation structure.
- Gaps/limitations:
  - Other aspects of the plant community may have been more sensitive to shrub stand structure.
  - Did not directly assess effects of competition or facilitation, which may have influenced richness
- Other comments:
  - The team intentionally selected sites with low non-natives and minimal evidence of grazing.
  - Includes background on how ecohydrology influences plant community dynamics in the sagebrush ecosystem.

Kleinhesselink, A. R., & Adler, P. B. (2018). The response of big sagebrush (Artemisia tridentata) to interannual climate variation changes across its range. ***Ecology*****,** ***99*****(5), 1139–1149.** https://doi.org/10.1002/ecy.2191

- Modeling effort estimated the population sensitivity of big sagebrush to annual climate variation range-wide, finding cooler locations responded more favorably to increased temperature and sensitivity to precipitation did not change significantly across the range.
- Geography: full range of big sagebrush
- Key points:
  - "estimated the population sensitivity of... big sagebrush... to annual climate variation across its range."
  - Benefits of warmer temperatures in colder sites outweighed the negative effects at hotter sites

    - Sagebrush population growth rates decline with warming where the average growing season temperatures are above 22°C
    - Sensitivity to precipitation did not vary across the range and is likely not a limiting factor.
    - There were differences in how sagebrush subspecies responded.
        - Mountain sagebrush: weak positive effects of above average temperature and precipitation
        - Wyoming sagebrush: positive effects of increased temperatures at warmer locations, negative response at cooler locations. negative response to increased precipitation in driest areas, positive response in wetter areas.
- Gaps/limitations:
    - Relatively fewer points from cold and wet regions
    - "model leaves out many factors that could influence the future of sagebrush including the effects of fire." (fire, cheatgrass, effects of climate on seed germination/regeneration, winter temperatures, etc.)
    - "future studies should focus on the effects of above average temperatures on sagebrush in the warmest parts of its range."
- Other comments:
    - Includes notes on differences between subspecies and lagging sagebrush climatic response.
    - Useful discussion of more counter-intuitive results.

Martyn, T. E., Palmquist, K. A., Bradford, J. B., Schlaepfer, D. R., & Lauenroth, W. K. (2023). Plant community predictions support the potential for big sagebrush range expansion adjacent to the leading edge. *Regional Environmental Change*, *23*(1), 27.

https://doi.org/10.1007/s10113-022-01999-9

- Modeled sagebrush community composition under future climate scenarios at the leading edge using STEPWAT2, showing these populations will likely remain stable and will have capacity to serve as dispersal sources for future expansion.
- Geography: big sagebrush communities in northeastern Montana
- Key points:
    - "Results show minimal overall change in plant community composition and little change in biomass, suggesting that range margin big sagebrush plant communities adjacent to the leading edge will remain stable to serve as essential dispersal sources for future range expansion, assuming no other relevant changes such as changes in disturbance regimes."
    - "Climate at the leading edge will increase in temperature and precipitation but remain within the ecological amplitude of big sagebrush plant communities"
    - Small decreases in big sagebrush, shrubs, and C3 grass biomass; moderate decreases in perennial forbs (less significant a decline in C3 grasses than Palmquist 2021); increases in C4 grasses
- Gaps/limitations:
    - "future simulation and empirical research should explore the impacts of concurrent invasive species establishment under current and future predicted climate" ("model did simulate annual grass biomass; however, there are many aspects (priority effects, nutrients, disturbance, fire, etc.) that were not modeled that could have impacted the response of annual grasses.")
    - "... future research focused on the response of big sagebrush plant communities to disturbance and different landscape configurations will be important"

- Other comments:
  - Useful discussion of projected climatic changes and possible impacts (intro)
  - Cites a bunch of studies that identified the leading edge and a study (Schlaepfer et al. 2015) which predicted "increased suitability for big sagebrush germination and seedling survival for this part of the big sagebrush leading edge"

Palmquist, K. A., Schlaepfer, D. R., Renne, R. R., Torbit, S. C., Doherty, K. E., Remington, T. E., Watson, G., Bradford, J. B., & Lauenroth, W. K. (2021). Divergent climate change effects on widespread dryland plant communities driven by climatic and ecohydrological gradients. ***Global Change Biology*****,** ***27*****(20), 5169–5185.** https://doi.org/10.1111/gcb.15776

- Explored the effects of climate change on big sagebrush using an individual-based plant simulation model (with ecohydrological components) (STEPWAT2), finding divergent responses in moisture-limited vs. temperature-limited sites and shifts in functional group dominance.
- Geography: big sagebrush plant communities of the western US
- Key points:
  - Temperate drylands:
    - Increasing temperatures
    - Modest increases in cool-season precipitation on average with the largest increases in the northernmost parts of the range
  - Responses: (measured in biomass, trends for most sites)
    - Divergent responses of big sagebrush in moisture vs. temperature limited sites
    - Increases in perennial C4 grasses
    - Decreases in perennial C3 grasses and perennial forbs
    - Little change for other functional types
  - "largest decreases in big sagebrush potential biomass in warm, dry sites"
    - Great Basin, Snake River Plains - more precipitation as rain, greater water loss, lower soil water
    - More vulnerable when water-limited
  - Currently there are fewer, larger individuals, but expect shift to greater number of smaller individuals, with changes most noticeable at moisture-limited sites
  - "simulated no change or small to moderate increases in sagebrush biomass in cold, moist sites due to smaller reductions in soil water availability"
  - Simulated potential shifts in the relative importance of perennial C3 and C4 grasses with decreases in C3 grasses and increases in C4 grasses. (photosynthetic advantage in warm conditions, reduced water loss)
- Gaps/limitations:
  - "Shifts in big sagebrush stand structure in response to climate change deserve additional attention"
  - Knowledge gaps: "(1) if projected warming and drying results in cheatgrass invasion in currently unimpacted cold, moist sites, to what degree will native plant communities resist invasion and which plant functional types will be especially affected by cheatgrass/changes in wildfire frequency? and (2) in the context of climate change and invasion, how will the impact of livestock grazing on plant community composition vary across the region in the coming decades?

Additional range-wide studies are needed that represent multiple plant functional types and evaluate plant community responses to climate–grazing– cheatgrass–wildfire interactions to determine how disturbances may alter responses..."
    - Need future efforts to generate climate projections at finer resolutions.
- Other comments:
    - Includes notes on how soil water availability works and its impacts, expected soil moisture trends.
    - Includes discussion of how ecosystem shifts may impact sagebrush-obligate species
    - Step up from other models which don't consider competitive interactions with other species

Renwick, K. M., Curtis, C., Kleinhesselink, A. R., Schlaepfer, D., Bradley, B. A., Aldridge, C. L., Poulter, B., & Adler, P. B. (2018). Multi-model comparison highlights consistency in predicted effect of warming on a semi-arid shrub. *Global Change Biology*, *24*(1), 424–438. https://doi.org/10.1111/gcb.13900

- Used a multi-model approach to investigate and predict the effect of climate change on sagebrush, finding decreases at warmer sites and increases in cooler sites, with a stronger response to temperature than precipitation.
- Geography: full sagebrush biome
- Key points:
    - Developed 4 predictive models (2 empirically derived: 1-spatial (cover + climate) and 2-temporal (cover + interannual variation in weather) relationships; 2 mechanistic: 3-seedling germination and establishment + 4-recruitment, growth, and mortality)
    - Three important findings:
        - “(1) sagebrush vulnerability to projected climate change is low in many locations
        - (2) sagebrush populations at warmer sites are more vulnerable [could increase in cooler parts; stronger response to temp than precip]
        - (3) the choice of ecological model is the largest source of uncertainty in future predictions [raises questions about forecasts with single model]"
    - "Our results indicate less vulnerability than previous studies... many of which predicted more dramatic declines in the area climatically suitable for sagebrush"
- Gaps/limitations:
    - "focused on... direct effects of climate change... indirect effects of climate change, however, may have a larger impact... Invasive species such as cheatgrass may expand into new areas or gain a competitive advantage... Feedbacks between climate, cheatgrass, and the fire cycle could prove detrimental... Additional research is needed to link the direct and indirect effects... in a cohesive modeling framework."
    - Suggested additional research:
        - "on the physiological and demographic processes that most limit sagebrush under different climatic conditions"
        - "to fully understand how recruitment and competition affect sagebrush under different climatic conditions, as well as the degree to which CO2 enrichment may buffer sagebrush populations at hotter sites against the effects of climate change."
        - on "the effect of precipitation change... [plus] subsequent model development"

- Other comments:
  - Includes notes on the sources of information that models predicting the ecological impacts of climate change can draw on and their strengths and weaknesses (spatial correlations, temporal correlations, and mechanistic representations)
  - Includes useful subspecies information
  - Includes discussion of sagebrush/precipitation relationship (may be more locally dependent)
  - Has useful discussion of results more generally

Requena-Mullor, J. M., Maguire, K. C., Shinneman, D. J., & Caughlin, T. T. (2019). Integrating anthropogenic factors into regional-scale species distribution models—A novel application in the imperiled sagebrush biome. *Global Change Biology*, *25*(11), 3844–3858. https://doi.org/10.1111/gcb.14728

- Incorporated human-induced factors into sagebrush SDMs, finding that models including fire attributes and restoration treatment performed better than models with only climate and topography.
- Geography: Great Basin
- Key points:
  - Explore whether including human-induced factors improves fit of SDM
  - "models including fire attributes and restoration treatments performed better than those including only climate and topographic variables"
  - "by demonstrating that specific fire attributes vary in importance depending on the response variable being considered, these results also provide an explanation for why previous SDMs revealed no or varying effects of fire, given the different fire metrics, ecosystems, and species responses being tested among studies."
  - "integrating data on restoration history with other environmental variables is a worthwhile endeavor, even when land management records contain ambiguous information"
- Gaps/limitations:
  - "results speak to the need for long-term demographic monitoring of restored plots to assess treatment effects, analyses that disaggregate restoration treatment into specific management actions, and the need for statistical analyses that more rigorously evaluate restoration impacts"
  - Suggest further "development of regional and global databases of land use and disturbance, coupled with additional methodological improvements to SDMs" to enhance functionality
  - "Future SDM research in similar ecosystems could use our approach to model co-occurrence between key species and quantify how fire and restoration alter outcomes of interactions between species." - could be applicable to modeling interaction between native/invasive species
- Other comments:
  - Seems like fire and restoration treatments only cover a small part of the anthropogenic factors question?

Tredennick, A. T., Hooten, M. B., Aldridge, C. L., Homer, C. G., Kleinhesselink, A. R., & Adler, P. B. (2016). Forecasting climate change impacts on plant populations over large spatial extents. *Ecosphere*, *7*(10), e01525. https://doi.org/10.1002/ecs2.1525

- Used a spatiotemporal population model incorporating remote sensing data to predict sagebrush population response in Wyoming, finding that sagebrush at this cold site is expected to increase in cover.
- Geography: southwestern Wyoming (colder extreme of sagebrush range)
- Key points:
  - "averaging across all GCMs, precipitation and temperature in [southwestern Wyoming] projected to increase; the magnitude increase depends on the RCP scenario."
  - Forecast an average increase in sagebrush cover, but decrease not outside "realm of possibility"
  - "generally increasing trend reflects the positive effect of precipitation on sagebrush cover change estimated for our study area"
  - positive posterior means for all precipitation and temperature effects, except for effect of fall-through-spring precipitation in first year of cover transition
  - Cumulative precip year before cover transition is the strongest predictor; "However, mean estimates for climate effects relatively weak"
  - Predict increase in heterogeneity of cover "because projected cover increases are smaller in low-cover than in high-cover pixels" - lack of correlation with landscape factors “leads us to conclude that the spatial structure in our data set emerges from some combination of fine-scale microhabitat associations and legacy effects of disturbance."
- Gaps/limitations:
  - In the future, "it will be important to allow climate effects to vary over space to better capture reality"
  - "parameter uncertainty could be reduced by regulating the variance of the posterior distributions of climate covariates via ridge regression"
  - "uncertainty associated with climate projections could be reduced by identifying GCMs that perform exceptionally well for a particular... location"
  - "Future modeling could include effects of nonclimate drivers [including] species interactions and disturbance." - fire and competition with invasives may be especially important for sagebrush
- Other comments:
  - Includes discussion of the benefits of using remote sensing in species modeling work (and weaknesses of SDMs).
  - Provides an ecohydrology-based explanation of a possible mechanism for sagebrush losses predicted by SDMs.
  - Explains how results are consistent with individual-level responses of sagebrush to climate-related variables.

Tredennick, A. T., Monroe, A. P., Prebyl, T., Lombardi, J., & Aldridge, C. L. (2023). Dynamic spatiotemporal modeling of a habitat-defining plant species to support wildlife management at regional scales. *Ecosphere*, *14*(6), e4534.

https://doi.org/10.1002/ecs2.4534

- Modeled the direct effects of climate change on sagebrush cover, seeing projections of increased cover for most management areas in Wyoming.
- Geography: Wyoming sage-grouse core areas
- Key points:
  - Sagebrush performance at most core areas showed positive sensitivity to temperature [most consistent pattern] and negative sensitivity to precipitation. Because average temperature is expected to increase in Wyoming and average precipitation is expected to remain relatively constant, project increase in cover at most core areas.
  - Projected increases larger in magnitude than decreases and on about 4x larger land area.
  - "results corroborate those of Palmquist et al. (2021) and Schlaepfer et al. (2021) by suggesting that climate change alone should benefit, or at least not significantly disadvantage, sagebrush in Wyoming" - cheatgrass may be bigger concern
  - "management actions aimed at reducing cheatgrass invasion and limiting disturbances in core areas might help mitigate the negative, indirect impacts of climate change"
- Gaps/limitations:
  - "biggest limitation... only quantified the direct effects of climate on sagebrush performance. Indirect effects of climate change and other non climate-related effects might be more influential. In particular, the fire-cheatgrass invasion cycle has been implicated as the major driver of sagebrush loss across most of its historical range."
  - "implicitly assume that the relationships between sagebrush percent cover and temperature and precipitation are log-linear. That is, by using the statistical models to project cover into the future, we are assuming that the relationships quantified from historical data will be maintained in the future"
  - models likely miss the impact of extreme events (drought, etc.)
- Other comments:
  - Includes some discussion on energy development needs and notes on why Wyoming may be a sagebrush stronghold.
  - "Recent modeling suggests that warming temperatures will benefit sagebrush more than cheatgrass at high-elevation sites, assuming fire is limited (Palmquist et al., 2021)."
  - "We do not use lagged covariates here because exploratory work indicates that lagged covariates result in correlated and confounded parameter estimates" - perhaps a consideration for interpretation of earlier work? (Tredennick 2016, Kleinhesselink 2018, + others)
  - Describe previous work that agrees with the finding of positive impact of temperature on performance at the cold edge of range along with mechanistic explanations.

Zimmer, S. N., Grosklos, G. J., Belmont, P., & Adler, P. B. (2021). Agreement and Uncertainty Among Climate Change Impact Models: A Synthesis of Sagebrush Steppe Vegetation Projections. *Rangeland Ecology & Management*, *75*, 119–129.

https://doi.org/10.1016/j.rama.2020.12.006

- Compare 19 different climate impact models, finding potential for pinyon-juniper declines, forage increases, and minimal impacts on cheatgrass and sagebrush (except at southern extremes).
- Geography: BLM lands in intermountain west - includes part of Colorado, Wyoming (NBR, CBR, Wyoming Basin, Colorado Plateau EPA Ecoregions)
- Key points:
  - “analyzed 19 models of climate change impacts on sagebrush, cheatgrass, pinyon-juniper, and forage production on BLM lands in the US Intermountain West”
  - Models consistently projected:
    - potential for pinyon-juniper declines
    - forage production increases
    - no cheatgrass climate change impacts
    - sagebrush - no change in most areas, declines in southern extremes
- Gaps/limitations:
  - Inherent uncertainty in projecting future climate which carries over into models projecting ecological impacts; models are complex, but can't consider all possible ecological change drivers - "For example, increases in extreme weather events due to climate change are likely... but may not be explicitly considered by many ecological impact models. Models account for interactions such as species competition or disturbance from wildfire or grazing in various ways, another limitation that can affect their generalizability."
  - Of particular note - "wildfire interactions are not well accounted for in our results"
- Other comments:
  - This was a good (and I think relevant) paper - models have weaknesses but discussion of them seemed useful (especially when put in context of other work).

Photo: Matt Lavin, Flickr

Bansal, S., & Sheley, R. L. (2016). Annual grass invasion in sagebrush steppe: The relative importance of climate, soil properties and biotic interactions. *Oecologia*, *181*(2), 543–557.

https://doi.org/10.1007/s00442-016-3583-8

- Use field data and modeling to assess what combination of factors are most important to invasive annual grass invasion and abundance, finding native perennial grass communities as the most relevant factor.
- Geography: eastern Oregon sagebrush steppe (northern Great Basin)
- Key points:
  - negative relationships between invasive annual grasses (AGs) and: biodiversity, perennial grass cover, resident species richness, biological soil crust cover, shrub density (in order)
  - no direct linkage: perennial and annual forb cover, tree cover, soil microbial biomass
  - Increasing AG cover with increasing temperature and aridity (likely indirect effects)
  - “soil properties appear to have stronger relationships with resident biota than invasives”
  - “overwhelming influence of biotic interactions on AG cover compared to other factors”
  - "increasing perennial grass cover coupled with supplementary amendments to belowground soil factors [C, N] may provide maximum effectiveness for controlling AG abundance and for restoring native sagebrush steppe communities."
- Gaps/limitations:
  - Didn’t get at directionality or cause/effect
  - Only looked at current-year grazing, maybe would be more useful to look at long-term
  - Future research needed disentangling mechanisms of competition under a range of conditions
- Other comments:
  - Includes useful discussion of factors going into plant community assembly and species distributions, plus how invasive species play in.
  - Insightful discussion of how native perennials influence below-ground nutrient availability and other activities - “suggest that an increase in perennial grass cover can mechanistically improve soil conditions to favor perennial forbs through belowground linkages.”

Blumenthal, D. M., Kray, J. A., Ortmans, W., Ziska, L. H., & Pendall, E. (2016). Cheatgrass is favored by warming but not CO2 enrichment in a semi-arid grassland. *Global Change Biology*, *22*(9), 3026–3038. https://doi.org/10.1111/gcb.13278

- Use a field experiment to test how CO2 enrichment and infrared warming affect cheatgrass, finding warming more than tripled biomass and seed production regardless of competition or water availability, but there was no effect of CO2 enrichment.
- Geography: field experiment (PHACE) at the High Plains Grassland Research Station, near Cheyenne, WY (southern edge of the northern mixed-grass prairie) - focus on northern mixed grassland prairie
- Key points:
  - "test how free-air CO2 enrichment and infrared warming influence... [cheatgrass] in semi-arid mixed-grass prairie" over two years (with competition context)
  - "conclude that (1) warming may expand *B. tectorum*'s phenological niche, allowing it to more successfully colonize the extensive, invasion-resistant northern mixed-grass prairie, and (2) in ecosystems where elevated CO2 decreases N availability, CO2 may have limited effects on *B. tectorum* and other nitrophilic invasive species"
  - "Strategies for increasing ecosystem resistance in the face of warmer temperatures could include promoting native species with very early or late phenology."
- Gaps/limitations:
  - This study was not done in the context of a sagebrush ecosystem
  - It remains difficult to "predict how competition will interact with warming and elevated CO2"
  - "climate envelope models are likely to be useful for guiding [cheatgrass] monitoring efforts"
- Other comments:
  - Includes background on why mechanistic responses to CO2 and temperature are tricky and discusses results from work studying them separately.
  - Discusses context dependence and need for studies with realistic water and nutrient limitation situations.
  - Provide sources for cheatgrass becoming more invasive in cooler, higher areas.
  - Share hypotheses for why large parts of the northern mixed-grass prairie have remained more intact than the intermountain region.
  - Includes helpful discussion of carbon/nitrogen/water physiology in the context of the results and possible explanations.

Boyd, C. S. (2022). Managing for resilient sagebrush plant communities in the modern era: We're not in 1850 anymore. *Rangelands*, *44*(3), 167–172. https://doi.org/10.1016/j.rala.2022.02.002

- This review discusses sagebrush plant community ecology over time, the effects of invasive annual grasses, and future steps for the preservation of sagebrush ecosystems.
- Geography: mainly Great Basin but likely generalizable
- Key points:

    - Moving forward will require: protecting the core, growing the core, restoring perennials, managing fuels
- Gaps/limitations:
    - "Currently, research has not progressed to the point where general management recommendations on when shrub reduction is needed, or what might constitute appropriate levels of shrub reduction, are available."
- Other comments:
    - Provides some useful historical context into the sagebrush ecosystem of the Great Basin as well as useful background on native perennial bunchgrasses

Bradley, B. A., Curtis, C. A., & Chambers, J. C. (2016). Bromus Response to Climate and Projected Changes with Climate Change. In M. J. Germino, J. C. Chambers, & C. S. Brown (Eds.), *Exotic Brome-Grasses in Arid and Semiarid Ecosystems of the Western US* (pp. 257–274). Springer International Publishing. https://doi.org/10.1007/978-3-319-24930-8_9

- Review findings related to climate limits of invasive Bromus species in the context of future climate projections.
- Geography: Complete sagebrush biome in the western US
- Key points:
    - Warming temps will likely positively impact *Bromus* species and may lead to invasion of formerly resistant ecosystems if natives negatively affected by climate changes
    - *Bromus rubens* will likely expand its range northward (but likely still not in CO, WY, MT)
    - Primary limitation to invasion and expansion is precipitation and projections are uncertain
    - "greater climate variability likely will favor invasion of annual weeds and negatively affect native species persistence in areas that remain otherwise climatically suitable"
    - "Managers should anticipate both shifts in the overall distribution of *Bromus* species, as well as changes in relative abundance within its existing range."
- Gaps/limitations:
    - "fewer studies have considered climate effects on interactions of *Bromus* with native species"
    - "Experimental and modeling studies that test biotic interactions across existing environmental gradients might provide better insight about overall invasion risk with climate change than studies of *Bromus* independently."
    - "Important information about likely species' response to climate change will come from long-term monitoring sites, experimental studies, and observations across environmental gradients."
    - "Prioritizing longer-term, multi-year experiments will improve our ability to project future ecological changes."
- Other comments:
    - Includes lots of useful discussion of projected response of cheatgrass to future climate projections and cool figures.

Bradley, B. A., Curtis, C. A., Fusco, E. J., Abatzoglou, J. T., Balch, J. K., Dadashi, S., & Tuanmu, M.-N. (2018). Cheatgrass (Bromus tectorum) distribution in the intermountain Western United States and its relationship to fire frequency, seasonality, and ignitions. ***Biological Invasions*****,** ***20*****(6), 1493–1506.** https://doi.org/10.1007/s10530-017-1641-8

- Developed regional models of cheatgrass distribution and cover and investigated the relationship between cheatgrass presence and fire characteristics, finding that cheatgrass is more extensive and abundant than previously documented and invasion greatly increases fire risk, even at low cover.
- Geography: hydrographic Great Basin
- Key points:
  - "Cheatgrass invasion is widespread across one-third of the Great Basin desert."
  - "Invasion is associated with a doubling of regional fire frequency and fire risk is elevated even at low levels of cheatgrass abundance."
  - "Strong association between human ignitions and fire on cheatgrass"
  - Reducing the cheatgrass-fire cycle should focus on management of invaded ecosystems, regardless of level of cover, especially in areas near human activity. Education and outreach to reduce human ignitions will also be important.
- Gaps/limitations:
  - "In order to improve regional models of percent cover, more current training data with a focus on wetter years when cheatgrass is most productive are needed."
  - "possible that inter-annual variability in measured cheatgrass cover adds uncertainty to this analysis, such that areas observed to have low cover in dry years later had higher cover and promoted fire following wet years"
- Other comments:
  - Includes useful description of what makes it possible to detect and map cheatgrass using satellite imagery (difference in timing, inter-annual variability, etc.).

Brummer, T. J., Taylor, K. T., Rotella, J., Maxwell, B. D., Rew, L. J., & Lavin, M. (2016). Drivers of Bromus tectorum Abundance in the Western North American Sagebrush Steppe. ***Ecosystems*****,** ***19*****(6), 986–1000.** https://doi.org/10.1007/s10021-016-9980-3

- Investigated the relative importance of climate in local factors in driving *B. tectorum* abundance and transformative ability, finding climate strongly limits the range where cheatgrass is likely to be transformative.
- Geography: western North American sagebrush steppe
- Key points:
  - "Climate strongly limits the transformative ability of *B. tectorum* to a portion of the [Wyoming big] sagebrush steppe with dry summers (July precip <10 mm and the driest annual quarter associated with a mean temp >15°C) and low native grass canopy cover [native canopy cover of at least 25% was associated with little or no cheatgrass canopy cover]"

        - “This portion includes the Bonneville, Columbia, Lahontan, and lower Snake River basins."
        - “Dry summer conditions greatly impede native plant productivity"
    - "Conversion of the sagebrush steppe by *B. tectorum*, therefore, is more likely to occur outside the confines of its current climatically optimal region because of site-specific disturbances, including invasive species control efforts and sagebrush steppe mismanagement, rather than climate change."
    - "However, some of the climate projections indicated the potential for relatively large expansion of the area where *B. tectorum* is highly abundant. Thus, uncertainty remains regarding the future extent of the transformative ability of *B. tectorum*."
- Gaps/limitations:
    - "The relationship of native perennial herb abundance and diversity with disturbance (including an abundance of *B. tectorum* as a proxy for disturbance) needs more investigation, especially with respect to beta diversity and phylogenetic beta diversity rather than alpha diversity."
- Other comments:
    - Results inconsistent with fire/cheatgrass cycle - a bit of a surprise.

Chambers, J. C., Bradley, B. A., Brown, C. S., D’Antonio, C., Germino, M. J., Grace, J. B., Hardegree, S. P., Miller, R. F., & Pyke, D. A. (2014). Resilience to Stress and Disturbance, and Resistance to Bromus tectorum L. Invasion in Cold Desert Shrublands of Western North America. *Ecosystems*, *17*(2), 360–375. https://doi.org/10.1007/s10021-013-9725-5

- Provided a general overview of resilience and resistance to cheatgrass.
- Geography: cold desert shrublands
- Key points:
    - Conversion "to annual grass dominance can change soil physical and chemical properties, decrease soil stability, and alter ecosystem processes like nutrient cycling and soil water flux and storage"
    - "Higher resilience... associated with greater resource availability and more favorable environmental conditions..." (often occurs at higher elevations)
    - Fundamental niche of cheatgrass in cold desert shrublands driven primarily by temperature and precipitation
    - Realized niche "strongly mediated by resource availability and interactions with natives"
    - "Fire and inappropriate grazing (timing, duration, intensity)... are the most common disturbances associated with decreased resilience and resistance in cold desert ecosystems. Inappropriate grazing can decrease the relative abundance of palatable grasses and forbs, disrupt biological soil crusts, and increase soil surface disturbance," and change soil water/nutrient profile.
- Other comments:
    - Found that the information provided wasn’t very specific or novel, might be a little outdated.

Chambers, J. C., Germino, M. J., Belnap, J., Brown, C. S., Schupp, E. W., & Clair, S. B. St. (2016). Plant Community Resistance to Invasion by Bromus Species: The Roles of Community Attributes, Bromus Interactions with Plant Communities, and Bromus Traits. In M. J. Germino, J. C. Chambers, & C. S. Brown (Eds.), *Exotic Brome-Grasses in Arid and Semiarid Ecosystems of the Western US* (pp. 275–304). Springer International Publishing. https://doi.org/10.1007/978-3-319-24930-8_10

- Book chapter provides great background on factors contributing to the likelihood of invasion by different Bromus species.
- Geography: Full sagebrush biome
- Key points:
  - "resistance to *B. tectorum* in the cold desert varies strongly over elevation gradients"
  - "Resistance to Bromus generally increases with increasing summer precipitation as a function of increasing grass dominance"
  - "Bromus also may be constrained in regions with predominant summer precipitation due to low soil phosphorus availability"
  - "Bromus is generally more effective than native species at using limiting soil resources on short timescales largely due to its life history strategies and rapid growth rates"
  - "Experimental removal of natives… can increase *B. tectorum* seed production"
  - "well-developed biocrusts can inhibit germination and establishment of invasives"
  - "crushed biocrusts can stimulate growth of invasives… when left in place"
  - "Soil and plant community disturbance often precede and reinforce Bromus invasions"
  - "Negative effects of herbivory on *B. tectorum* can be exceeded by indirect positive effects through competitive release when herbivores preferentially target natives…"
  - "cattle grazing reduced resistance to invasion by decreasing bunchgrass cover, increasing the size of gaps between perennial herbaceous plants, and reducing biological soil crusts"
- Gaps/limitations:
  - "Better define the climate suitability (space) of Bromus species and of co-occurring native species…"
  - Increase understanding of:
    - "resource pools and their influence on resistance to Bromus…"
    - "how native species' life history and ecophysiological traits influence competitive interactions with Bromus."
    - "community processes, such as herbivory by native herbivores and livestock, on resistance to Bromus."
- Other comments:
  - Chapter 10 of Exotic brome-grasses in arid and semiarid ecosystems of the Western US by Germino et al. 2016

Davies, K. W., Leger, E. A., Boyd, C. S., & Hallett, L. M. (2021). Living with exotic annual grasses in the sagebrush ecosystem. *Journal of Environmental Management*, *288*, 112417. https://doi.org/10.1016/j.jenvman.2021.112417

- Provides a management framework for living with exotic annual grasses.
- Geography: full sagebrush range, but more mention of Great Basin
- Key points:
  - The outlined framework for living with exotic annual grasses includes:
    - 1 - “preventing exotic annual grass dominance of new areas, and maintaining the integrity of high-priority areas”
    - 2 - “breaking the annual grass-fire cycle in already invaded areas”
    - 3 - “judiciously using introduced perennial species to prevent exotic annual grass invasion and revegetate invaded-areas where native seedlings are unlikely to be successful/not feasible”
    - 4 - “improving restoration with native species, including considering more intensive methods to restore natives in strategically- located refugia”
    - 5 - “recognizing invaded landscapes that will likely remain exotic annual grasslands and managing them as such"
- Gaps/limitations:
  - "Efforts to improve native vegetation establishment and persistence are needed to expand their use and increase their efficiency."
  - Research is needed to investigate "the effects of different types of grazing management on composition, fuel accumulations, habitat value, and forage."
- Other comments:
  - Core paper.

Larson, C. D., Lehnhoff, E. A., & Rew, L. J. (2017). A warmer and drier climate in the northern sagebrush biome does not promote cheatgrass invasion or change its response to fire. *Oecologia*, *185*(4), 763–774. https://doi.org/10.1007/s00442-017-3976-3

- Used experimental warming, drying, and burning experiments to explore cheatgrass responses to changes in climate in Montana, finding changes in climate won't necessarily facilitate invasion in this region without disturbance.
- Geography: Montana sagebrush steppe
- Key points:
  - Experimental warming and warming plus drying led to:
    - reduced cheatgrass cover, biomass, fecundity
    - negatively affected *P. spicata*
    - decreased native grass cover
    - community biodiversity
  - Fire: only increased cheatgrass fecundity, no effect on cover; negatively affected native grass cover, particularly when warmer/drier

    - "native grass community was most significant factor that affected *B. tectorum* metrics" (native community and *P. spicata* also negatively impacted by cheatgrass presence)
    - "because of our site's low late winter/early spring precipitation [limited fall/winter germination and therefore dependence on spring precipitation], the results of warming and warming + drying treatments had deleterious effects on *B. tectorum* growth and abundance... only observed limited positive response by *B. tectorum* to fire, which was not heightened by warming and drying... show a lack of positive fire-feedback in the cold and wet northern sagebrush biome, including Montana"
    - "In the colder northern sagebrush biome that receives more summer than winter precipitation:
        - (1) warmer/drier growing seasons lower ecosystem resilience
        - (2) threat of *B. tectorum* becoming a transformative species as the result of climate warming [warmer and drier spring/summer growing season] is low unless shift in seasonal precip [more more winter precip to facilitate earlier establishment]
        - (3) effects of climate change may be modified by spring burning, which negatively impacts native grasses more than cheatgrass"
- Gaps/limitations:
    - Plants were only sampled throughout the growing season in which they were implemented - very short term? (especially for fire recovery piece)
    - "Conclusions about the long-term resilience to fire of our site under warmer and warmer and drier conditions are limited."
- Other comments:
    - Includes background on cheatgrass (a winter annual that germinates in fall/winter/spring and relies on ample winter/spring soil moisture) as well as citations for mechanisms and regional patterns related to cheatgrass dominance (both Chambers 2014) and response to climate change.
    - Offers potential explanation for why everything responded poorly to warming here, contradicting previous work.
    - Includes comments on reasons for why cheatgrass was not more competitive under warm + dry like found in Larson et al. 2018.

Larson, C. D., Lehnhoff, E. A., Noffsinger, C., & Rew, L. J. (2018). Competition between cheatgrass and bluebunch wheatgrass is altered by temperature, resource availability, and atmospheric CO2 concentration. *Oecologia*, *186*(3), 855–868.

https://doi.org/10.1007/s00442-017-4046-6

- Growth chamber experiment showing cheatgrass outcompeted under 2 sets of climate change conditions when planted one month after *P. spicata* (manipulating temp, water, CO2, nutrients).
- Geography: growth chamber experiment - conditions based on Southwest Montana
- Key points:
    - Tested expectation that cheatgrass would benefit from warmer and drier conditions and increased CO2 and nutrient availability (experiment 1: + temp, - water, + nutrients; experiment 2: + CO2, - water)
    - Native perennial bunchgrass *Pseudoroegneria spicata* suppressed cheatgrass under all conditions, but cheatgrass had increased competitiveness under experiment 1 conditions.

    - Both species responded positively to elevated CO2 when grown separately - in competition, increased suppressive effect of *P. spicata*.
    - "B. tectorum competitiveness with P. spicata responds differently to global change drivers; thus, future conditions are unlikely to facilitate B. tectorum invasion into established P. spicata communities of the northern sagebrush steppe. However, disturbance (e.g., fire) to these communities, and the associated increase in soil nutrients, elevates the risk of B. tectorum invasion."
- Gaps/limitations:
    - Study focused on conditions where native bunchgrass had 1 month head start and treatment affected cheatgrass germination.
    - "we were unable to address the phenological differences of the species and the seasonality of the water availability, which are important for competition between these species."
- Other comments:
    - Includes science background on elevated CO2 and plants and competition with invasives.
    - Cites sources for expected shift in cheatgrass range/ecosystem dominance (one is book in invasive grasses) and for fire increasing soil nutrient levels.
    - Discussion of how cheatgrass does well with elevated temperature and precipitation, CO2 (not in community setting) - responded neutrally to elevated CO2 in community setting in the past.

Reich, P. B., Hobbie, S. E., Lee, T. D., & Pastore, M. A. (2018). Unexpected reversal of C3 versus C4 grass response to elevated CO2 during a 20-year field experiment. *Science*, *360*(6386), 317–320. https://doi.org/10.1126/science.aas9313

- CO2 enrichment experiment unexpectedly demonstrated that C4 grasses performed better than C3 grasses in the later years of the study and highlighted nitrogen as a potential limiting factor.
- Geography: field experiment in Minnesota
- Key points:
    - "we report results from a long-term (20-year) FACE experiment in Minnesota, USA, that support the long-held paradigm for the early part of the experiment but reveal a gradual reversal to a much more positive response to eCO2 by C4 than by C3 grasses"
    - "findings challenge the current C3-C4 eCO2 paradigm and show that even the best-supported short-term drivers of plant response... might not predict long-term"
    - "shifting soil N biogeochemistry partially explains shifting biomass responses to eCO2."
- Gaps/limitations:
    - "Why these soil N cycling responses played out in this fashion remains an open question"
- Other comments:
    - Most relevant part likely finding that nitrogen a limiting factor when considering plant response to elevated CO2

Root, H. T., Miller, J. E. D., & Rosentreter, R. (2020). Grazing disturbance promotes exotic annual grasses by degrading soil biocrust communities. *Ecological Applications*, *30*(1), e02016. https://doi.org/10.1002/eap.2016

- Explored the effects of grazing on biocrusts and invasion, finding strong support for biocrusts helping to reduce invasion by exotic annual grasses, with certain functional groups playing more critical roles.
- Geography: Idaho - Snake River Plain
- Key points:
  - Biocrust cover, species richness negatively related to grazing intensity, exotic annual grass abundance
  - Biocrust cover is important for maintaining resistance to invasion and different functional groups may have unique ecological roles in maintaining native plant communities.
  - "Biocrust species richness, which is reduced by livestock grazing, also appears to promote native perennial grasses."
  - "Short mosses, as a functional group, appear to be particularly valuable for preventing invasion"
  - "Maintaining biocrust communities with high cover, species richness, and cover of short mosses can increase resistance to invasion."
- Gaps/limitations:
  - Limited ability to grow diversity of lichens in bulk for restoration - need to develop cultivation methods, especially for short mosses, and improve establishment.
- Other comments:
  - Includes some useful background on biocrusts.

Seipel, T., Rew, L. J., Taylor, K. T., Maxwell, B. D., & Lehnhoff, E. A. (2018). Disturbance type influences plant community resilience and resistance to Bromus tectorum invasion in the sagebrush steppe. *Applied Vegetation Science*, *21*(3), 385–394. https://doi.org/10.1111/avsc.12370

- Studied the effect of fire and soil disturbance (via creation of a fire break) on resilience and resistance to cheatgrass invasion over 3 years in the cooler and wetter portions of the sagebrush steppe, finding that communities with native cover were resilient to fire but not soil disturbance.
- Geography: southwestern Montana sagebrush steppe
- Key points:
  - Resilience and resistance to invasion impacted by disturbance type (and vary in response to the extant plant community) - here largely resistant to fire, but R&R lower where soil disturbance (low native grass cover a predictor of invasion)
  - "A prescribed burn in an area dominated by the non-fire adapted *A. tridentata* could increase the dominance of *B. tectorum* if a sufficient cover of native grasses and forbs is not present." - there may be a threshold

    - Within the sagebrush biome “where native grass cover is considerable (>20%) the community is resilient to fire, with native grasses recovering rapidly and the plant community composition resembling pre-burn composition. The only exception is the shrub *A. tridentata*, which is slower to recover."
    - Suggest avoiding excessive soil disturbance
- Gaps/limitations:
    - None noted.
- Other comments:
    - Noted that plant communities in cooler and wetter, high-elevation sites tend to have more resprouting shrubs and bunchgrasses, available resources, and are more resistant and resilient to invasion.
    - Contrasts other studies of fire response to fire in other parts of the range.

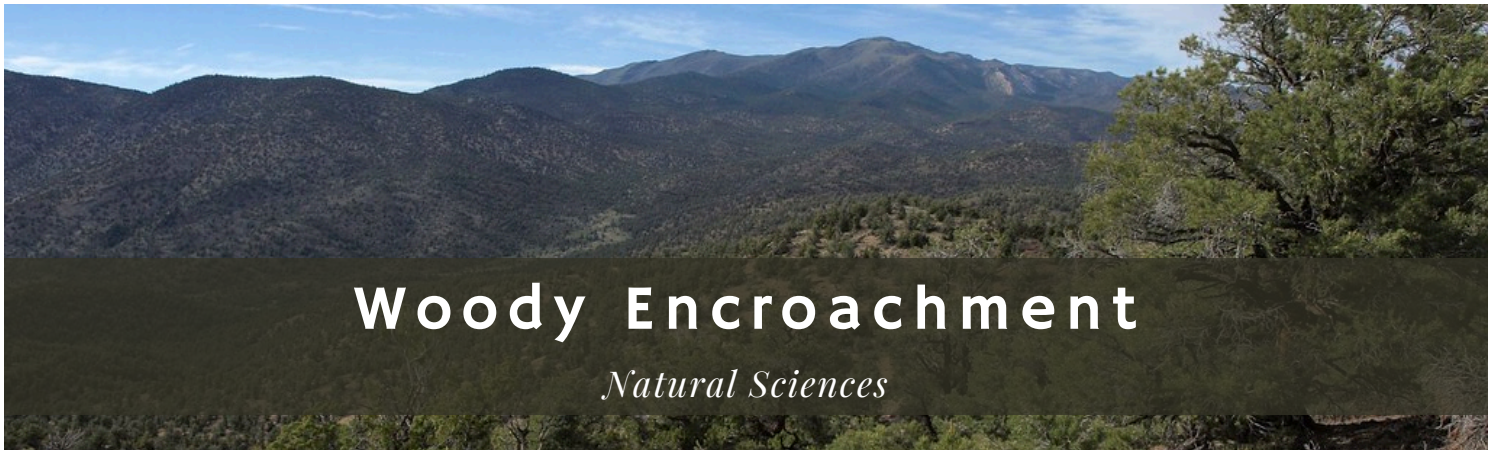
Smith, J. T., Allred, B. W., Boyd, C. S., Davies, K. W., Kleinhesselink, A. R., Morford, S. L., & Naugle, D. E. (2023). Fire needs annual grasses more than annual grasses need fire.

***Biological Conservation*, *286*, 110299.** https://doi.org/10.1016/j.biocon.2023.110299

- Use remotely sensed vegetation and fire datasets to examine the role of transitions to annual grass dominance, finding invasion is not dependent on fire.
- Geography: Great Basin
- Key points:
    - "Most transitions have occurred without fire"
    - "Fire catalyzes transitions already underway"
    - Similar post-transition outcomes are observed regardless of whether the area was burned
    - Fires aren't needed to maintain annual grass dominance
    - "Fire is overemphasized as a driver of change"
    - More proactive management of invasives is needed
- Gaps/limitations:
    - "broad similarities at the scale of plant functional types may obscure important differences at the species level."
    - More research on the effectiveness and best practices for using pre-emergent herbicides is needed.
- Other comments:
    - Useful background and citations.

Williamson, M. A., Fleishman, E., Mac Nally, R. C., Chambers, J. C., Bradley, B. A., Dobkin, D. S., Board, D. I., Fogarty, F. A., Horning, N., Leu, M., & Wohlfeil Zillig, M. (2020). Fire, livestock grazing, topography, and precipitation affect occurrence and prevalence of cheatgrass (Bromus tectorum) in the central Great Basin, USA. *Biological Invasions*, *22*(2), 663–680. https://doi.org/10.1007/s10530-019-02120-8

- Authors compiled a time-series of data on cheatgrass and various covariates in the Great Basin, with results that do not support the use of grazing for cheatgrass suppression.
- Geography: central Great Basin, Nevada
- Key points:
  - Fire and grazing history positively associated with cheatgrass probability
  - "Potential response of cheatgrass to any one predictor, regardless of whether that predictor can be managed, is affected by other biotic and abiotic environmental attributes and feedbacks."
  - Cheatgrass more likely at lower elevations, but given it is present, it is more abundant higher and in areas with lower solar exposure
  - Saw a negative relationship between prevalence of native perennials and prevalence of cheatgrass cheatgrass (in models only looking at unburned data points)
  - "Prevalence tended to be lower in years in which precipitation at a given point was high relative to that point's long-term median, but higher when regional winter precipitation was high and regional spring precipitation was at or below the median"
- Gaps/limitations:
  - Uncertainties about long-term trajectories
  - Uncertainty in characterization of grazing history
- Other comments:
  - Includes thorough background on cheatgrass and summary of findings of other related work related to establishment and response under disturbance and general cheatgrass distributions and drivers.



Woody Encroachment

Natural Sciences

Photo: Jim Morefield, Flickr

Barger, N. N., Adams, H. D., Woodhouse, C., Neff, J. C., & Asner, G. P. (2009). Influence of Livestock Grazing and Climate on Pinyon Pine (Pinus edulis) Dynamics. *Rangeland Ecology & Management*, *62*(6), 531–539. https://doi.org/10.2111/.1/REM-D-09-00029.1

- Investigated the relationships between historical grazing and climate and pinyon recruitment and growth in persistent woodlands, finding past climate (particularly winter/spring water precip) may be more important than grazing.
- Geography: Colorado Plateau
- Key points:
  - Stand structure similar between sites, similar growth dynamics, recruitment dynamics & annual growth highly correlated
  - Introduction of livestock didn't impact growth rates
  - Growth rates strongly influenced by winter through early summer precip and negatively correlated with June temp
  - Historical grazing appears less important than past climate in structuring population
  - "Climate during the early-20th-century wet period may have played an important role in structuring the modern pinyon population.""
  - Possible that larger recruitment events will be less frequent in the future
  - "Suggest that anthropogenic changes in grazing and fire regimes have not played a significant role in structuring PJ populations""
  - "The call to restore mature, persistent PJ woodland to a more historic condition using mechanical methods and prescribed fire must be closely scrutinized"
- Gaps/limitations:
  - "limited goat grazing did occur in the late 1920s on NMM (1927–1928), and this grazing event cannot be ruled out as having an influence on pinyon recruitment and growth dynamics"
- Other comments:
  - Study focused on “persistent woodland” sites, not sure how that might influence generalizability of results.

Bradley, B. A., & Fleishman, E. (2008). Relationships between expanding pinyon–juniper cover and topography in the central Great Basin, Nevada. *Journal of Biogeography*, *35*(5), 951–964. https://doi.org/10.1111/j.1365-2699.2007.01847.x

- Use combination of satellite imagery and field data to explore trends in pinyon-juniper cover over time related to elevation and aspect with a focus on mountains/valleys within the Great Basin.
- Geography: central Great Basin in Nevada
- Key points:
  - Highest pinyon-juniper cover at relatively high elevations (2200-2700m)
  - Tree cover increasing disproportionately at low elevations and on south-facing slopes
  - Climate [higher precip in areas that had been too dry], increased CO2, and land use [timber harvest, grazing] could have contributed to expansion
- Gaps/limitations:
  - approach underestimated green vegetation and overestimated shadow and dark soil
  - Expect that relative between-year comparisons more accurate and precise than absolute data from a given year
  - “We emphasize that local variability can strongly influence regional-scale trends." - results may not be applicable to other regions
- Other comments:
  - Specific findings likely not incredibly relevant or generalizable to the CO/MT/WY sagebrush biome.
  - Useful background and citations for historical context and potential drivers of woody encroachment, effects of pinyon-juniper expansion, and pinyon-juniper ecology and characteristics.

Coates, P. S., Prochazka, B. G., Ricca, M. A., Gustafson, K. B., Ziegler, P., & Casazza, M. L. (2017). Pinyon and Juniper Encroachment into Sagebrush Ecosystems Impacts Distribution and Survival of Greater Sage-Grouse. *Rangeland Ecology & Management*, *70*(1), 25–38. https://doi.org/10.1016/j.rama.2016.09.001

- Employ a modeling approach to investigate the relationship between pinyon-juniper cover and sage-grouse avoidance and survival, finding that PJ cover negatively influences sage-grouse fitness, especially in areas with relatively low tree cover but high primary productivity.
- Geography: area along the border of California and Nevada
- Key points:
  - Sage-grouse avoided areas with pinyon-juniper, but strength of avoidance varied based on encroachment phase:
    - variation in avoidance behavior greatest for lowest canopy cover
    - consistent strong avoidance when greater coverage

- "Relative importance of cover class was opposite for survival compared with avoidance... disproportionate use of CC1 imposed greater risks"
- In the absence of pinyon-juniper cover, sage-grouse that used high-productivity areas had greater survival rates.
- Sparsely distributed trees located within a highly productive habitat can lead to the formation of an ecological trap.
- "Managers might consider focusing efforts in areas of CC1 and targeting removal in areas relevant to sage-grouse as low as 1.5–2.0% tree canopy cover... especially in areas of high plant productivity"
- "Differences in mortality risk among cover classes and plant productivity are likely attributable to greater exposure to predators."

- Gaps/limitations:
  - Don't explore how sage-grouse might respond to specific pinyon-juniper treatment methods.
- Other comments:
  - Includes notes on sage-grouse predators and their predation habits.

Curtiss, W., Majumder, S., Martinez, R., & White, A. (2022). *Grand Valley Ecological Forecasting II: Forecasting Trends in Pinyon-Juniper and Sagebrush Habitat Relative to Wildfire, Drought, Beetle Disturbance, and Treatment Impact for Management Planning*.

https://ntrs.nasa.gov/citations/20220014232

- Used satellite data to forecast trends in pinyon-juniper and sagebrush habitat in the Grand Valley region, seeing some support of some transition from tree to shrub in this area.
- Focus on methods rather than findings and narrow geography make this work not broadly applicable in this context.

Davies, K. W., Rios, R. C., Bates, J. D., Johnson, D. D., Kerby, J., & Boyd, C. S. (2019). To burn or not to burn: Comparing reintroducing fire with cutting an encroaching conifer for conservation of an imperiled shrub-steppe. Ecology and Evolution, 9(16), 9137–9148.

https://doi.org/10.1002/ece3.5461.

- Compare the efficacy of burning or cutting as methods to manage conifer encroachment, finding results dependent on time-scale of interest.
- Geography: mountain big sagebrush in northern Great Basin and Columbia Plateau
- Key points:
  - Reintroducing fire more effective than cutting over extended time frames; however, cutting more effective for short-term conservation
  - Variation in exotic annual grass cover explained by environmental variables and perennial grass abundance, but not treatment (a somewhat surprising result)
  - Results counter to "recommendations to limit fire in all sagebrush communities"

- Gaps/limitations:
  - None mentioned.
- Other comments:
  - Good background on woody vegetation
  - Fire vs. fire surrogates, historical context and present-day nuance for fire
  - Interesting discussion of fire/invasive grass increase issue - call for still treating juniper - preemptive planning better option

Jiang, P. (2018). *Vegetation Disturbance Regimes and Conifer Succession in Gunnison Sage Grouse (Centrocerus minimus) Habitat*. Regis University.

- Uses analysis of tree cores, climate data, and disturbance to explore key drivers of woody encroachment and find precipitation/drought as the best predictors.
- Geography: Fruitland Mesa in Montrose County, Colorado
- Key points:
  - Tree establishment post the 1970s was driven by a wet and cool growing season after severe drought in the 1950s.
  - Tree growth negatively correlated with drought and monthly growing season temperature, with greater growth at times of lower moisture stress during the growing season.
  - Woody encroachment is recent, with the majority of trees having established in the late 20th century.
  - “This analysis explains how current drought seasons benefit conifer trees as conifers outcompete shrubs. The dormant seeds of trees have stronger resprouting ability than grass or shrub seeds. Once the climate turns wetter after drought season, tree stem growth rate reaches a maximum where trees begin to infill shrubland (Higgins et al., 2000).”
- Gaps/limitations:
  - Need more work looking at fire as a potential driver of woody encroachment. - “Future research should seek to reconstruct past fire occurrence using fire-scarred trees to determine whether growth releases in the old-growth stand correspond with fire dates.”
- Other comments:
  - Note that this is an unpublished Master’s thesis. Unsure about the rigor of the methods/results.
  - Includes source for and discussion of ways grazing could lead to encroachment.

Noel, A. R., Shriver, R. K., Crausbay, S. D., & Bradford, J. B. (2023). Where can managers effectively resist climate-driven ecological transformation in pinyon–juniper woodlands of the US Southwest? *Global Change Biology*, *29*(15), 4327–4341.

https://doi.org/10.1111/gcb.16756

- Use climate models to predict future population dynamics for various PJ species, finding species-to-species variability with P. edulis and J. monosperma most likely to experience population declines.
- Geography: US Southwest (including parts of Arizona, New Mexico, Colorado, and Utah)

- Key points:
  - "Decreased population growth rate for *P. edulis* resulted from increased mortality rate while declines in *J. monosperma* population growth rate resulted from both increased mortality and large decreases in recruitment"
  - "potential range shifts northward and upslope for *P. edulis*, and general reductions in *J. monosperma* cover..." --> JM may have "a more difficult time dealing with future climate"
  - "many *P. edulis* sites [may] reside in areas that will experience climate shifts still tolerable to this species, while only a portion of sites [may] shift to unfavorable conditions"
  - Future climate conditions are enhancing uncertainty about *P. edulis* population growth but decreasing uncertainty about *J. monosperma* - "high confidence signal for declining *J. monosperma* populations, but growing uncertainty about *P. edulis* populations"
  - - "a proportion of vulnerable sites in *P. edulis* and *J. monosperma* populations could resist population declines via BA [stand basal area] reduction." - but may not be as helpful for JM
- Gaps/limitations:
  - Need research on climate effects on juniper recruitment
  - "need for further studies on these species and their sensitivities to future climate."
  - "Possible ways to reduce future demographic uncertainty could be improving the links between monitoring plots and environmental conditions (i.e., plot-specific measurements of soil moisture and temperature), larger sample sizes, more frequent measurements, and/or larger sample areas for regeneration."
  - "greater understanding of biotic drivers of PJ recruitment is needed in general"
- Other comments:
  - Includes background on PJ woodlands and description of some typical drivers of tree mortality.
  - There's other potentially more relevant results for other species of relevance in the supporting information

Reinhardt, J. R., Filippelli, S., Falkowski, M., Allred, B., Maestas, J. D., Carlson, J. C., & Naugle, D. E. (2020). Quantifying Pinyon-Juniper Reduction within North America's Sagebrush Ecosystem. *Rangeland Ecology & Management*, *73*(3), 420–432.

https://doi.org/10.1016/j.rama.2020.01.002

- Use remote sensing to map reductions in conifer cover that occur due to management or fire, finding that conifer reduction may just be keeping pace with expansion.
- Geography: Intermountain west - largely overlaps the Great Basin and extends into the Columbia and Colorado Plateaus
- Key points:
  - "Total pinyon-juniper reduction was an estimated 2,207 km2, with 65% attributable to management and another 35% to wildfire"
  - "Approximately 87% of reductions occurred in the three Great Basin states"
  - "Half (53%) of pinyon-juniper reductions were inside sage-grouse PACs [Priority Areas for Conservation]"
  - "Reductions on private lands and across ownerships in Colorado and Oregon were targeted to early (1-10% cover) and mid (11-20%) pinyon-juniper seral stages. Other ownerships and states included more dense stands (21-35%) in their management."

    - "The overall amount of reduction is low (1.6% of 134 000 km2, which supports trees) given the concerted effort to combat expansion in recent years."
- Gaps/limitations:
    - Everything not in a fire area is marked as management, but "it is possible that some reductions could have been caused by other agents of mortality such as pests, disease, or drought"
    - "approach described here cannot distinguish between infill within historic pinyon-juniper woodlands and expansion"
    - Current reduction map excludes restoration efforts that predate the initial cover map and associated imagery availability (likely underestimate)
    - Since mapping across large areas, trade-off with reduction in accuracy/resolution
    - "landscapes with low initial cover or partial disturbances, such as thinning, posed a technological challenge" - "significantly lower accuracies"
- Other comments:
    - Includes great background on woody encroachment and removal/management
    - "Falkowski et al. (2017) created a publicly available conifer cover map (https://map.sagegrouseinitiative.com)"
    - Includes discussion of fire vs. cutting as management strategies.
    - Background, discussion, and cited sources likely more relevant to this project than specific findings.

Reinhardt, J. R., Tack, J. D., Maestas, J. D., Naugle, D. E., Falkowski, M. J., & Doherty, K. E. (2023). Optimizing Targeting of Pinyon-Juniper Management for Sagebrush Birds of Conservation Concern While Avoiding Imperiled Pinyon Jay. *Rangeland Ecology & Management*, *88*, 62–69. https://doi.org/10.1016/j.rama.2023.02.001

- Performed spatial optimization of areas for pinyon-juniper management based on the needs of both sagebrush-obligate species and pinyon jay, finding prioritized areas changed with the inclusion of pinyon jay, but not in a way that dramatically impacts ongoing efforts.
- Geography: Intermountain West - parts of Oregon, Idaho, Montana, California, Nevada, Utah, Wyoming, and Colorado
- Key points:
    - Larger areas prioritized for conifer management when additional sagebrush-obligate songbirds added
    - Substantial changes in distribution of priority areas when pinyon jay included
    - "Areas most important to pinyon jay, comprising most of the species' range, were largely located in Nevada and Utah." - corresponding gains in priority in Oregon, Idaho, and other parts of Utah and Nevada
    - "small proportion (13–18%) of management efforts had occurred on areas we surmise as being important for pinyon jay"
    - Many opportunities for sagebrush habitat restoration outside pinyon jay strongholds
    - "some of the highest-priority areas remain consistent whether pinyon jay is included in the assessment or not. This includes large parts of central and southeastern Oregon, the northeastern corner of California, northern Utah, and Idaho, particularly southwest Idaho."
- Gaps/limitations:

    - There are gaps in knowledge of how pinyon jay responds to conifer management.
    - "While these results may be limited by the fact that the analysis of conifer removal was conducted across roughly the same time period as the pinyon jay analyses, this result remains encouraging because it falls in line with other recent work"
    - "Local-level assessments of ecological site potential and conditions are still required to determine appropriateness of conifer removal treatments and risks (e.g., invasive annual grasses)."
- Other comments:
    - Includes background on woody encroachment and pinyon jays.
    - Study does include parts of Colorado, Wyoming, and Montana, but the majority of *relevant* areas were elsewhere.

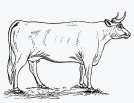
Sankey, T. T., Glenn, N., Ehinger, S., Boehm, A., & Hardegree, S. (2010). Characterizing Western Juniper Expansion via a Fusion of Landsat 5 Thematic Mapper and Lidar Data. ***Rangeland Ecology and Management*****, *63*(5), 514–523. https://doi.org/10.2111/REM-D-09-00181.1**

- Combined Landsat 5 TM and lidar-based juniper mapping techniques to explore juniper expansion in southwestern Idaho from 1965-2008.
- Focus on methods perhaps not the most relevant for our work, especially given the lack of generalizability of the results given the geography (Idaho).

Photo: Bureau of Land Management Oregon and Washington, Flickr

Davies, K. W., Wollstein, K., Dragt, B., & O'Connor, C. (2022). Grazing management to reduce wildfire risk in invasive annual grass prone sagebrush communities. *Rangelands*, *44*(3), 194–199. https://doi.org/10.1016/j.rala.2022.02.001

- Summarize support of grazing for fire management, but highlights logistical challenges.
- Geography: full sagebrush biome
- Key points:
  - Fires have increased - in part because more fuels - grazing likely to be the best option here. Moderate grazing decreases wildfire probability and can improve fire suppression, but there are logistical, social, and administrative challenges.
  - Fall-winter grazing: can decrease highly flammable invasives, increase perennial bunchgrasses (targeted, careful grazing can have a similar effect in the spring)
  - Moderately grazing pre fire reduces severity
  - Grazing for fire reduction is not necessary/productive in all years or locations (most useful in above-average plant production years - easier to manage this in off-season when bunchgrasses also dormant)"
- Gaps/limitations:
  - "Using grazing to manage fire probability has logistical, social, and policy challenges that need to be overcome for it to be effectively used."



Porensky, L. M., McGee, R., & Pellatz, D. W. (2020). Long-term grazing removal increased invasion and reduced native plant abundance and diversity in a sagebrush grassland. *Global Ecology and Conservation*, *24*, e01267. https://doi.org/10.1016/j.gecco.2020.e01267

- Used long-term vegetation exclosures to assess the effects of grazing removal in the cold desert shrublands/great plains ecotone in Wyoming, finding some level of grazing is needed for invasion resistance.

- Geography: northeast Wyoming where cold desert shrublands and great plains prairies form an ecotone
- Key points:
  - Ungrazed exclosures: less native perennial grass cover, fewer native species, more invasive cover, higher vegetation structure, less bare ground, more litter (which can facilitate cheatgrass establishment), less lichen/moss
  - No strong effects on: sagebrush cover, density, or size; total species richness; erosion; soil stability; biocrust cover
  - Lack of association with soil stability/biocrust supports the idea that "eastern edge of the sagebrush steppe is more resistant to livestock grazing than sites farther west."
  - "Long-term exclosures supported taller vegetation structure" - likely due to long-term changes in species composition rather than short-term utilization effects
  - "To maximize invasion resistance and drought tolerance it will be critical to maintain natural disturbance regimes such as grazing in ecosystems that evolved with disturbance."
- Gaps/limitations:
  - Do not explore the effects of higher grazing intensities
  - Only investigated "upland enclosures, rather than exclosures in riparian areas, which may respond differently"
  - "Future research is needed using larger exclosures in order to rule out the potential effects of fencelines and species movement between treatments (i.e. species pool effects)."
- Other comments:
  - Includes context for the use of exclosures and discussion of effects of grazing removal in other systems.
  - There are useful sources for work like this in just the cold desert shrublands and discussion of the results from this work.
  - Includes discussion of the ecotone.

Reintsma, K. M., Szczypinski, M., Running, S. W., Coons, S. P., & Dreitz, V. J. (2024). Sagebrush Steppe Productivity, Environmental Complexity, and Grazing: Insights From Remote Sensing and Mixed-effect Modeling. *Rangeland Ecology & Management*, *95*, 20–29. https://doi.org/10.1016/j.rama.2024.04.001

- Investigate the relationship between grazing (point and pasture-level metrics) and productivity while accounting for environmental variables.
- Geography: sites near Roundup, Montana in the Northern Great Plains (cold and semi-arid)
- Key points:
  - "point-level field measures of grazing [cow patties, % dung, # plants grazed] showed positive effects, especially on perennial forbs and grasses. Grazing measures at the pasture-level showed a small negative effect on annual forbs and grasses."
  - "every final GLMM showed environmental factors [moisture, temperature, plant composition, FPAR] were more influential than grazing based on their covariate effects in our study area… suggests the influence of environmental factors to be more influential to rangelands than grazing"
  - "rangelands respond to grazing differently at varying temporal and spatial scales"

- Gaps/limitations:
  - Sampling was opportunistic - landowners already doing moderate grazing and adaptive management - existing practices not intense enough to see true grazing optimization curve
  - Annual resolution - may have reduced ability to detect effects
  - Focus on short-term effects - some effects may take longer
  - "Spatial and temporal scale mismatches between remotely sensed vegetation data and livestock grazing may dilute rangeland responses." - recommend using data collected before, during, AND after active grazing (while actually affecting productivity)
  - Environmental factors may lead to adaptive management which may impact grazing regimes
- Other comments:
  - Long list of limitations, left feeling unsure about results.
  - Included citations for grazing being the most prevalent land use globally and for ways people have found that grazing manipulates rangeland vegetation.
  - Included list of factors that affect grazing outcomes - point that every livestock operation is unique.

Veblen, K. E., Nehring, K. C., McGlone, C. M., & Ritchie, M. E. (2015). Contrasting Effects of Different Mammalian Herbivores on Sagebrush Plant Communities. *PLOS ONE*, *10*(2), e0118016. https://doi.org/10.1371/journal.pone.0118016

- Used 22-yr grazing exclosures to explore the effects of cattle vs. wild ungulate herbivores on plant communities, observing no dramatic state shifts but still notable effects.
- Geography: field site in northern Utah
- Key points:
  - Distinct effects of cattle vs. native ungulates on major plant species and growth forms
  - Total exclusion had perceptible effects on overall plant community composition, and there were clear wild ungulate and small domestic grazer effects.
  - Total exclusion increased larger sagebrush densities and decreased smaller sagebrush densities. There was also an increase in shrub biomass during a wet year. During this same year, grasses were not impacted, but forbs were reduced with greater shrub cover. A reduction in wild ungulate grazing could negatively impact wildlife dependent on forbs especially.
  - No significant difference in overall plant community composition with just cattle exclosure
  - *E. elymoides* had a positive response to cattle grazing exclusion, suppressing Sandberg's blue grass (expected positive response to exclusion from *P. spicata*, but surprisingly didn't see that)
  - Release from cattle grazing led to an increase in grass biomass during a dry year, but a total biomass decrease
  - Non-native biomass was higher in plots with cattle in the wet year - cattle grazing also limited cheatgrass competitor, *E. elymoides*.
  - Biological soil crusts higher with total exclusion.
  - Effects can vary considerably across sites.
- Gaps/limitations:
  - “It is not possible to parse out the relative contributions of long-term changes in shrub density vs. short-term browsing effects on annual shrub biomass patterns.”
  - Need for study designs that can explicitly distinguish effects of different types of herbivory

    - “Cannot rule out the possibility that the effects of “wild ungulate” removal discussed above are actually additive or synergistic effects of removing both cattle and wild ungulates from Total exclosure plots."
    - "Continued efforts to untangle the effects of large ungulates on biological soil crusts are important."
- Other comments:
    - Useful background on large herbivore diets and behavior

Wild Horses and Burros

Natural Sciences

Photo: Peter Robinson/ BLM Idaho, Flickr

Davies, K. W., Collins, G., & Boyd, C. S. (2014). Effects of feral free-roaming horses on semi-arid rangeland ecosystems: An example from the sagebrush steppe. *Ecosphere*, *5*(10), art127. https://doi.org/10.1890/ES14-00171.1

- Compared vegetation/soil characteristics in horse grazed areas vs. exclosures, finding that horse grazing negatively impacted ecological function.
- Geography: northern Nevada
- Key points:
  - Horse-grazed areas had: lower sagebrush density, plant diversity, soil aggregate stability; greater soil penetration resistance
  - Heavily grazed areas had lower perennial grass cover
  - "Suggests that they may affect the ecological function of semi-arid rangelands by increasing the risk of soil erosion and potentially decreasing availability of water for plant growth." - may limit sagebrush recruitment
  - "May degrade the habitat value of these communities for associated wildlife"
  - "Effects of feral horse trampling may have as much or even more influence on ecosystems than their selective consumption of plants."
  - "Feral horses' value to society must be weighed against their ecological costs."
- Gaps/limitations:
  - Study sites close to riparian areas that can concentrate horse use
  - Need additional research to "determine the mechanisms underlying these varying responses to herbivore removal" and long term studies so see if other variables such as perennial grass density and forb cover and density increase with long-term horse removal.
- Other comments:
  - They compared and contrasted their findings with previous results, and provided some useful explanations for possible differences.

Jenkins, D. (2022). New Research and Wild Horse and Burro Management. *Human–Wildlife Interactions*, *16*(2). https://doi.org/10.26077/b148-a4f3

- This commentary summarizes the research priorities and challenges highlighted by the recent BLM strategic plan related to wild horse and burro management: fertility control and environmental studies related to sustainability, climate change, forecasting, and ecosystem resilience.
- While it is useful to understand what the BLM sees as research priorities, a full entry is not provided here given the minimal level of depth of this commentary. However, this does not mean it was not a relevant reference.

United States Department of the Interior Bureau of Land Management Burns District Office. (2023). *Palomino Buttes Herd Management Area Wild Horse Population Management Plan/Environmental Assessment*.

- Wild horses and burros can have critical impacts on rangeland ecosystems and restoration efforts, lowering resilience and resistance, and rapidly growing populations could have exponential impacts if not actively managed.
- Geography: report focused on Palomino Buttes, but literature review seemed more broad
- Key points:
  - The presence of horses:
    - Is a threat to sage-grouse habitat quality
    - lowers shrub and plant cover, species richness, native plant cover, plant biomass
    - decreases soil penetration resistance
    - leads to increases in invasives such as cheatgrass
    - leads to damage to biological soil crusts
    - causes reduced degree of greater sage-grouse lekking behavior and population sizes
  - Can't manage grazing timing or intensity, only numbers/distribution
  - Shrubs (e.g., sagebrush) can be large part of a horse's diet (at least in the summer in the Great Basin)
  - Impacts to riparian vegetation per horse are greater than impacts per cow
  - "Increased... density would be expected to increase the spatial extent and frequency of seed dispersal [through dung piles], whether the seeds distributed are desirable or undesirable."
- Gaps/limitations:
  - It may be difficult to separate the effects of horses from historical or ongoing effects of livestock grazing in some cases.
  - "Analyses have generally not included horse density as a continuous covariate; therefore, ecosystem effects have not been quantified as a linear function of increasing wild horse density."
- Other comments:
  - Focused summary on Appendix F, section 2: effects of wild horses and burros on rangeland ecosystems. Other sections contained information on contraceptives, sterilization, and gathers which are not covered in these notes.

Photo: Bureau of Land Management Oregon and Washington, Flickr

Wollstein, K., Creutzburg, M. K., Dunn, C., Johnson, D. D., O'Connor, C., & Boyd, C. S. (2022). Toward integrated fire management to promote ecosystem resilience. *Rangelands*, *44*(3), 227–234. https://doi.org/10.1016/j.rala.2022.01.001

- Authors propose an integrated fire management approach focused on activities before, during, and after fire.
- Article is not super relevant to ecological transformation, focusing on specific details of fire management.

Photo: Hailey Robe

Baughman, O. W., Kulpa, S. M., & Sheley, R. L. (2022). Four paths toward realizing the full potential of using native plants during ecosystem restoration in the Intermountain West. *Rangelands*, *44*(3), 218–226. https://doi.org/10.1016/j.rala.2022.01.003

- Summarize four strategies for using native seeds for restoration efforts.
- Geography: intermountain west (but likely applicable to other regions)
- Key points:
  - "Several important paths to improved success of native plant restoration are clear: recognize and leverage intraspecific variation and local adaptation in plants, increase the development and use of seed transfer guidance, build seed production partnerships to benefit restoration and local communities, and be ready and willing to adopt changes to the way things are done when the evidence is clear that change will help."
  - "Why work so hard to be successful with native plant species in the sagebrush steppe when there is already a suite of desirable nonnative species that establish reasonably well? This long-standing, regional debate will continue, and it is not our aim to end it or pick sides"
- Gaps/limitations:
  - Understanding and manageably applying complex natural variation to benefit restoration
  - Development of partnerships to ensure land managers have the right native seed to use for restoration (and planning ahead given the time needed for seeds to be available)
  - Lack of adoption

Holfus, C. M., Boyd, C. S., Rios, R. C., Davies, K. W., Copeland, S. M., & Mata-González, R. (2024). Wyoming Big Sagebrush Transplant Survival and Growth Affected by Age, Season of Planting, and Competition. *Rangeland Ecology & Management*, *92*, 1–11. https://doi.org/10.1016/j.rama.2023.09.005

- Explore how transplant age, season, and competition with invasives affect Wyoming big sagebrush restoration success, finding that seedlings can be planted younger than is conventional and there are strong climatic drivers of success.
- Geography: Northern Great Basin Experimental Range - Oregon
- Key points:
  - "transplants ranging from 12 to 24 wks of age had comparable within-planting-year survival and transplant vigor (canopy volume)" - suggest can reduce grow-out time to 10-12 weeks from the traditional 24 weeks
  - Spring-planted transplants had higher survival (possibly due to climate or lack of hardening) while fall-planted transplants had greater volume, but recommend spring planting because competition more of a driver of volume
  - After two growing seasons, survival negatively affected by competition (and more so for smaller plants)
  - Weather variation (especially precip) can greatly affect survival and volume"
- Gaps/limitations:
  - "Further studies should follow to confirm the results of this study, especially in different climate conditions"
  - Competition treatments should be interpreted with caution because treatments could not be randomized
- Other comments:
  - Includes background on why seeding sagebrush for restoration can be a challenge.

Leger, E. A., Atwater, D. Z., & James, J. J. (2019). Seed and seedling traits have strong impacts on establishment of a perennial bunchgrass in invaded semi-arid systems. ***Journal of Applied Ecology*****, *56*(6), 1343–1354.** https://doi.org/10.1111/1365-2664.13367

- Combined a greenhouse study with a common garden experiment to explore the influence of seed and seedling characteristics alongside abiotic factors in influencing establishment success of *Elymus elymoides* in invaded areas, finding that the best seed sources were in populations with longer roots, larger seeds, and earlier emergence in this environment.
- Geography: Western Great Basin (California, Nevada, Oregon)
- Key points:
  - "Phenotypic traits were strongly correlated with performance across all sites, with remarkably high predictive power. Seeds from populations with longer roots, larger seeds, and earlier emergence [mostly found at drier, less productive sites] were significantly more likely to survive the first growing season"
  - "Abiotic variables explained less variation in performance than traits""
  - "Populations that performed best at each field site were from locations with climate variables similar to planting sites""
  - "Abiotic conditions are important considerations when selecting seeds, but these conditions may not sufficiently predict which populations will establish. Understanding population differences in seedling functional traits can improve predictions of restoration success."
  - "Observed a small number of populations that performed well in all sites, which may represent 'general-purpose genotypes'"

- Gaps/limitations:
  - Results could be different for different (less extreme) conditions
  - Future work could see if the pops with greater than avg success across sites are more phenotypically plastic
  - Different traits could be associated with success under diff conditions (e.g., under conditions that favor competition over stress tolerance)
  - Further investigation of genetic vs. environmental contributions to seed mass needed
  - Need to understand "direct and indirect relationships among seed mass and other phenotypic traits" (e.g., trade-offs between seed size and other life-history traits)
  - "With this highly selfing species, it is challenging to determine how individual traits contribute to performance, but similar studies on outcrossing species would allow the breeding designs necessary to [help]"
  - Recommend "an experimental strategy that combines direct seeding… directly alongside transplanting of juvenile plants from the same populations [which] could allow for identifying trade-offs among fitness at different life history stages…"
- Other comments:
  - Ways the results may vary from other conditions/sites:
    - "Early emergence can be detrimental in some cases, such as in areas with variable precipitation, and optimal emergence time may vary among years."
    - "Longest roots were favoured under our extreme field conditions, but in a previous experiment measuring selection within a single field site, we observed that plants with intermediate root lengths had the highest fitness, indicating that population means can be close to the local optimum"

Porensky, L. M., Baughman, O., Williamson, M. A., Perryman, B. L., Madsen, M. D., & Leger, E. A. (2021). Using native grass seeding and targeted spring grazing to reduce low-level *Bromus tectorum* invasion on the Colorado Plateau. *Biological Invasions*, *23*(3), 705–722. https://doi.org/10.1007/s10530-020-02397-0

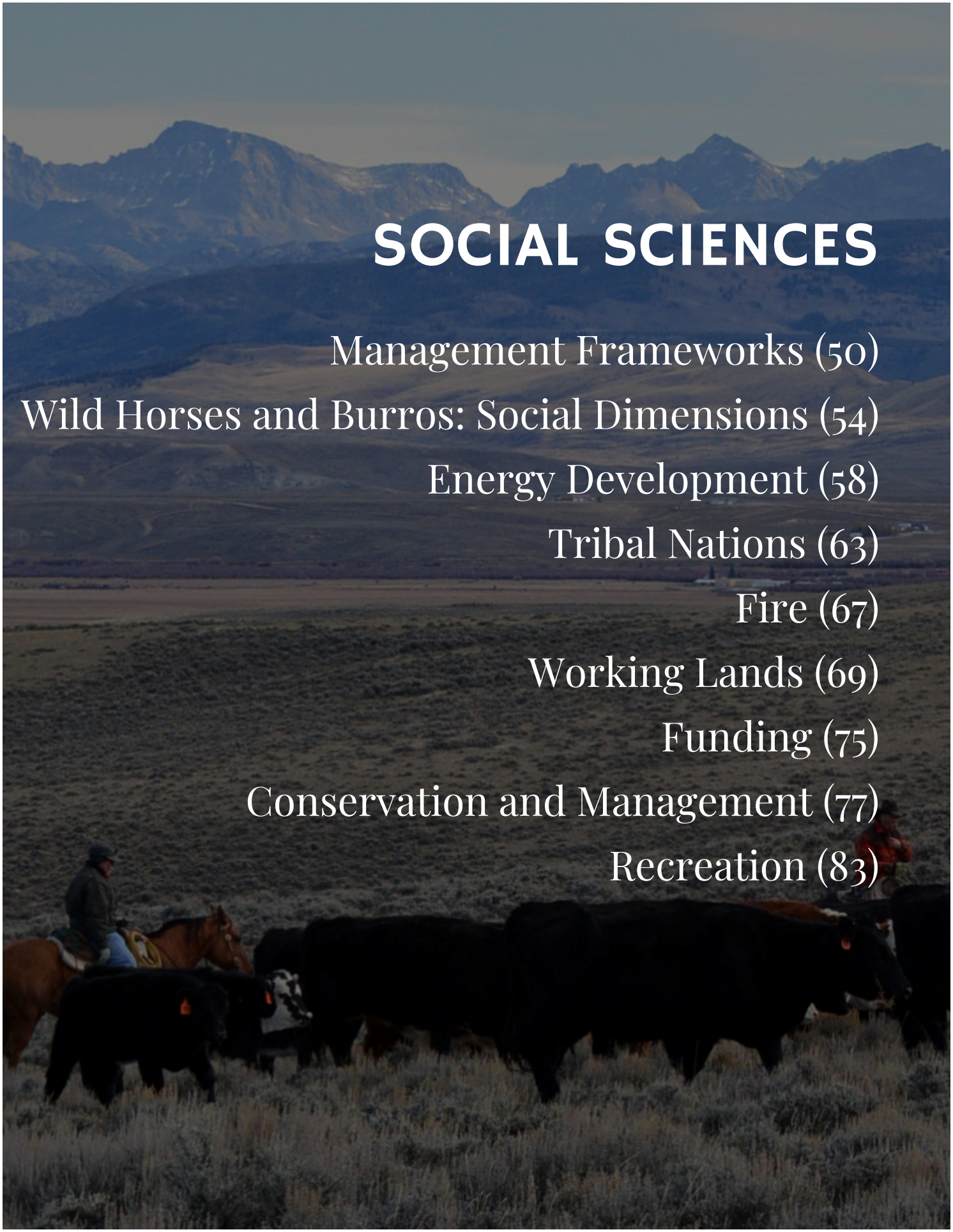
- Used a field experiment to explore what plant community components were associated with lower levels of invasion and test the effects of native grass seeding and grazing on cheatgrass abundance, finding that broadcast seeding of native C3 perennial species at high rates can improve site resistance during the early stages of invasion.
- Geography: northern Arizona
- Key points:
  - "C3 (cool-season) perennial grass cover displayed strong, negative associations with all *B. tectorum* abundance metrics, regardless of growth form, while the same was not true for C4 (warm-season) perennial grasses"
  - Shrub cover associated with reduced *B. tectorum* inflorescence
  - No strong relationship between litter and *B. tectorum* cover
  - Species identity important in driving resistance, with *P. fendleriana* and *P. smithii* having the greatest suppressive effects
  - "high-rate broadcast seeding can produce native perennial grass seedlings that quickly begin suppressing *B. tectorum* abundance" - "even with high seed rates, establishment rates remained

fairly low"
    - Slight negative effect of surfactant seed coating on establishment
    - "targeted spring grazing had marginally significant positive effects on seedling establishment and negative effects on *B. tectorum* abundance"
- Gaps/limitations:
    - Didn't test mechanisms behind suppressive effects of *P. fendleriana* and *P. smithii*
    - *P. fendleriana* may be a good candidate for further study "in climate-suitable areas where *B. tectorum* suppression is desired"
    - Need development of seed coating tech to improve broadcast seeding
    - Targeted spring grazing should be evaluated at more sites and across a broader range of conditions as a tool for lightly invaded sites in the Colorado Plateau, particularly those without biocrust
    - Future work needed to evaluate long-term effects of grazing
    - Need additional exploration into combined effects of seed addition and targeted spring grazing for both wet and dry years
- Other comments:
    - Includes notes on drivers of invasion found in previous work.
    - Includes notes on previous findings related to what specific species are good at suppressing cheatgrass and hypotheses about why.

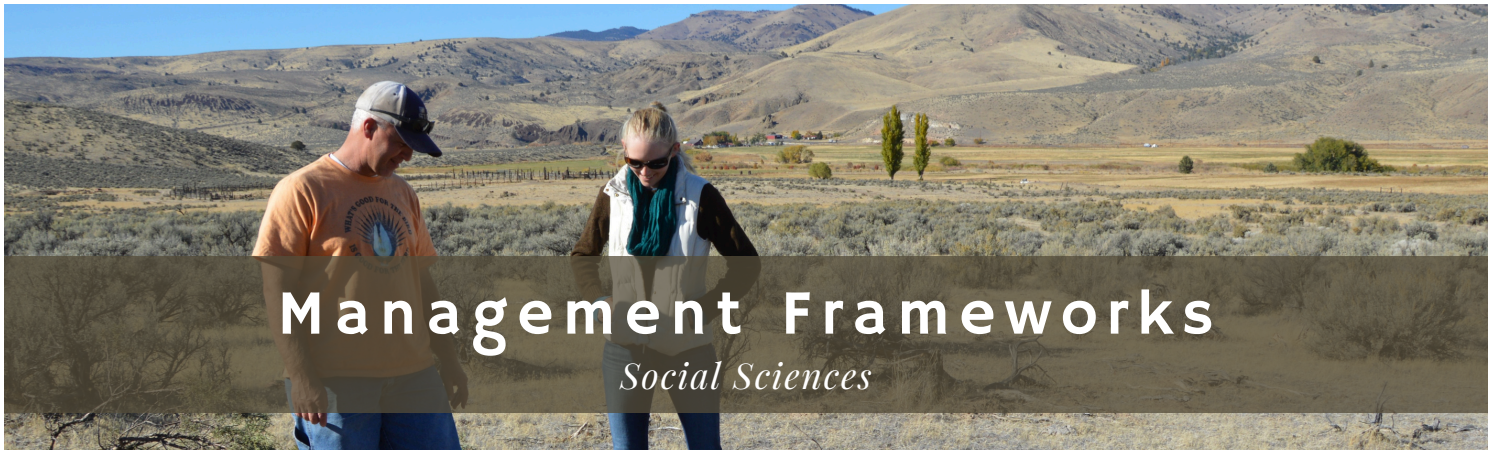
Svejcar, T., Boyd, C., Davies, K., Hamerlynck, E., & Svejcar, L. (2017). Challenges and limitations to native species restoration in the Great Basin, USA. *Plant Ecology*, *218*(1), 81–94. https://doi.org/10.1007/s11258-016-0648-z

- Provides overview of historic context and current challenges for restoration seeding in the Great Basin.
- Geography: Great Basin
- Key points:
    - "multitude of environmental factors contribute to lack of restoration success in [Great Basin], but seedling mortality from freezing/drought identified as a primary demographic limitation to successful bunchgrass establishment. Novel approaches to overcoming... will be required"
    - Highly variable environment, spatial variation in climate, high annual weather variability - challenges for reseeding and other restoration
    - "Biomass of sagebrush seedlings have shown both positive and neutral responses to elevated CO2... response of adult sagebrush or seedlings in field settings currently unknown."
    - In much of biome: overall warming, increasing proportions of cool-season rainfall (declining snowpack), and increase in more highly variable summer rainfall - "result in sagebrush steppe vegetation adapting to a more pronounced ‘‘pulsed’’ ecohydrological regime, altering the spatial and temporal variation in community and ecosystem functioning, and increasing the probability of conditions conducive to fire"
- Gaps/limitations:
    - Identify factors limiting successful seedling establishment and the conditions under which natural recruitment occurs
    - Develop methods to overcome variable environments (methods for artificial dormancy, to speed up germination, etc.)

    - "accelerating research and scaling up the application of these practices is critical"
- Other comments:
    - The team intentionally selected sites with low non-natives, minimal evidence of grazing.
    - Includes background on how ecohydrology influences plant community dynamics in the sagebrush ecosystem
    - "consistent evidence in big sagebrush ecosystems that shrub stand structure influences subordinate species richness while the reverse relationship is not as clear"



SOCIAL SCIENCES



Management Frameworks

Social Sciences

Photo: NRCS Oregon, Flickr

Natural Resources Conservation Service (NRCS). 2021. A framework for conservation action in the Sagebrush Biome. Working Lands for Wildlife, USDA-NRCS. Washington, DC.

Overview: This framework details 4 key threats (woodland expansion, land conversion, Riparian and Wet Meadow Degradation, and exotic grass invasion) to sagebrush ecosystems and how working lands can address such threats.

Geography: Sagebrush Biome

- **Cropland conversion** risk occurs primarily in Montana, North and South Dakota, Colorado and Washington, while housing sprawl is rangewide but localized in parts of the 11 states except Washington.
- **Woodland Expansion**: Primarily in the Great Basin (CA, OR, ID, NV, UT) but also located farther east.

Key findings:

- WLFW "uses win-win solutions to target voluntary, incentive-based conservation that improves agricultural productivity and wildlife habitat on working lands."
  - Framework serves as NRCS' ongoing contribution to the Sagebrush Conservation Strategy administered by Western Association of Fish and Wildlife Agencies
- Rangelands support a diversity of grass, forb and shrub communities and benefit people by providing healthy air, clean water, food and fiber, abundant fish and wildlife habitat, and recreational and cultural values. Covering one out of every three acres in the contiguous U.S., rangelands constitute the lower 48's single largest land use.
- Rangelands are being lost at more than a million acres of working rangelands annually
- In the West 70% of all land is rangeland and ⅔ of this rangeland is privately owned
- Rangelands can store above and below-ground carbon, connect protected areas together to provide an ecological footprint large enough to sustain nature and people

Land Use Conversion

- Conversion of rangeland to crops or new housing developments destroys grazing lands and fragments intact sagebrush landscapes

- Conversion to cropland disproportionately affects the most productive soils, taking them out of use by livestock and wildlife.
- Impacts from constructing homes or other buildings are more localized, the habitat destruction is more severe and virtually impossible to reverse
- Approach: The acquisition of conservation easements and transition expiring Conservation Reserve Program (CRP) grasslands to grazing lands.

Riparian and Wet Meadow Degradation

- wet habitats comprise less than two percent of the sagebrush landscape yet 80% of wildlife depend upon them to complete their life cycle
- Over half of riparian areas and more than 80% of wet meadows are privately owned, reflecting the importance of these habitats to working lands
- Essential to improving overall rangeland resilience to drought, fire and flooding.
- Restoration and management strategies include: improved riparian grazing management, low- tech restoration of degraded streams and meadows using Zeedyk structures and beaver dam analogues, and conifer removal around headwater springs and meadows

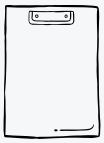
Woodland Expansion

- woodland expansion into grasslands and shrublands is a global problem as trees displace rangeland wildlife and reduce productivity of grazing lands
- conifer expansion fragments and degrades sagebrush habitat, reduces forage production, and increases the risk of wildfire and cheatgrass invasion
- Approach:
- WLFW prioritizes maintenance of treeless sagebrush rangelands and restoration of early phase expansion areas
- mechanical tree removal (e.g., hand-cutting, shredding)
- Slash treatment– reduces or eliminates conifer seed sources, preserves perennial shrubs and grasses, and minimizes sage grouse predator perches.

Exotic Annual Grass Invasion

- Invasion of cheatgrass/other exotic annual grasses (such as medusahead and ventenata) represents one of the single-largest threats to sagebrush rangelands, reducing forage productivity and carbon storage, and threatening wildlife habitat and rural economies
- Doubles risk of wildfire resulting in a vicious cycle over time (cheatgrass encourages wildfire→wildfire promotes cheatgrass). Robs soil of moisture, exacerbating drought
- Approach:
- Detection and prevention of early invasions, targeted herbicide use to eliminate or reduce invasive annual grass seed sources, and grazing management to maintain and promote perennial grass health.
- Grow the core through restoration of perennial vegetation in the transitioning zone– often requires weed control and seeding.
- Perpetual management will be required in annual grass dominated regions to mitigate the most severe impacts of the cheatgrass-fire cycle on life and property.

Other comments: While this framework outlines what can be done to address each threat, it does not look at how WLFW establishes the relationships/trust/education needed to successfully work with private property owners to carry out such objectives.



Doherty, K., Theobald, D.M., Bradford, J.B., Wiechman, L.A., Bedrosian, G., Boyd, C.S., Cahill, M., Coates, P.S., Creutzburg, M.K., Crist, M.R., Finn, S.P., Kumar, A.V., Littlefield, C.E., Maestas, J.D., Prentice, K.L., Prochazka, B.G., Remington, T.E., Sparklin, W.D., Tull, J.C., Wurtzebach, Z., and Zeller, K.A., 2022, A sagebrush conservation design to proactively restore America's sagebrush biome: U.S. Geological Survey Open-File Report 2022–1081, 38 p., https://doi.org/10.3133/ofr20221081.

Overview: This report aims to provide a strategic conservation design to restore and conserve the sagebrush biome, addressing its significant ecological degradation and fragmentation. The design is intended to serve as a roadmap for conservationists, land managers, and policymakers to effectively manage and protect this vital ecosystem.

Geography: Sagebrush Biome

Key Findings:

- This biome, which covers approximately 500,000 square kilometers in the western U.S., provides essential habitat for over 350 wildlife species, including the sage-grouse, pronghorn antelope, and various plants. The biome also contributes to ecosystem services such as soil stabilization and water regulation.

Priority Areas:

- Core Areas: These are the most ecologically significant areas, containing relatively intact sagebrush habitats. They are prioritized for protection and restoration.
- Connectivity Areas: These areas link core habitats, facilitating wildlife movement and genetic exchange. They help maintain ecological processes across landscapes.
- Buffer Zones: Surround core and connectivity areas to reduce external threats such as encroachment and invasive species. Buffers help maintain the integrity of core habitats.

Restoration Strategies:

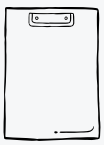
- Native Plant Restoration: Reintroduce native sagebrush and other vegetation to restore ecosystem functions and habitat quality. This may involve direct seeding, planting, and soil rehabilitation.
- Invasive Species Control: Implement strategies to manage and control invasive species, such as mechanical removal, herbicide application, and biological control measures.
- Fire Management: Adjust fire management practices to maintain natural fire regimes while preventing large, destructive fires. This includes prescribed burns, creating firebreaks, and managing fuel loads.

Stakeholder Engagement:

- Federal Agencies: Collaborate with agencies such as the Bureau of Land Management (BLM), U.S. Forest Service, and the Fish and Wildlife Service to align efforts and share resources.
- State Agencies: Engage state wildlife and land management agencies to coordinate on regional and local conservation actions.
- Tribal Nations: Incorporate the traditional knowledge and conservation practices of Native American tribes, who have a historical connection to the sagebrush biome.
- Local Communities: Involve local landowners, ranchers, and conservation groups to build support and ensure that conservation actions are practical and effective.

Gaps/Limitations

- Authors call for further research on the long-term effects of conservation actions to refine restoration techniques



Lynch, A. J., Thompson, L. M., Beever, E. A., Cole, D. N., Engman, A. C., Hawkins Hoffman, C., Jackson, S. T., Krabbenhoft, T. J., Lawrence, D. J., Limpinsel, D., Magill, R. T., Melvin, T. A., Morton, J. M., Newman, R. A., Peterson, J. O., Porath, M. T., Rahel, F. J., Schuurman, G. W., Sethi, S. A., & Wilkening, J. L. (2021). Managing for RADical ecosystem change: Applying the Resist-Accept-Direct (RAD) framework. *Frontiers in Ecology and the Environment*, *19*(8), 461–469. https://doi.org/10.1002/fee.2377

Overview: This article explores the RAD framework as a structured way to approach radical ecosystem changes by providing clear strategies for resistance, adaptation, and direction.

Geographic focus: N/A

Key Findings:

- The RAD framework provides a structured approach to managing ecosystems in the face of significant change. It consists of three main strategies:
- **Resist**: Efforts to maintain or restore the ecosystem to its historical state by resisting changes.
  - Includes actions such as controlling invasive species, enforcing regulations to limit land use changes, and restoring native habitats.
- **Accept**: Acknowledging that some changes are inevitable and adjusting management goals and practices accordingly.
  - Involves adapting management practices to accommodate new conditions, such as shifting species ranges or altered fire regimes.
- **Direct**: Actively guiding or altering the trajectory of ecosystem changes to achieve desired outcomes.
  - Entails proactive interventions to guide ecosystems towards more desirable states, such as enhancing resilience through managed relocation of species or habitat modification.
- Emphasizes the importance of involving stakeholders in the management process to ensure that strategies are practical and aligned with societal values and goals.

Gaps/Limitations: More research is needed to understand how RAD can further integrate human dimensions of ecological transformation

Wild Horses and Burros: Social Dimensions

Social Sciences

Photo: John Graffio, Flickr

Danvir, R. (2018). Multiple-use Management of Western U.S. Rangelands: Wild Horses, Wildlife, and Livestock. *Human–Wildlife Interactions*, *12*(1). https://doi.org/10.26077/cz0b-6261

Overview: This article examines the complexities of managing Western U.S. rangelands where wild horses, wildlife, and livestock coexist. It highlights the challenges and conflicts that arise from balancing the needs of these different groups, focusing on how resource management strategies can address issues such as overgrazing, habitat degradation, and competition for resources. The article advocates for integrated management approaches that consider the ecological and social dynamics of these multi-use landscapes to achieve sustainable and equitable outcomes.

Key Findings:

- In western U.S. rangelands there are multiple uses and interests, including wild horses, wildlife, and livestock.
- Wild horse populations have surged due to the lack of natural predators and reproduction rates.
  - This increase has led to significant ecological impacts, such as overgrazing and habitat destruction- competition with wildlife for water sources, forage loss and altered plant communities, altered avian communities, impacts to soils and insects, and sagebrush ecosystems
  - Horse management strategies include fertility control, adoption programs, and population removals.
- The habitat needs of wildlife species on rangelands, such as deer, elk, and various bird species, can conflict with those of livestock and wild horses.
- Livestock grazing can also lead to overuse of vegetation, soil erosion, and competition with wild horses and wildlife for resources.
  - Sustainable grazing practices, such as rotational grazing and improved range management techniques, are ways to mitigate negative impacts on rangeland health.
- Need for integrated management approaches and research that considers the interactions between wild horses, wildlife, and livestock
  - Challenges for doing this include conflicting interests, limited resources, and regulatory hurdles.

Frey, S. N., Scasta, J. D., Beck, J. L., Singletary, L., & Snell, L. K. (2022). Public Knowledge of Free-Roaming Horses in the United States. *Proceedings of the Vertebrate Pest Conference*, *30*(30). https://escholarship.org/uc/item/5d03p3hw

Overview: This article investigates the level of public knowledge and perceptions regarding free-roaming horses in the United States. The study surveys the general public to assess their awareness of issues related to the management, ecological impacts, and welfare concerns of these horses.

Geography: Participants from across US, but were asked questions about WFR horses in western US rangelands

Key Findings:

- Wild Horses and Burros were given federal protection from private roundups or harassment by the Wild and Free Roaming Horse and Burros Act of 1971
  - This Act created 31.6 million acres of Herd Management Areas or Wild Horse Territories, with an appropriate management level of WFR horses and burros of 26,785 animals. However, WFR horse populations have grown on
- “Public opinion ranges from considering WFR horses on western rangelands as an invasive species to support for the preservation of these horses as an American icon”
- Conducted survey across the US to assess public knowledge about free-roaming horse ecology and management in North America.
- The survey results indicate a substantial lack of detailed knowledge among the public about the ecological impacts of free-roaming horses.
  - Lack of understanding can lead to confusion and disinformation concerning the impacts of WFR horses on western rangelands.
- A minority of the respondents were aware that the horse is not native to North America.
- Survey indicated that most of our respondents did not understand the reproductive ability of horses. A major management challenge
- The respondents did not know the vegetation communities in which horses live; while some horses do live in grasslands, most live in high-desert and wooded environments
- “While increased knowledge of a contentious management issue does not always lead to increased support, it can lead to increased understanding, which influences the ability of disparate groups to achieve consensus and make informed decisions”

Gaps/Limitations: authors explore limitations of survey participants and analysis

Scasta, J. D. (2019). Why are humans so emotional about feral horses? A spatiotemporal review of the psycho-ecological evidence with global implications. *Geoforum*, *103*, 171–175. https://doi.org/10.1016/j.geoforum.2018.12.007

Overview: This article examines the emotional and historical ties that humans have to horses and how that can influence perceptions of wild horse management.

Key Findings:

- Authors argue no other animal conjures up the levels of emotion and concern as horses in the US, likely due to the co-evolutionary history between humans and equids
- A persistent challenge has been the conflicting litigation surrounding feral horses that can either be emotionally driven out of concern for horse welfare or the land that supports horses and other uses.
  - Suing for managing horses or suing not managing horses
- There is evidence that over-abundant US horse populations may be degrading rangelands with documented degradation to native ecosystems- negative effects on soils, plants, riparian areas, native wildlife, and reduced wildlife richness and diversity near horse-occupied watering sites
  - the potential negative effects of horse overpopulation can also have negative feedbacks on horses themselves bc degraded range is unable to support horses in adequate body condition leading to the need for emergency gathers
- Understanding early horse-human relations is critical to understanding modern human emotions for horses
  - through domestication, horses and humans have interacted in an intimate and dependent manner for millennia
- “human emotions for feral horses are deeply ingrained due to the co-evolutionary history and more consideration of emotions could offer novel approaches and participation in effective management when contextualized and reconciled with data regarding the effects on native ecosystems and horse welfare”

Yonk, R.M., 2021. Understanding the Economic Impact of Wild Horse Management on Local Communities. Self-published report.

https://www.ndsu.edu/fileadmin/centers/pcpe/Research/Wild_Horse_Management.pdf

Overview: The report evaluates the economic impacts of wild horse management on local communities, particularly focusing on the costs and benefits associated with various management strategies like population control, relocation, and public adoption programs.

Geography: Beaver County, Utah

Key Findings:

- Study of Beaver County, Utah indicates that counties where HMAs are located have lower total tax receipts and lower overall economic activity in the form of total non-farm payroll. Suggests that management decisions, such as those stemming from having an HMA that covers a substantial portion of the county, are likely having negative economic effects on those counties.

- Economic Benefits of wild horses include:
  - Tourism: revenue from tourists visiting areas to see wild horses, which supports local businesses such as hotels, restaurants, and tour operators.
  - Recreational Activities: Economic benefits from recreational activities related to wild horses, including photography and equestrian events.
  - Increased demand for local services and products due to management activities and associated tourism.
- Costs
  - Impact on local government budgets and public resources allocated to wild horse management instead of other community services.
  - Potential costs related to habitat degradation due to overpopulation or management activities.
  - Expenses incurred during wild horse round-ups, including labor, equipment, and logistics.
  - Costs associated with moving captured horses to holding facilities or adoption centers.
  - Financial requirements for maintaining and feeding horses in holding facilities.

Energy Development

Social Sciences

Photo: USFWS Mountain-Prairie, Flickr

Aldridge, C., Chalfoun, A., Deibert, S., & Holleran, M. (2020). *Chapter O. Energy and Mining (Sagebrush Conservation Strategy- Challenges to Sagebrush Conservation) [Open-File Report].*

Overview: This chapter looks at the energy development and mining activities that impact sagebrush ecosystems and what is known about their impacts on the ecosystem.

Geographic focus: Sagebrush Biome

Key Findings:

- Mining and development of energy resources have impacts on sagebrush habitats, including habitat removal or fragmentation, introduction of invasive plant species, and potential impacts on surface and groundwater.
  - indirect effects include noise, exposure to contaminants, and disturbance from vehicles and human presence.
- Approximately 8 percent of sagebrush habitats across the entire biome are directly affected by oil and gas development, with greater than 20 percent of sagebrush habitats affected in the Rocky Mountain area.
  - Restrictions and conservation actions primarily apply to greater sage-grouse habitats.

Mining

- Actual impacts of mining and energy development to a particular species depend on the location and extent of the disturbance.
- Many States within the sagebrush ecosystem are significant producers of both nonfuel minerals and coal
  - Three classifications of minerals on federally administered lands within the sagebrush ecosystem:
    - Locatable minerals: metallic mineral deposits,
    - Leasables include: energy products
    - Saleables: used primarily for construction purposes
- Mining in sagebrush includes coal, uranium, and lithium and approximately 90 different non-energy resources are also mined, including sand, gravel, bentonite, gold, silver, copper, diamonds, gypsum,

lime, rare earth elements, and decorative rock (
    - The density and expanse of mining activities varies depending on the location of the desired resource, ease of access, market commodity prices, and associated regulations governing extraction.

Oil and Gas

- Construction of oil and gas wells results in the direct loss of sagebrush, but impacts have negative consequences at larger scales
    - habitat fragmentation and alteration because of road and pipeline construction and changes in wildlife behavior
    - Infrastructure-supporting drilling activities can lead to opportunities for the spread of invasive plant species, provide increased opportunities for some predators (such as common ravens and red fox), increase fugitive dust, and potentially affect water quality.
    - A number of studies indicate that activities associated with oil and gas development have significant effects on greater sage-grouse

Renewable energy

- Most renewable energy development (wind, solar, geothermal, and biofuels) does not degrade air and water quality or contribute to greenhouse gas emissions
- The BLM has authority to manage facilities for generation, transmission, and distribution of electric energy under FLPMA
- Construction of wind farms requires clearing areas to create access roads and turbine pads.
    - Collector electrical cables and circuits are buried, typically along access roads
    - Activities require clearing of topsoil, compaction of subsoils, and gravel deposition for the roads, resulting in loss and fragmentation of sagebrush habitats.
- The FLPMA allows for the development of facilities of transmission/distribution of electricity generated by wind and granting rights-of-way for access to wind development on private lands.
- Indirect influence of wind-energy development on sagebrush-associated species is not yet well understood
- Geothermal methods require drilling production wells to access the steam or hot water and injection wells to return the cooled water to the subsurface reservoir
    - The associated infrastructure is very similar to other energy development facilities, and includes transmission lines, improved roads, fencing, and storage facilities.
- BLM has authority to manage solar facilities under FLPMA and the associated right-of-way regulations (leases have a 30-year life)
    - Large land area required for solar facilities and water consumption are concerns.

Gaps/Limitations:

- Authors identify a need for a better understanding of long-term impacts of energy development, the interaction between long-term national priorities of increased renewable energy development and sagebrush health, and how technologies can be developed to minimize impacts.

***Clean energy, Healthy habitat | Bureau of Land Management Blog*. (2024, April 23).**

https://www.blm.gov/blog/2024-04-23/clean-energy-healthy-habitat

Overview: This blog post highlights the agency's commitment to balancing clean energy development with habitat conservation. It discusses recent initiatives and partnerships aimed at promoting renewable energy projects while ensuring the protection and health of natural landscapes and wildlife habitats. The

post emphasizes the importance of sustainable practices to achieve both energy goals and environmental stewardship.

Geography: Sagebrush public lands managed by BLM

Key points:

- Nearly 67 million acres of sagebrush habitat on BLM-managed lands may hold potential for renewable energy generation or as locations for transmission lines that connect power projects to the grid
- There is concern that wind energy development leads to fragmentation and loss of sagebrush habitat, increased noise, surface disturbance and collisions with turbine rotor blades. Birds may be more sensitive to these effects during some stages of their life than in others.
- Utility-scale solar power sites use large land areas and require a great deal of water
- DOI recently announced new solar and wind permitting rules to streamline the process
- See draft EIS updates to sage-grouse habitat that gives different scenarios for energy development and protection of sage-grouse

DiMauro, D. (2024). Renewable Energy on Federal Public Lands BLM Initiatives and the Value of Regional Planning. *Natural Resources & Environment*, *39*(1), 14–18.

Overview: This article emphasizes the importance of regional planning in optimizing energy projects while balancing environmental and land use considerations. The article highlights BLM initiatives aimed at streamlining the energy project permitting process and ensuring that renewable energy projects are effectively integrated into broader land management strategies to maximize benefits and minimize conflicts.

Geography: US BLM lands

Key Findings:

- There is a growing emphasis on renewable energy as part of national efforts to reduce greenhouse gas emissions and combat climate change. Federal lands play a crucial role in meeting these energy goals.
- The BLM has launched several initiatives to promote renewable energy development on federal lands, including establishing renewable energy zones and streamlining the permitting process.
- The BLM uses Programmatic Environmental Impact Statements (PEISs) to evaluate the potential environmental impacts of renewable energy projects and guide the development of suitable areas for energy generation.
  - Initiatives also include updating land use plans to incorporate renewable energy development while balancing other land uses and conservation objectives.
- Regional planning helps in the strategic allocation of land for renewable energy projects, identifying areas with high potential for energy generation while avoiding sensitive habitats and areas with competing uses.
- Effective regional planning can reduce conflicts between energy projects and other land uses, such as recreation, grazing, and conservation, by assessing and addressing potential overlaps and impacts.
- The article provides examples of Solar Energy Zones (SEZs) established by the BLM, which are areas designated for solar energy development based on their solar potential and minimal environmental conflicts

- Engaging stakeholders early and often in the planning process is crucial to address concerns, gather input, and build support for renewable energy projects.
- There is a need for improved coordination between the BLM and other federal, state, and local agencies involved in land management and energy development. Current efforts sometimes suffer from fragmented approaches that hinder the effectiveness of renewable energy initiatives.
- Existing policies and regulations may not fully support or incentivize the integration of renewable energy development with other land management goals. There is a need for policies that align better with regional planning efforts and support sustainable development.
- Adequate funding and resources for implementing regional planning efforts and managing renewable energy projects are often lacking. This affects the ability to conduct thorough assessments and carry out effective planning.

Gaps/Limitations: More data is needed to understand the long-term implications of renewable energy development on land use and ecological health

Latif, Q. S., Van Lanen, N. J., Chabot, E. J., & Pavlacky Jr., D. C. (2023). Causal mechanisms for negative impacts of energy development inform management triggers for sagebrush birds. *Ecosphere*, *14*(4), e4479. https://doi.org/10.1002/ecs2.4479

Overview: This article investigates how energy development negatively affects sagebrush birds by examining the underlying causal mechanisms. The study identifies key factors such as habitat fragmentation, disturbance, and pollution that contribute to adverse impacts on these bird species. The authors propose management triggers and strategies to mitigate these effects, aiming to better protect sagebrush bird populations amidst ongoing energy development activities.

Geography: Sagebrush Biome

Key Findings:

- Monitoring populations and determining drivers of population change are important for making state-dependent decisions and evaluating conservation success within an adaptive management framework
- Development of energy infrastructure, including well pads, roads, and pipelines, reduces and degrades habitat
- Roads for transporting resources can fragment habitat and facilitate spread of invasive vegetation
- Study corroborated other studies that point to negative relationships of bird species distributions with well pad density
  - Localized habitat loss
- Well pad densities represent the most obvious potential focus for management aimed at limiting or offsetting energy development impacts
  - Managers could offset negative impacts by limiting or excluding well pads where doing so would ensure increases or no net loss of critical habitat
- Non-native grasses planted for reclamation of well pad sites can promote deer mice, which may elevate nest predation pressure for birds in general
  - The BLM requires native seed mixes for reclamation, which occurs both after well activation in disturbed areas not required for production and after well retirement, but non-native grasses can become established, especially on private lands.
- Techniques such as horizontal drilling technologies could also limit the negative impacts of energy development on birds while facilitating continued resource extraction.

Walker, B. L. (2022). ***Resource selection by greater sage-grouse varies by season and infrastructure type in a Colorado oil and gas field*****.** **https://doi.org/10.1002/ecs2.4018**

Overview: This article explores how greater sage-grouse in a Colorado oil and gas field select their resources differently depending on the season and the type of infrastructure present. The study reveals that sage-grouse adjust their habitat use in response to various infrastructure types associated with energy development, such as wells and roads. The findings underscore the importance of considering seasonal variations and infrastructure impacts when managing habitats for greater sage-grouse in areas affected by oil and gas activities.

*Much of the literature on the impacts of energy development on sagebrush are on the impacts of development on bird species, particularly greater sage-grouse. This article further fills in that context, but is not the focus of the social science review, so it was not given a full entry.

Photo: Bureau of Land Management, Flickr

Friday, C., & Scasta, J. D. (2020). Eastern Shoshone and Northern Arapaho Traditional Ecological Knowledge (TEK) and Ethnobotany for Wind River Reservation Rangelands.

***Ethnobiology Letters*, *11*(1), Article 1.** https://doi.org/10.14237/ebl.11.1.2020.1654

Overview: This article examines the Traditional Ecological Knowledge (TEK) and ethnobotany of the Eastern Shoshone and Northern Arapaho peoples as it relates to rangeland management on the Wind River Reservation. The study highlights specific ethnobotanical knowledge, including traditional uses of plants for food, medicine, and cultural practices. By integrating this TEK with contemporary rangeland management strategies, the authors advocate for a more holistic and culturally informed approach to land stewardship that respects and leverages indigenous knowledge alongside modern scientific methods.

Key Findings:

- Eastern Shoshone and Northern Arapaho use plants found on the Wind River Reservation's rangelands. This includes:
  - Medicinal Uses: Plants used in traditional medicine for treating ailments such as digestive issues or respiratory health.
  - Food Sources: Edible plants that are part of traditional diets.
  - Cultural Practices: Plants used in ceremonies, rituals, and crafts
- TEK is often passed down through generations through oral traditions, storytelling, and hands-on learning
- Traditional rangeland management practices of Eastern Shoshone and Northern Arapaho include controlled burns, seasonal/rotational grazing strategies to manage soil health, and selective harvesting of plants
- One significant challenge is the loss of traditional knowledge due to cultural shifts and generational changes. Efforts are needed to preserve and revitalize this knowledge.
  - There is a need to conduct more research to document TEK and ethnobotanical practices systematically, ensuring that this knowledge is preserved and utilized effectively.
- There is a potential to incorporate TEK into formal land management plans, ensuring that traditional knowledge complements scientific approaches.

Gaps/Limitations: this article doesn't focus on non-extractive ways of incorporating TEK into land

management strategies

Souther, S., Colombo, S., & Lyndon, N. N. (2023). Integrating traditional ecological knowledge into US public land management: Knowledge gaps and research priorities.

***Frontiers in Ecology and Evolution*, *11*.** https://doi.org/10.3389/fevo.2023.988126

Overview: This article delves into the challenges and opportunities associated with integrating Traditional Ecological Knowledge (TEK) into U.S. public land management. It discusses how TEK, which encompasses indigenous and local knowledge about ecosystems and land use, can complement scientific data and enhance management practices. The authors identify several key knowledge gaps, such as the need for more systematic methods to incorporate TEK and better mechanisms for collaboration between indigenous communities and land management agencies.

Geography: U.S. with some information on indigenous scholarship across the globe

Key findings:

- Traditional Ecological Knowledge (TEK) is often encoded in rituals, beliefs, and cultural practices
  - Any group of people routinely interacting with the environment for extended time periods develop TEK, though the term often refers specifically to Indigenous Traditional Ecological Knowledge (ITEK). The term '*traditional ecological knowledge*' has been criticized, since the word '*traditional*' can be construed negatively to imply a regressive or static knowledge system.
- Indigenous communities were relocated to reservations a fraction of the size of ancestral territories, and so many tribes rely on public lands to access sacred areas and harvest sites to supply natural products used in traditional foods, crafts, and ceremonies
  - Mismanagement of public lands could trigger irrevocable cultural loss since language, traditions and spiritual practices are often tied to particular species and ecosystems
- Literature on TEK has focused on describing knowledge systems without tangible ecological or management connections.
  - Within the US, TEK-research is geographically skewed toward the west coast, with notable gaps in publications on the central and eastern portion of the country
- "Before modern supply chains introduced global commodities to local communities, human groups, particularly from non-agricultural societies, relied on nearby ecosystems for food, clothing, shelter, and other essentials. Irresponsible use of natural resources would therefore negatively impact reliant human communities. These feedback loops between ecological and social systems drove the development of cultural mechanisms that promoted sustainability"
- For some ecosystems, removing traditional human communities has resulted in ecosystem degradation and loss of diversity
  - human populations influenced ecosystems for thousands of years prior to the imposition of contemporary land management.
- Indigenous communities shaped ecosystems through multiple pathways, including burning practices, harvest, hunting, and transport of species
- TEK is a comprehensive understanding of ecosystems, with humans situated within biotic communities, and landscapes representing ecological features and place-based sociocultural memories
  - "Recognition of the complexities and interrelationships within biotic communities broadly supports scientific understanding of ecological systems."
- Ignoring local traditions and use patterns has resulted in conflict and non-compliance with imposed regulations;
  - Can be resolved by co-development of management plans with local communities

- Support of bio-cultural sovereignty, the right of people to access landscapes and natural resources necessary for cultural practice, itself an important management goal
- Traditional harvest practices often integrate triggers to slow, pause or alter harvest based on on-the-ground observations, adjusting behavior to prevent resource degradation
- Engaging local communities in the development of ecological monitoring and assessments has the potential to advance our ability to track ecological changes
- Some challenges of co-developing strategies that integrate TEK
  - Many funding sources do not provide support for project co-development, leading projects to skip the critical step of building trust and consensus
  - Funding constraints often prevent providing food and travel to participants, limiting participation of historically disadvantaged, impoverished, or rural groups
  - Revolving doors of key project personnel limit the ability to build the trust and relationships to effectively engage with local or Indigenous communities.

Trisos, C. H., Auerbach, J., & Madhusudan, K. (2021). Decoloniality and anti-oppressive practices for a more ethical ecology. *Nature Ecology & Evolution*, *5*(9), 1205–1212.

https://doi.org/10.1038/s41559-021-01460-w

Overview: This article addresses the need for decolonial and anti-oppressive practices within the field of ecology to foster more ethical and equitable research and conservation efforts. They argue that traditional ecological practices often perpetuate colonial legacies and systemic inequalities, which can marginalize indigenous communities and underrepresented groups. The paper proposes a framework for integrating decoloniality into ecological research, emphasizing the importance of acknowledging historical injustices, involving diverse stakeholders, and prioritizing equity and justice in ecological practice.

Geography: general Western ecology studies

Key Findings:

- The growth of ecological science as an academic discipline is embedded in colonialism
  - Colonial access to land for expeditions.
  - Insights from Western scientific ecology were used to justify social and environmental control-dispossessing colonized peoples of land and ways of life and discounting their knowledge systems
  - More ecologists need to reflect on consequences of this legacy
- Mainstream ecological and conservation practices continue to systematically marginalize Indigenous knowledge. This marginalization is evident in how research questions are framed, how data is interpreted, and how conservation strategies are implemented.
  - Western scientists and institutions hold authority over ecological knowledge and management decisions, often disregarding or undervaluing the contributions of Indigenous peoples and local communities.
- Anti-oppressive practices aim to address and rectify systemic injustices and power imbalances. Key principles include:
- Equity and Justice: Ensuring fair treatment and opportunities for marginalized communities in ecological research and decision-making processes.

- Cultural Sensitivity: Recognizing and respecting diverse cultural perspectives and practices related to ecology and conservation.
- Inclusivity: Valuing and integrating contributions from a diverse range of stakeholders, including Indigenous and local communities.
- Decoloniality refers to the process of challenging and dismantling colonial structures and perspectives that continue to influence various fields, including ecology and conservation.
- Some ways to implement anti-oppressive practices:
    - Collaborative Research: Encouraging collaborative research approaches that involve Indigenous communities as equal partners. This means co-developing research questions, methodologies, and interpretations with community members.
    - Participatory Decision-Making: Ensuring that decision-making processes in ecological management and conservation are inclusive of Indigenous and local perspectives.
    - Ethical Engagement: Developing ethical guidelines for engaging with Indigenous communities and respecting their knowledge and rights.
    - Decolonial Training: ecological practitioners and researchers receive training in decolonial and anti-oppressive frameworks to increase their awareness and ability to apply these principles in their work.

Photo: USFWS - Pacific Region, Flickr

Crist, M. R., Belger, R., Davies, K. W., Davis, D. M., Meldrum, J. R., Shinneman, D. J., Remington, T. E., Welty, J., & Mayer, K. E. (2023). Trends, Impacts, and Cost of Catastrophic and Frequent Wildfires in the Sagebrush Biome. *Rangeland Ecology & Management*, *89*, 3–19. https://doi.org/10.1016/j.rama.2023.03.003

Overview: examines the increasing frequency and intensity of wildfires in the sagebrush biome, noting significant ecological and economic impacts. The study highlights how these fires disrupt habitats, alter species composition, and impose high costs on communities and governments. It advocates for improved land management, restoration efforts, and policy changes to mitigate wildfire risks and support ecosystem resilience.

Geography: Sagebrush Biome with focus on western sagebrush ecosystems

Key Findings:

- Sagebrush ecosystems are experiencing larger and more frequent fires (particularly the western ecosystems)
- Sagebrush recovery times cannot keep up with expanding invasive grass/fire cycle
- Frequent fires also impact ecosystem services people rely on for health and survival: impacts of smoke, loss of carbon storage, erosion that affects water quality and availability, loss of recreational opportunities, cultural traditions and sites, and values of native plants/wildlife communities
- More fires demand more resources for fire prevention, suppression, and restoration. Other costs include: emergency evacuation, relief aid, damage to public/private/commercial infrastructure, loss of income and tax revenue, housing market impacts, and long-term psychological effects
- Fires can increase or decrease forage availability for livestock. Ranchers face higher costs if they must adjust forage following a fire- the likelihood of ranchers going out of business goes up with increasing fire frequency
- Authors emphasize the need for prioritizing management aimed at addressing interactions between uncharacteristically frequent fire and invasive grass expansion in sagebrush ecosystems

Gaps/limitations: point to very little scholarship/data on the quantification of ecosystem service loss with increased fires, as well as uncertainty in the cost of damages from fires

Wollstein, K., & Johnson, D. D. (2023). Integrating Rangeland Fire Planning and Management: The Scales, Actors, and Processes. *Rangeland Ecology & Management*, *86*, 9–17. https://doi.org/10.1016/j.rama.2022.10.001

Overview: This article discusses the integration of fire planning and management in rangelands, emphasizing the importance of aligning efforts across different scales, stakeholders, and processes. The authors argue for a coordinated approach that involves various actors—from local land managers to policymakers—to effectively address fire management challenges. They propose frameworks for improving collaboration and communication to enhance the resilience and sustainability of rangeland ecosystems.

Geography: Great Basin

Key Findings:

- Different “rules and tools” at different scales
  - Different actors are subject to different rules and have different tools available to them to achieve objectives in relation to fire mitigation and management bc of how grazing to manage fine fuels may be implemented by different actors
  - Private landowners may apply grazing wherever them deem appropriate on their private landholdings but do not have authority to do so on any allotments associated with their ranch outside of the terms and conditions of their permit
  - Different actors involved in rangeland and fire management may each have their own norms, cultures, adn unwritten rules that guide their actions
- Defining the right scale: Us department of Agriculture Forest Service is using firesheds: grouping of areas with similar fire regimes, fire history, and wildfire risk
- Authors propose fireshed councils- similar to watershed councils to coordinate among different jurisdictions and actors within the fireshed
  - Membership must include diverse stakeholders
  - Must include flexible and adaptable strategies
  - Needs recognition and support from higher levels to be perceived as legitimate and to sustain the council long term

Limits/Gaps:

- Authors point to the challenges and gaps of creating fireshed councils
  - Long-term participation
  - Including relevant stakeholders
  - Overcoming institutional inertia
  - Securing resources

Working Lands

Social Sciences

Photo: USDA NRCS Texas, Flickr

Ayambire, R. A., Pittman, J., Drescher, M., Moreno-Cruz, J., & Olive, A. (2022). Governance of working landscapes: A conceptual framework. *Sustainability Science*, *17*(6), 2579–2596.

https://doi.org/10.1007/s11625-022-01178-z

Overview: Article provides review/synthesis of the governance dimension of working landscapes to construct a comprehensive framework for the working landscapes approach.

Geographic location: Non-specified working landscapes

Key Findings:

- working landscapes refer to rangelands, forests, and cultivated fields managed for human well-being and to protect the natural environment
  - term describes an approach to environmental management where land managers adopt management approaches that foster production and still maintain the ecological integrity of the landscapes to support wild species and mitigate climate change
- Working landscape approach for promoting sustainability requires an understanding of the governance processes and conditions that underpin its success–governance issues remain unaddressed, and the approach still lacks a comprehensive conceptual framework that brings together its different elements.
  - Important to understand ownership of working lands, rules that control their use, and how rules are made and enforced

Authors suggest the following framework:

- (1) the working landscape approach focuses on simultaneously achieving social well-being and environmental protection within the landscapes,
- (2) the working landscape approach is concerned with fostering collective action among multiple actors to deliver sustainable outcomes,
- (3) the social-ecological context affects and is affected by the working landscape in question,

- (4) five common elements—equity, facilitative leadership, local autonomy, incentives, and trust—are essential for facilitating collective action in working landscapes
- (5) collaborative and multilevel interactions enhance governance fit in working landscapes.

Bruno, J. E., Jamsranjav, C., Jablonski, K. E., Dosamantes, E. G., Wilmer, H., & Fernández-Giménez, M. E. (2020). The landscape of North American Rangeland Social Science: A Systematic Map. *Rangeland Ecology & Management*, *73*(1), 181–193.

https://doi.org/10.1016/j.rama.2019.10.005

Overview: This article reviews and analyzes 296 articles on rangeland social science between 1970 and 2017 to identify key themes and gaps.

Geographic Focus: USA rangelands

Key Findings:

- The Taylor Grazing Act of 1934 and the Soil Conservation and Domestic Allotment Act of 1936, are often viewed as the inception of rangeland science
- Most studies analyzed focused on ranchers, with less frequent investigation of other rangeland stakeholders such as natural resource management agency employees, ranch workers including guest workers, and the general public
- Limited consideration of gender, race, or ethnic identities.
  - A need to not only consider these identities but how they interrelate
- Also limited understanding of the impacts of climate change on social dynamics, the role of indigenous knowledge, and the effectiveness of specific policy interventions.
- Authors recommend stakeholder mapping: used to identify participants in a system and understand factors such as their needs, level of engagement, and interests.
- Future research directions:
  - Expand Geographic Focus: Encourage research in under-represented regions to capture a more complete picture of social dynamics and management practices across North America.
  - Address Emerging Issues: Focus on emerging issues such as climate change impacts, integration of traditional ecological knowledge, and the effectiveness of new management strategies.
  - Promote Interdisciplinary Research: Foster collaboration between social scientists and natural scientists to develop comprehensive approaches to rangeland management that address both ecological and social dimensions.
  - Better understanding of how to build more effective data sharing practices to build on existing knowledge and fill research gaps
  - Engagement of stakeholders to ensure findings are relevant and actionable

Ramsdell, C. P., Sorice, M. G., & Dwyer, A. M. (2016). Using financial incentives to motivate conservation of an at-risk species on private lands. *Environmental Conservation*, *43*(1), 34–44. https://doi.org/10.1017/S0376892915000302

Overview: This article explores the effectiveness of financial incentives in encouraging private landowners to engage in conservation efforts for at-risk species. It concludes that targeted financial incentives can significantly enhance conservation efforts on private lands, but the overall conservation program design also plays a major factor in landowners' desire to participate.

Geographic Location: south-west Nebraska private lands

Key Findings:

- Private landowners in the US tend to prioritize concerns about property and livelihoods over participation in species or habitat recovery actions
  - Authors assert this is largely because the Endangered Species Act of 1973 (ESA) to protect endangered species over other land uses, combined with a strong private property rights orientation in the USA
- 72% of land in the USA is privately owned
- Prelisting programmes have begun to emerge that focus on conserving declining species before the restrictions of the ESA are triggered
- Financial incentives are often used to motivate stewardship behavior- paying landowners to take conservation actions
  - Concerns that such incentives frame conservation as voluntary and "extra" rather than inherently part of land stewardship. Also concerns over whether behaviors will continue after payments stop
- Study explored the relationship between programme participation from private landowners in prelisting conservation programs in south-west Nebraska with and without the financial incentive as a motivator.
- The study found:
  - Potential participants jointly consider both the economic and non-economic elements of a programme when deciding to participate
  - Landowners tend to prefer programmes that build in choice and autonomy
  - "Programmes that support the antecedents of self-determination (autonomy, competence and relatedness) are expected to be more likely to lead to continued engagement in the conservation behavior of interest due to the attribution of behavior as stemming from personal volition"

Gaps/Limitations: only looked at private landowners who were receiving financial incentives, mostly white, male participants.

Comments: this study is commonly cited in other areas of the literature as an example of why a deeper understanding of motivation is important. While financial incentives were a "market choice" the design of the programs and the ability to be self-reliant were more important than the amount landowners received.

Robinson, N. P., Allred, B. W., Naugle, D. E., & Jones, M. O. (2019). Patterns of rangeland productivity and land ownership: Implications for conservation and management. ***Ecological Applications*****,** ***29*****(3), e01862.** https://doi.org/10.1002/eap.1862

Overview**:** This article examines how rangeland productivity varies across different types of land ownership and its implications for conservation and management. The study finds that land ownership patterns significantly influence rangeland productivity and highlights the need for tailored management

strategies that consider these ownership patterns to improve conservation outcomes and sustainable land use practices.

Swette, B., & Lambin, E. F. (2021). Institutional changes drive land use transitions on rangelands: The case of grazing on public lands in the American West. *Global Environmental Change*, *66*, 102220. https://doi.org/10.1016/j.gloenvcha.2020.102220

Overview: This article explores how shifts in institutional frameworks affect land use patterns, particularly focusing on grazing practices on public lands in the American West. The study highlights how changes in policies, regulations, and land management institutions have led to significant transitions in rangeland management, impacting both ecological outcomes and socio-economic conditions.

Geographic location: The High Divide

Key Findings:

- "Passage of the National Environmental Protection Act (NEPA, 1970), the Endangered Species Act (ESA, 1973), and the Federal Land Planning and Management Act (FLPMA, 1976) all elevated environmental value in public land decision-making and created legal recourse for environmental groups seeking to enforce them through new controls on livestock grazers"
- Urban-to-rural migration has intensified in many parts of the American West, with impacts on ranching by increasing land values and creating a clash of cultures
    - Amenity migration is understood as the "pattern of movement of relatively affluent urban or suburban people to rural places in search of particular lifestyle attributes, such as natural scenery, proximity to outdoor recreation, cultural richness of a sense of rurality"
- Ranchers often cite economic vulnerability as a primary challenge in ranch sustainability, and most ranch families depend on off-farm income to maintain their livelihood
- The High Divide is an understudied region of the American West that is highly valued for its large stretches of intact open space. A large proportion of public land with a long history of livestock grazing and amenity-driven migration and population growth are suggestive of dynamics affecting grazing land use.
- Study analyzed 90 years of USFS rangeland management records for 90 allotments on three ranger districts (RD) under USFS management.
- One Animal Unit Month (AUM) is the amount of dry forage required by one mature cow and her calf up for a 30-day period
- The public rangelands of the High Divide have undergone a slow but steady land use transition away from livestock grazing and driven primarily by shifting paradigms of range management by the USFS.
- The increased power of environmentalists and amenity migrants did not directly drive reductions in grazing, rather these indirectly influenced the USFS decision-making at local and national scales.
- Economics of ranching are a challenge for ranch owners and managers but did not drive the land use transition.
    - This result highlights the key role of policy and institutions in guiding rural land use transitions on rangelands.

York, E. C., Brunson, M. W., & Hulvey, K. B. (2019). Influence of Ecosystem Services on Management Decisions by Public Land Ranchers in the Intermountain West, United States. *Rangeland Ecology & Management*, *72*(4), 721–728.

https://doi.org/10.1016/j.rama.2019.02.002

Overview: This article examines how public land ranchers in the Intermountain West incorporate ecosystem services into their management decisions. The study finds that ranchers consider various ecosystem services, such as water quality and soil health, when making decisions about land use and management. It underscores the need for policies and support systems that align with the ecological and economic values of ranchers, aiming to promote sustainable land management practices.

Geography: rangelands in the intermountain west

Key Findings:

- Ecosystem services: refer to the various benefits that humans derive from ecosystems. These include provisioning services (e.g., food, water), regulating services (e.g., climate regulation, flood control), cultural services (e.g., recreation, aesthetic values), and supporting services (e.g., nutrient cycling, soil formation).
    - For ranchers, ecosystem services such as soil health, water quality, and habitat provision are critical as they directly impact the productivity and sustainability of their operations.
- This study used surveys and interviews to identify patterns and relationships between ranchers' understanding of ecosystem services and their management decisions.

Study found:

- Ranchers generally recognize the importance of ecosystem services but often do not prioritize these benefits in their daily decision-making processes.
- The economic value of ecosystem services is often overshadowed by more immediate economic concerns, such as livestock productivity and feed costs.
- Decisions regarding grazing intensity and rotation are influenced by the perceived impacts on soil health and vegetation. Ranchers who recognize the link between grazing practices and soil or vegetation health are more likely to adopt practices that support ecosystem services.
- Choices related to land use, such as fencing and conservation practices, are sometimes guided by considerations of how these practices affect water retention, erosion control, and habitat provision.
- Short-term financial needs often take precedence over long-term ecosystem benefits. Ranchers face economic pressures that may limit their ability to implement practices that enhance ecosystem services.
- There is a lack of detailed knowledge about how specific management practices affect ecosystem services. This gap in understanding can hinder ranchers' ability to make informed decisions that balance productivity and ecosystem health.

Recommendations

- Improve education and outreach programs to help ranchers better understand the connections between their management practices and ecosystem services. Providing practical examples and demonstrations can bridge knowledge gaps.
- Develop policies and incentives that encourage ranchers to adopt practices that benefit ecosystem services. Financial incentives, cost-share programs, and policy frameworks that support sustainable practices can help align economic and ecological goals.
- Collaboration between ranchers, land managers, conservation organizations, and policymakers is essential for developing effective strategies to incorporate ecosystem services into ranching practices.

Photo: Bureau of Land Management, Flickr

Press Release: "Biden-Harris Administration Announces Over $10.5 Million from President Biden's Investing in America Agenda for Collaborative Sagebrush Projects in the West" 2023. https://www.fws.gov/press-release/2023-09/over-105m-president-bidens-investing-america-agenda-sagebrush

Overview: Press release detailing the new funding for sagebrush projects in the Bipartisan Infrastructure Law and the Inflation Reduction Act.

Geographic Location: Sagebrush Biome

Notes:

- The U.S. Fish and Wildlife Service announced $10.5 million in fiscal year 2024 from BIL. Will support 59 strategic projects in Western states focused on habitat restoration and on-the-ground science
- The Department of the Interior is implementing $2 billion in investments to restore lands and waters and advance the *America the Beautiful* initiative to restore and conserve 30% of lands and waters by 2030.
  - To guide investments, the Department released a *restoration and resilience framework* early in 2023 to support coordination across agencies–includes a commitment to defend and grow sagebrush ecosystems.
  - Framework aims to work collaboratively with farmers and ranchers, state and local leaders, Tribal Nations, the outdoor recreation community, private landowners, and other stakeholders, with the goal of "working to build ecological resilience in core habitats and make landscape-scale restoration investments across sagebrush country"
  - sagebrush projects will combat invasive grasses and wildfire, reduce encroaching conifers, safeguard precious water resources for neighboring communities and wildlife, and promote community and economic sustainability
- Over $1 million of the $10.5 million of BIL funding will be invested in conservation delivery work with Tribal partners. Some examples include:
  - Wind River Indian Reservation Riparian Fencing (Wyo.), $300,000. to construct approximately 8.1 miles of new, wildlife-friendly fence to exclude cattle from important mesic areas, installing solar wells and livestock tanks to provide off-stream livestock water. The project completed in cooperation with the Eastern Shoshone and Northern Arapaho tribes.

- Invasive Annual Grass Management Collaborative (Wyo.), $584,763. to manage invasive annual grass and defend about 100,000 acres of high-quality sagebrush habitats on mixed-ownership lands in Wyoming. Partners include the Eastern Shoshone and Northern Arapaho tribes, the State of Wyoming, U.S. Department of Agriculture, local government and private landowners.
- Northwestern Nevada Large-Scale Rangeland Restoration (Nev.), $303,000. to reduce the spread of invasive annual grasses through herbicide application and native seeding to improve rangeland conditions in and around core sagebrush habitats in northwestern Nevada. This project is in collaboration with the Summit Lake Paiute Tribe and Nevada Department of Wildlife.

**full list of fiscal year 2024 projects on the Sagebrush Conservation website.

- Sagebrush funding is allocated to existing and new projects based on priorities established by the Service's Sagebrush Ecosystem Team and partners, including the Western Association of Fish and Wildlife Agencies.

The SET, WAFWA and others are using the Sagebrush Conservation Design – a landscape-scale tool to prioritize conservation investments in sagebrush -- to collaboratively defend and grow intact, functioning sagebrush geographies and mitigate the primary threats to sagebrush ecological health, namely invasive grasses and wildfire, drought and encroaching conifers

Conservation and Management

Social Sciences

Photo: Oregon State University, Flickr

Bennett, D. E., & Pierce, J. (2020). *Chapter B Human Dimensions of Sagebrush* (Sagebrush Conservation Strategy- Challenges to Sagebrush Conservation) [Open-File Report]. US Department of Interior and US Geological Survey.

Overview: This chapter addresses the challenges and complexities involved in managing sagebrush habitats, highlighting how various human factors such as land use, economic interests, and cultural values impact conservation efforts.

Geography: Sagebrush Biome

Key Findings:

- Big Sagebrush has 216 documented traditional uses by Native Americans- medicinal, ceremonial, building (fiber), clothing materials
- Ecosystem services of sagebrush
  - Regulating: water purification, water infiltration and flood attenuation, carbon sequestration, wildfire resistance
  - Provisioning: products from livestock; water from municipal, industrial, and irrigation use; mineral extraction; food from hunting wildlife
  - Cultural: recreational opportunities such as cycling, hiking, hunting, and wildlife viewing
  - Supporting: production of grasses, nutrient cycling
- Ranching communities benefit from mult sagebrush ecosystem services- forage for livestock which allow for provisioning services. Also strong cultural ties to sagebrush.
  - Study showed that ranchers often don't allow access or charge for recreation on their ranches, suggesting further opportunity and value for ranching communities
  - Ranchers have become key partners in conservation efforts- particularly to avoid the listing of sage-grouse as endangered, which would have greatly limited ranchers
  - Health of ranches closely tied to health of sagebrush ecosystem
- Fostering trust between land management agencies and local citizens is an ongoing process that requires engagement, communication, and good-faith decision making
- Mining is an example of a contentious land use in sagebrush. Provides revenue to landowners and direct, indirect, and induced economic benefits to local economies but can degrade and destroy

sagebrush habitat
- Two of the most hard to measure values for sagebrush ecosystems are sense of place and spiritual beliefs

Bennett, D. E., Barnwell, C., Freedman, K., Smutko, S., Wittman, T. M., & Western, J. (2019).

Developing a social science research agenda to guide managers in sagebrush ecosystems.

Geographic Focus: Sagebrush ecosystems in Colorado, Idaho, Oregon, and Wyoming

Research Project: April 2018- September 2019. Involved a Q-study to understand how resource issues and conservation challenges are discussed among stakeholders. Gave 38 participants made up of state and federal agency staff, landowners, and conservation organizations (from Colorado, Idaho, Oregon, and Wyoming) statements related to social science research needs to rank in priority. Interviewed participants to understand rationale. This was followed up by a large survey, and then focus groups of 9-10 participants.

<u>Perceptions of social science</u>

- Few participants familiar with the applicability of social science to decision making and conservation efforts.
- Need to increase social science literacy of stakeholders AND make social science more accessible with less jargon and public-facing publications/forums (webinars, in-person presentations,
- Recommend more collaboration b/wn social scientists and organizations. Embedded research (participant observation). Create frameworks/templates that work with agency and organizational plans
- Raise profile of social science by emphasizing impact
- Less theory driven research, more applied research questions relevant to decision makers
- Primary perceived value of social science for many stakeholders was behavior change (from changing one's own behavior to changing others)

<u>Priority research topics</u>

Participants rated given topics as follows:

1. Conservation practice adoption
    1. Why practices were adopted
    2. Understanding compatibility of different conservation practices with landowner goals in sagebrush areas
    3. Could lead to improved outreach
    4. Barriers to adoption
2. Economics
    1. Participants felt economic findings are easy to communicate to general public, particularly those outside of sagebrush areas
    2. Management decisions tied to funding
    3. Quantifiable data are easy to understand
    4. Proof that conservation measures could benefit society as a whole
    5. Overall, authors speculate that economic data is prioritized because it is influential for policymaking
3. Other

1. Need for better communication about sagebrush conservation efforts and methods to “get others to care”
2. “Conservation marketing” (13)

4. Collaboration
    1. There has been extensive efforts to foster collaboration, but a lot of variation in these efforts. This offers opportunity for comparison
    2. Need to better understand strengths, limitations, and applications of these approaches
5. Values, Attitudes and perceptions
    1. Rated low on survey, but many focus group participants rated them higher after discussing the importance of understanding community and landowner values as well as a diverse set of stakeholders, and the public more broadly (registered voters)

Notes: Resources in article include Society for Conservation Biology, The Wildlife Society and the Society for Range Management, SageWest Communications Network, Sage Grouse Initiative’s (SGI) Science to Solutions program

Bennett, N. J., Roth, R., Klain, S. C., Chan, K., Christie, P., Clark, D. A., Cullman, G., Curran, D., Durbin, T. J., Epstein, G., Greenberg, A., Nelson, M. P., Sandlos, J., Stedman, R., Teel, T. L., Thomas, R., Veríssimo, D., & Wyborn, C. (2017). Conservation social science: Understanding and integrating human dimensions to improve conservation. *Biological Conservation*, *205*, 93–108. https://doi.org/10.1016/j.biocon.2016.10.006

Overview: This article emphasizes the critical role of social science in conservation efforts. It argues that integrating human dimensions—such as cultural values, social norms, and economic factors—into conservation strategies can enhance effectiveness and sustainability. The authors propose a framework for incorporating these human factors.

Geographic Focus: N/A

Key Findings:

- Conservation social science: refers to diverse traditions of using social science to understand and improve conservation policy, practice and outcomes.
- Among many conservation scientists and practitioners, there’s a lack of awareness about the social sciences and the different disciplines, objectives, methods and outputs, and uncertainty about the purpose of the conservation social sciences.
- The authors argue that the failure of conservation social science to be mainstream stems in part from a lack of clearly articulated objectives and values associated with the social sciences.
- Social science concepts that deserve more attention in conservation science: well-being, values, agency, and inequality
- Some SS objectives include:

    1) To understand and describe social phenomena, processes or individual attributes under study by asking why or how something is occurring. Second,

    2) Developing theory or testing pre-existing theories

3) Critically deconstruct a situation or issue to construct more effective solutions

4) Anticipate future trends through modeling and forecasting social and/or economic conditions.

5) Imagine desirable futures or to plan and identify courses of action to improve policies, programs, or social outcomes

- Research design considerations include if/how to collaborate, which methods to use, and how to analyze
  - Method categories: qualitative, quantitative, participatory, planning and decision-making, evaluative, spatial, historical and meta-analytical methods.
  - Authors emphasize all methods have benefits and drawbacks– being more familiar with how to mix and match is important
  - SS research can be inductive or deductive
- * Article gives overview of many of the conservation science disciplines

Contributions of Conservation SS:

- Can be valuable for descriptive, diagnostic, disruptive, reflexive, generative, innovative, or instrumental reasons.
- Document and describe the diversity of conservation practices, including historic and current examples
- Help diagnose why conservation is succeeding or failing, what scales are appropriate for different conservation processes and projects and how different processes might fail as a result of the interactions between groups
- Can be disruptive when insights reveal inequities, power imbalances or systemic issues at the scale of specific conservation initiatives or in global conservation organizations
- Reflexive value which allow us to explore the history and underlying assumptions of conservation and what constitutes ethical or responsible conservation actions
- Generative by producing innovative ways of thinking about or planning conservation.

Due to these values/contributions conservation SS is instrumental to conservation science in the following ways: 1) improve management practices and governance processes, 2) enable better conservation designs and models, 3) justify conservation actions, 4) help to achieve ecological outcomes and 5) facilitate more socially equitable processes and outcomes.

- On one hand, there needs to be more awareness of the breadth of social science and the variety of methods, on the other hand there needs to be more “proof of concept” from the SS

Spalding, A. K., Biedenweg, K., Hettinger, A., & Nelson, M. P. (2017). Demystifying the human dimension of ecological research. *Frontiers in Ecology and the Environment*, *15*(3), 119–119. https://doi.org/10.1002/fee.1476

Overview: This article explores the often-overlooked human aspects of ecological research. It highlights the importance of understanding how human values, behaviors, and social dynamics influence ecological systems and conservation outcomes. The authors advocate for integrating social science perspectives into ecological studies to create more holistic and effective environmental strategies, emphasizing that acknowledging and addressing human factors can enhance both research and conservation practices.

Geography: US

Key Findings:

- Historically, ecological research has primarily focused on natural systems, often treating human factors as external variables- more integrated approach is needed that includes human dimensions to enhance the relevance and impact of ecological studies.
- Human Dimension: Refers to the study of how human actions, perceptions, and social contexts interact with and affect ecological systems. This includes factors like land use, resource management, and cultural values.
    - Integrating human dimensions into ecological research helps to understand how human activities impact ecosystems and how changes in ecosystems affect human well-being.
- Social-Ecological Systems: This framework views ecosystems and human societies as interconnected and co-evolving. It emphasizes the need to understand both ecological processes and human activities to manage ecosystems effectively.

Need for more:

- Participatory Research: Involves engaging stakeholders, such as local communities, land managers, and policymakers, in the research process. This ensures that their knowledge, values, and perspectives are incorporated.
- Training: researchers should be trained in social science methodologies and theories to better incorporate human dimensions into their studies. This includes understanding social research methods and integrating them with ecological research.
- Interdisciplinary Teams: Foster collaboration between ecologists and social scientists to develop comprehensive research approaches that address both ecological and human factors. Interdisciplinary teams can provide a more holistic understanding of environmental issues.
- Applied Research: Aim for research outcomes that have practical applications in real-world contexts. This involves developing solutions that consider both ecological and human dimensions to ensure that findings are relevant and actionable.

Wittman, T. M., & Bennett, D. E. (2021). A Synthesis of Research on the Human Dimensions of Sagebrush Ecosystem Management. *Rangeland Ecology & Management*, *78*, 155–164. https://doi.org/10.1016/j.rama.2021.07.001

Overview: This article offers a detailed overview of research on the human aspects of managing sagebrush ecosystems. It explores how factors like land ownership, stakeholder interests, and cultural values influence management decisions. It stresses the importance of engaging communities and considering diverse perspectives in conservation efforts. Additionally, it discusses economic incentives and decision-making challenges in balancing conservation with economic interests. Overall, the article highlights the need for interdisciplinary approaches to effectively manage sagebrush ecosystems while addressing the complexities of human dimensions.

Geographic Focus: Sagebrush Biome

Key Findings:

- Distinct management challenges of sagebrush biome: balancing multiple uses (i.e. grazing and recreation), mitigating wildfire risk, invasive species, and maintaining viable economies while supporting preservation.
- Supports food production (ranching and farming), wildlife populations, energy extraction, and critical ecosystem services for inhabitants
- North American sagebrush steppe has been reduced to approximately 50% of its historic range leading to reduction and fragmentation.
    - Declining greater sage-grouse populations have lead to the potential of listing it under ESA
- Current social science on rangelands indicates a need to incorporate diverse populations and intersectionality.

Themes from synthesis:

- Local involvement in decision-making: Need for stakeholder agency in management strategies, implementation of regulatory measures, and long-term monitoring
- Collaboration: Local Working Groups (LWG) mostly composed to address sage-grouse conservation:
    - Neutral facilitator very important
    - Lack of structure in membership and decision making processes lead to failed outcomes
    - Focus on consensus building and democratic processes important for success
    - Sense of ownership over the process important
    - Local participation demystified science and contributed to trust, acceptance, and support of initiatives
    - Rapid turnover of agency personnel hurt engagement efforts
- Perceptions and Attitudes
    - Landowner perceptions and attitudes affected by family history on the land, personal ownership rights, awareness of management concerns, and prevalence of public lands in the region
    - Outreach programs to inform new landowners about proactive land management methods found to be beneficial to combating invasives and mitigating wildfire
    - Engagement efforts should be tailored to context/demographics
- Gaps- little to no social science literature on the following topics
    - wild horses and burros- contentious issue and pressing for sagebrush
    - carbon sequestration/energy development
    - Ecosystem services
    - Local knowledge
    - Invasive plant management
    - Conservation practices and incentives
    - Climate change
    - Drought
        - They also found a lack of research on social issues: political movements, local knowledge, outdoor recreation, and adaptive management and how these issues overlap with the resource categories above
    - Large gap in perspectives: most literature on perspectives of ranchers, farmers, and landowners but little to nothing on other groups (outdoor recreationists, hunters, tourists, workers in tourism, female stakeholders, seasonal agricultural workers, BIPOC communities)

Notes: Good resources - Journal *Rangelands*, Web of Science

Recreation

Social Sciences

Photo: Tom Koener/ USFWS Mountain-Prairie, Flickr

Requena-Mullor, J. M., Brandt, J., Williamson, M. A., & Caughlin, T. T. (2023). Human population growth and accessibility from cities shape rangeland condition in the American West. *Landscape and Urban Planning*, *232*, 104673.

https://doi.org/10.1016/j.landurbplan.2022.104673

Overview: The study aims to understand how increasing human population and proximity to urban areas influence the condition of rangelands in the American West.

Geographic focus: American West

Key Findings:

- The researchers employed a combination of spatial data analysis and ecological metrics to assess rangeland conditions. They looked at various factors, including population density, distance from urban centers, and other socio-environmental variables.
- **Population Growth**: Areas experiencing higher population growth tend to show deteriorating rangeland conditions. This is likely due to increased development, land use changes, and higher pressure from recreational activities.
- **Accessibility**: Proximity to cities correlates with poorer rangeland conditions. Increased accessibility facilitates more intense human activity, which can lead to overgrazing, habitat fragmentation, and other negative impacts on rangeland health.
- **Implications**: The findings suggest that managing rangelands requires considering both human demographic trends and urban proximity. Effective policies should address sustainable land use and development practices to mitigate adverse effects on rangeland ecosystems.
- The authors recommend buffers or protected zones to safeguard rangelands from urban encroachment and population pressures.

Gaps/Limitations: the article looks at impacts of human activities on rangelands in relation to urban centers, but does not consider the potential benefits of exposure to these areas for general public support of conservation efforts.

Switalski, A. (2018). Off-highway vehicle recreation in drylands: A literature review and recommendations for best management practices. *Journal of Outdoor Recreation and Tourism*, *21*, 87–96. https://doi.org/10.1016/j.jort.2018.01.001

Overview: The study reviews existing literature on the environmental and ecological impacts of OHV recreation in drylands and offers recommendations for managing these activities to minimize harm.

Key Findings:

- Environmental Impacts: OHV activities can lead to significant environmental degradation in drylands, such as increased soil erosion, habitat destruction, and disruption of plant and animal communities.
- Ecological Challenges: The fragile nature of dryland ecosystems makes them particularly susceptible to damage from OHV use. The review highlights how these vehicles can exacerbate problems such as invasive species spread and loss of native flora and fauna.
- Best Management Practices (BMPs): The paper suggests a range of BMPs to mitigate the negative impacts of OHV use. These include implementing designated trails to reduce habitat fragmentation, using barriers or signage to guide recreational activities, and promoting restoration efforts in areas damaged by OHVs.
- Regulatory Measures: Switalski advocates for stronger regulations and enforcement to ensure that OHV use is conducted in environmentally sensitive ways. This could involve creating protected areas or seasonal closures to allow for ecosystem recovery.