**Statement of Issues and Justification**

**INTRODUCTION**

Sagebrush (*Artemisia* spp.) systems occur through most of the semi-arid western North America and is considered one of the most imperiled ecosystems in the world (Knick et al 2003, Doherty et al. 2022). Characterized by relatively low temperatures and precipitation, which comes primarily in the form of snow during the winter, the rate of ecosystem processes is relatively slow as evidenced by the life histories of the associated flora and fauna (Connelly et al. 2011).  However, the rate of change within sagebrush systems has periodically increased beyond natural processes. One example is when Europeans began to pioneer this semi-arid region and subsequently developed agriculture and infrastructure to support settlement.

Currently, only half of the historic distribution of sagebrush land cover persists (Schroeder et al. 2004). Along with the conversion of landscapes from natural sagebrush ecosystems to agricultural lands, Euro-American settlement has resulted in an influx of exotic flora and fauna species (U.S. Fish and Wildlife Service 2013). Countless acres within sagebrush ecosystems are compromised by the presence of exotic vegetation that reduces primary productivity and has resulted in a heightened ignition risk for wildfire – a disturbance for which sagebrush systems are generally not well-adapted. Juxtaposed to the threat of exotic vegetation with too frequent fire cycles, fire suppression has led to increases in conifer encroachment into western sagebrush ecosystems (75 FR 13910 2010, Doherty et al. 2022). When considering both threats together, i.e., exotic vegetation with increased fire cycles and conifer encroachment, it is difficult to determine which conservation actions are best for the future of sagebrush landscapes.

In eastern portions of the sagebrush biome, a different set of threats predominate. As commodity prices increase private sagebrush lands are at increased risk to conversion to cultivated croplands. Additionally, energy development is a threat as oil and natural gas resources are abundant throughout much of the area. Infrastructural support for energy extraction (e.g., roads, powerlines, associated traffic), leads to fragmentation and direct loss of sagebrush habitats. Renewable energy, such as wind power, can also result in the disturbance and loss of sagebrush habitats and is an increasing threat primarily in eastern, but also throughout, sagebrush systems (U.S. Fish and Wildlife Service 2013, Doherty et al. 2022).

Much of the remaining sagebrush biome is working agricultural lands, and is commonly used for grazing of domestic livestock.  Interestingly, evidence is mounting that the drivers of ecological function in this fragile system are not only beneficial to wildlife resources but have shared values with sustainable agricultural practices.  Recent unprecedented conservation efforts put forth to ensure long-term population viability of obligate sagebrush species such as sage-grouse (*Centrocercus urophasianus*; USFWS 2013, Doherty et al. 2022), present a unique opportunity to evaluate both the biological and socio-economic outcomes of sagebrush conservation actions at a continental scale.

The fate of greater sage-grouse, an endemic and obligate of the sagebrush ecosystem, is directly linked to sagebrush (Connelly et al. 2011). As sagebrush has been lost or degraded, the distribution and abundance of the species have diminished commensurately (Schroeder et al. 2004). Sage-grouse are considered an umbrella species for sagebrush ecosystems, because their life-history requires a heterogeneous landscape of sagebrush species and habitat structure. A variety of sagebrush structure types are necessary for concealing and incubating nests, providing available forage in deep snow, or more open canopy mesic areas for young chicks (Hanser and Knick 2011). Thus, landscapes that contain all of these components are not only beneficial to sage-grouse, but provide resources for other sagebrush obligate and dependent species. Additionally, ecosystem services provided by intact and healthy sagebrush systems benefit society as well as these important species.

**SAGEBRUSH ECOSYSTEM SERVICES AND SOCIETY**

In light of the various threats, the human and economic dimensions for sagebrush system communities have unique and unprecedented landscape-level dimensions for the western U.S. (Sayre et al. 2012).  Recent theoretical work by Bestelmeyer and Briske (2012) documented the need for resilience-based management of rangelands and is arguably applicable to the sagebrush system specifically, but did not extend the integration of socio-economic components to a distilled threats framework. Some successful efforts are showing positive effects on decision-making outcomes by including local knowledge (e.g., rancher participation in program efforts) as well as increasing collaborative capacity (Wilmer et al. 2017).  Integration of the human community impacts within the sagebrush system has multiple elements. Examples of this integration may include, 1) quantifiable economic relationships related to livestock production components (Ritten et al 2010); 2) the need to understand valuation of more qualitative components such as sense of place, community cohesion; 3) anxiety from the contemporary threat of litigation (Wulfhorst et al. 2006) ; and 4) broader trends of changes to culture and landscape structure (Nassauer 1995).

Human communities in the sagebrush system span a rural-to-urban continuum. However, rural communities are typically most directly and disproportionately affected by public lands policy and management of sagebrush systems, and often lack planning resources, resulting in gaps between small municipalities and larger ecosystem services expectations. Moreover, community motivations, incentives, and behaviors to adapt to shifting public policies relating to natural resource management needs (e.g., sage-grouse conservation) vary substantially. In this context, threats to the sagebrush ecosystem can manifest in human dimensions in the form of increased stress or anxiety, impacts to morale and cohesion, intergenerational change affecting management and land-use, as well as perceived constraints on livelihood scenarios. Effects to each scale within the human communities – individuals, families, organizations – manifest relative to social and economic relationships that are based on public lands resource management for western landscapes.

The economic returns of grazing are highly dependent on annual forage production.  The increased presence of exotic annual species, especially cheatgrass (*Bromus tectorum*), alters both the amount and timing of forage production in these systems (Smith et al. 2022).  Cheatgrass specifically limits season of use in that it is palatable to domestic livestock for only in the spring and fall, and limits native forage species, resulting in reduced native biomass production later in the grazing season. Likewise, conifer encroachment into grazing lands negatively impacts both the production of perennial grasses and forbs, and shortens growing seasons due to decreased soil water availability (Miller et al. 2017), and access to forage production (Schmelzer et al 2014).  The impact of this phenomena results in decreased returns to livestock producers, which ultimately negatively impacts rural communities. Further, changes to precipitation patterns can have a negative impact on livestock production. Cow/calf producers that are forced to liquidate breeding stock in the face of reduced annual forage are impacted as retaining heifers post-drought results in at least a two-year lag before reaching calf sales levels prior to any liquidation. Given forage production responses to growing season precipitation, wetter years do not have the same positive impacts that dryer years have (non-linear response to precipitation). Thus, if annual precipitation becomes more variable, as is predicted under some climate forecasts, the benefits of some wetter years are overshadowed by the increased threats of dryer years and increased evapotranspiration (Polley et al. 2013).

Increasing commodity prices may make sagebrush conversion for cultivation economically viable, potentially creating a conflict on private lands between economic development and habitat conservation. Fragmentation and loss of sagebrush due to energy development and supporting infrastructure may have negative impacts to agricultural producers through loss of net primary productivity (Allred et al. 2015). Alternatively, some forms of energy production may increase water availability (e.g. coal bed methane ponds) or provide an additional economic resource to individual landowners (e.g. annual rental fees for wind turbines). The benefits and costs from energy development, and resulting conservation efforts implemented for sagebrush dependent species, on land users and owners, and associated economies is poorly understood.

The sagebrush biome provides many other benefits to society beyond forage for livestock production including maintenance of rural economies and lifestyles. Management of these systems is complex as often the trade-offs between these other services (e.g., habitat for wildlife, plant biodiversity, water quality, and resistance to soil erosion), are often not well understood.  While decisions such as the timing and intensity of livestock grazing, and energy development can impact the provision of these other services, exogenous factors such as weather and fire can dramatically shape system evolution over time. Further complicating the problems of management of these large systems is that many of the accrued associated benefits are not market-based making profit-motivated decisions difficult. There are also benefits to people that are not directly tied to the landscape. This landscape is also often defined as a mix of private and public land holdings, with management decisions rarely being coordinated at the landscape level.

A framework for research, monitoring, and conservation of the sagebrush biome is based on concepts of ecological resilience and resistance (R&R; *sensu* Chambers et al. 2017). Resilience is defined as the capacity for an ecosystem to recover when altered by pulses, like fire, and presses, like increasing temperatures. Resistance is defined as the capacity of an ecosystem to retain its fundamental structure and function when exposed to disturbances, such as invasive species (Chambers et al. 2017). To develop a model of R&R across the sagebrush biome, Chambers et al. (2017) investigated factors related to the occurrence of annual invasive grasses and frequency of disturbance. They documented that higher elevation sites with greater precipitation and cooler temperatures have greater soil nutrients and plant productivity and recover sooner after disturbance than lower elevation sites that tend to be drier and hotter. Biome-wide resilience and resistance tend to increase across a southwest to northeast gradient. However, there is measurable variation along this transect as resilience and resistance respond to changes in elevation (Table. 1). We will use these principles of ecological R&R and a sagebrush biome-wide geographic information systems (GIS) model to characterize our study areas and predict outcomes of socioeconomic resilience as a function of ecosystem health and various stressors in these areas (Table. 1).

**Related, Current and Previous Work**

While the basic biology and ecology of sage-grouse has been thoroughly studied (Knick and Connelly, editors 2011, Coates et al. 2021) as have several components of the larger sagebrush biome (Wisdom et al 2005, Doherty et al. 2022), efforts to link this knowledge base with socio-economic dimensions are sparse.  Recent research efforts have focused on evaluating the biological and ecological outcomes of conservation actions to restore populations and vegetation communities. For example, the journal *Rangeland Ecology and Management* dedicated an entire issue (REM volume 70) to research evaluating the effects of conifer-removal to at-risk sagebrush ecosystem obligates (Miller et al. 2017). These evaluations provide an opportunity to begin examinations of socio-ecologic relationships of these actions, and ultimately quantify mutual benefit where it occurs.

Limitations in primary productivity create the potential for strong competition between livestock and wildlife in sagebrush systems and stressors that limit livestock grazing have potentially profound influences on vegetation communities, wildlife populations and ecosystem health (Mosley and Brewer 2006). These feedback mechanisms create tight coupling within socio-ecological systems (SESs). Such feedbacks are strengthened further by industrial and exurban developments and the projected climatic shifts on the near horizon. Energy development and other extractive resource uses have both direct and indirect effects on ecosystem health. The direct effects of vegetation removal from oil and gas development reduced the available NPP by ~10 Tg (dry biomass) in the western US (Allred et al. 2015). Additionally, the total loss of livestock grazing capacity was approximately 5 million animal unit months, which is more than half the total amount currently available for grazing on Bureau of Land Management public land grazing allotments (Allred et al. 2015). These impacts are conveyed to other ecosystem services as this 60,000 km2 footprint further fragments available habitat for wildlife, reduces migratory pathways, and negatively affects space use and demography (Sawyer et al. 2009, Kirol et al. 2015; 2020). While the economic benefits of such industries may provide stability to rural communities, less is known about how community identity and security may be impacted. Evidence from previous energy booms suggests that energy dependent communities are supportive of energy development (Ramo and Behles 2014). After the “bust,” transitions away from energy development create~~s~~ internal and external political conflicts that have implications in both the community’s collective identity and quality of life

Recent examples of the analysis of the economic impacts of federal management decisions regarding natural resources can be found in the US Department of Interior’s Bureau of Land Management (BLM) draft Resource Management Plans amendments and accompanying Environmental Impact Statements for all 15 BLM planning units that contain greater sage-grouse habitat (reviewed by Baier and Segal 2014). There is a lack of consistency in the reporting of the economic impact results across the plans (Baier and Segal 2014) which aggregation of results to obtain an overall regional perspective.  In an independent study, Stoellinger and Taylor (2017) found that the economic loss from no livestock grazing on core sage-grouse habitat in Wyoming would result in a direct economic impact loss of $445.1 million, a total economic impact loss of $922.8 million, a loss of 10,201 jobs, and total labor income loss of $304.1 million over an eight-year time period.

For livestock grazing and other natural resource industries, greater accuracy in economic impact estimates can be achieved by incorporating region specific data into the economic impact models. As an example, a detailed discussion of how to incorporate enterprise budgets for livestock grazing into common economic planning models (e.g., Impact Analysis for Planning hereafter, IMPLAN) can be found in Coupal and Holland (1995) and Fadali et al. (2012). Once an appropriately specified regional model is in place, the next step is to incorporate the ranch-level production responses from changes in federal grazing policy in order to estimate the economic impact on the overall economy in the region. A common approach used in estimating the economic impact of federal livestock grazing is a simple change in livestock production based on the potential change in federal animal unit months (AUMs) of grazing.  A problem with this approach is that federal grazing is not typically used by a rancher in isolation but rather as a part of an individual ranch’s overall grazing system. Previous analysis has demonstrated that if a ranch is seasonally dependent on federal grazing, as is typically the case for many western ranches in northern climates, a reduction in federal AUMs can create forage imbalances that result in greater reductions in production than those that just result from reduction in federally allotted AUMs (Torell et al. 2014). The potential for cascading economic effects suggests a ranch-level economic analysis first needs to be conducted to determine the potential changes on overall production from a change in federal grazing allotment. These changes can then be incorporated into the economic impact analysis (e.g., Stoellinger and Taylor 2017).  The regionalization of economic impact models would also be appropriate for other natural resource industries.

The Western Association of Wildlife Agencies has recently completed their inter-agency Sagebrush Conservation Strategy (Dougherty et al. 2022) and is intended to build on collaborative efforts between State and Federal agencies, academia, tribes, and stakeholders, all of whom are implementing conservation efforts in the sagebrush biome. The U.S. Fish and Wildlife Service has funded 6 projects under the related Sagebrush Science Initiative to address knowledge gaps in our understanding of different biological components of the sagebrush ecosystem. These parallel efforts will provide additional biological scientific underpinnings to further our understanding of how any proposed conservation efforts may affect the human and economic components proposed here.

**Objectives**

Resilience is a construct well-suited to transdisciplinary investigations of SES. Many ecologists, economists, and sociologists alike hypothesize resilience is the key to biodiversity conservation, economic sustainability, and social well-being, respectively. We intend to evaluate multi-scalar relationships between socioeconomic-ecological resilience~~,~~ and ecosystem health, while accounting for co-occurring socioeconomic and environmental stressors that may undermine resilience in the sagebrush biome, including livestock ranching, energy development, exurban growth, and climate change. Utilizing our extensive demographic data of sage-grouse from 39 landscapes across 5 western states, we will identify thresholds for transformative changes in sagebrush ecosystem health. We will conduct our work across 3 socioeconomic-ecological “community corridors.” These community corridors will be large geographic regions derived using clustering algorithms on a suite of covariates (i.e., R&R, human footprint, energy development, economic indices) that surround our 39 sage-grouse study sites and will result in geographic units described by their socioeconomic-ecological similarities. We also will identify levels of socioeconomic and ecological resilience that correspond to transformative thresholds of ecosystem health. We postulate the corresponding thresholds of socioeconomic resilience will vary across landscapes depending upon the extent of livestock ranching, extractive energy development (both renewable and non-renewable sources), and exurban development. We include both renewable and non-renewable energy development as “extractive” development, although their long-term sustainability and carbon footprints may be different, they are similarly disruptive to ecological processes with regards to habitat fragmentation and socioeconomic structures. We further posit that predicted increases in the frequency and severity of extreme droughts will cause transformative changes in ecosystem health to occur at lower thresholds of socioeconomic-ecological resilience.

1. **Objective 1 (Economic Resilience):** *Quantify how the tradeoffs, feedback loops, and threshold effects of regional economies translate to socio-economic resilience, including socioeconomic structure,  at multiple scales and identify linkages with ecological resilience and ecosystem health as affected by energy development, exurban development, and invasive plant species. (carried out by Coupal, Lee, Mazcko, Ritten)*
2. **Objective 2 (Social Resilience):** *Assess the socioeconomic-ecological resiliency of rural communities across a spatial R&R gradient to these stressors. (carried out by Wulforst, Mosely, Huntsinger)*
3. **Objective 3 (Ecosystem Health):** *Quantify how the tradeoffs, feedback loops, and threshold effects of sage-grouse population viability translate to ecological resilience at multiple scales and identify linkages with social and economic resilience as affected by energy development, exurban development, and invasive plant species. (carried out by Beck, Dahlgren, Dinkins, Hagen, McNew, Sedinger, Thacker, Williams)*
4. **Objective 4 (Outreach)** *Engage local communities in research and outreach*  
   Comments: Engagement implies a dialogue between researchers and stakeholders. Results from integrated research on threats and consequences to sagebrush and human communities and the links between sagebrush land management and the health of rural communities must be communicated to key stakeholders to be meaningful. In addition, listening to those stakeholders on their concerns, issues, solutions, and alternatives will inform researchers as to the important questions to address. In both cases, education about science, values, and culture will occur in all directions. *(carried out by all researchers)*

Our sub-objectives are to:

4.1. Provide land and wildlife management agencies with factsheets and presentation that summarize the relationship between ecological outcomes of land management actions to socio-economic consequences.

4.2. Produce outreach materials that clearly communicate how the ecological threats to sagebrush systems can have impacts on local and state socio-economics.

**Methods**

To address Objective 1, we will first assess well-being at the scale of an individual livestock producer to determine the relationships between ecological resilience, ecosystem health, and socio-economic resilience for communities in our study area where the predominant economic activity is livestock production. To assess whether the presence of energy and exurban development in addition to livestock production influences socioeconomic resilience and its correlation with ecological and ecosystem factors, we will develop regional economic models to analyze the effects of these multiple industries existing simultaneously on socio-economic resilience in our study system. Once these models have been developed, we will assess how predicted climate changes and possible development patterns or policy shifts will affect socio-economic resilience by modeling anticipated changes in our developed frameworks.

To assess the impacts at the operational (i.e., ranch) level, we will develop a stochastic dynamic programming (SDP) model that represents a decision framework for a representative livestock producer, parameterized for each of our three identified study sites. The SDP model will include the feedback loops between ecological resilience and rangeland management (e.g., altering livestock stocking rate, stock density, season of use, brush management), to incorporate ranchers’ response to changes in policy and ecological conditions. Firm-level production data for these models will be informed by Dyer et al. (2018) and Maher et al. (2023) as well as local primary data collection and validation with producers located in each study area. These state variables will evolve in response to management and stochastic variables, and will include both ‘presses’ and ‘pulses’ as described above. The model solves for a stream of discounted net benefits (ranch income) as a function of management and stochastic variables. The model will be parameterized using primary (Objective 2) and secondary data in order to represent characteristics of communities  to assess the economic resilience  across the R&R gradient. To assess how climate stressors impact the resilience of ranching dependent communities, predicted climate changes will be included in the model as stochastic state variables to assess how outcomes at the ranch level are impacted by climate projections.  These climate forecasts will be informed by, the forthcoming Intergovernmental Panel on Climate Change’s (IPCC) sixth assessment cycle reports. To assess how development stressors impact the resilience of ranching dependent communities, we will model possible future scenarios with increased nonrenewable extraction and/or exurban development impacts on the ranching community, to be informed by the regional model described below. Some expected impacts include increased costs of production, decreased/more expensive labor supply and increased land costs coupled with threats of land conversion.

Regional economic models will then be used to show the structural impact changes and resilience measures  of changes in management and profitability to industries associated in the functional community economies surrounding the sites  as well as on local employment and public financial metrics. Input-output models (IO) combined with lifecycle assessments have been used extensively in the engineering and applied science literature to provide economic assessments of projects and technologies. Both have benefits and limitations in the use of the methods individually and in a hybrid-approach used in this proposal (Croft and McKenzie 2010). Two types of regional models will be constructed to evaluate small region resilience and economic impacts. More recently this hybrid approach between the two modeling systems has been used in evaluating sustainable development. Croft and McKenzie (2010) proposed a prescriptive approach to evaluate sustainable goods and service development. Chen et al. (2010) constructed an ecological IO model for embodied resources and emissions in the Chinese economy. The economic accounting and flow framework used can provide a start in building more focused ecological IO models initiated here.

The first stage will be building regional resilience models that estimate changes in employment, income, industry structure, public finance revenue and expenditure metrics as a result of climate and potential regulator stressors to the natural environment. The analysis will evaluate and compare both site based functional local economies and functional economies in the sagebrush biome related to sage-grouse habitat area. The model structure will start with expanding on work in Ringwood et al (2019) and Han and Goetz (2015) but adding variations in measuring resilience ranging from income and jobs based to growth or economic base indicators. The goal is to identify a range of recovery metrics without biasing a specific economy comparison. We will incorporate Martin (2012) typology to identify those economic structures that are sensitive to changes in climate change but also regulatory impacts related to the changes.

The second modeling framework will build upon the EPA environmental economic impact model system (i.e.,STATEEIOR), but scaled down to functional local economies surrounding our study sites. We will incorporate land use and habitat types into the model as best as can be subject to existing data. The analysis will identify the types of industries and growth potential factors that could create more resiliency or less and how that correlates to the regional sage-grouse population viabilities. Detailed environmental flows are under eight categories of resource use and expand to over 1900 specific environmental flows and life cycle analysis as part of the EPA's and the engineering output. The national level profile of economic environmental flows provides a useful picture that can inform policy makers and analysts.  However, the national view is a limitation to many environmental issues that are local in impact. As such, we propose two modifications of US Environmentally-Extended Input-Output (USEEIO) models to make it more flexible and useful to local, small area analyses (e.g., the community corridors explained in Objective 2). The first step is to create a version of the USEEIO that reflects the small area. We will use IMPLAN models to create relevant local social accounting matrices for project identified study areas. Then using Robinson et al. (2000) and collecting relevant environmental economic data from the work by the team to build a local USEEIO model for each study area. Also using the modified small region models based on STATEEIOR we will run scenarios that conform to results in Objective 2.

Using the information gained about communities in our study systems using the individual and regional scale models, we will construct a framework to assess how socioeconomic and ecological pressures together create a multi-attribute decision model (Wallace 2020) based on community fiscal and economic metrics developed from the economic models, community structure result from the sociological models, and metrics from the ecological modeling. The framework would be used for general optimization results but can also be used iteratively for scenario planning and analysis. The process would be to initially identify levels or preferences for each  ‘community corridor’ using data collected in Objective 2 with scenario sensitivity analysis around different weighting mechanisms for different inputs into the function. It would also inform any global or multi-region optimal trajectory for any transition and/or responses to stressors (or changing demographics and ecology). Broad level constraints would include land area, size, ecological metrics for plausible future outcomes (e.g. development possibilities). Finally, the models can be used iteratively with community corridor representatives, government agency representatives, and scientists on the team if need be to understand the tradeoffs or synergies between socio-economic objectives and ecosystem health while considering preference-weighted values specific to the community corridor.

**Objective 2 (Social Resilience): Assess the socioeconomic-ecological resiliency of rural communities across a spatial R&R gradient to these stressors.**

To address this objective, we will use outputs from Objective 1 to inform the larger community and social impacts of management of sage-grouse habitat at the ranch level. Coupled with outputs from Objective 1, the agroeconomics modeling will incorporate measures of social structure, public finance, capital, and ties measured through primary data collection. In rural geographies, communities remain highly dependent on social functions still bound to relatively higher densities of acquaintanceship. Thus, the social capacity of rural communities may have fewer interaction opportunities that develop breadth of networks, but often sustain tightly coupled interactions with in-network actors that may tend to share overlapping if not common sets of beliefs, values, and norms. In this context, social degrees of heterogeneity provide the conceptual basis for characterizing community  interactions and social structure.

*Socio-environmental orientation / context*.  The degree of social heterogeneity relates to a socio-ecological system as a function of how communities organize geographically within a landscape.  Ecological structure -- such as livable spaces vs. rugged, remote, or difficult to access spaces -- enables human settlement, along with soil fertility, water access, and other amenities that may enhance basic needs elements of structure. Given the limitation of key resources such as water in the sagebrush biome of the western US. Much of the geography also has structure that enables human concentration adjacent or accessible to a gradient of premium-to-marginal resources. This gradient includes time as distance-to- or technological connection-to-resource, social power and control that also serves as a means to operationalize affluence, inequality, and dimensions of social equity. These elements characterize a more holistic measurement of social heterogeneity, how it functions in relation to community resistance and resilience, and what factors will cause greatest influences on it within an integrated system.

We will measure social heterogeneity within sampling units designated as social-ecological community corridors.  The concept of corridors is useful for socio-environmental integration because of how and where in the landscape human dimensions overlap (or not) with ecological connectivity such as riparian areas, wildlife habitat, and mixed land-use.  Previous research has leveraged the notion of biological corridors, but the concept remains underutilized for social science, and socio-environmental systems. The corridor concept also allows integration of key social and economic components needed to measure a gradient of social heterogeneity because rural economic commerce patterns organize along socio-geographic boundaries naturally limited by corridors and environmental access. This socio-economic organization pattern has become more complex due to greater effects from interactions related to distance-to-commodities and online purchasing but remains true for many basic needs for rural community populations. Scholars have not applied notions of sustainable corridors to the sagebrush biome at the intersection of wildlife habitat, energy development and community resistance vs. resilience. For our transdisciplinary project, the corridor structure also forms a basis for methodological sampling and fieldwork organization for the primary sociological data collection within the project.

Recent review of holistic approaches to managing livestock called for more integrated analyses tied to ranching operations and nuances of decision-making (Gosnell et al. 2020). Related research has expanded upon the need to consider localized dimensions of decision-making that may not have predictable origins when considering notions of sense of place, family relations, and amenity values (Abrams et al. 2012, Nielsen-Pincus et al. 2017, Eaton et al. 2019). Complexity of individuals’ decision-making has breadth and depth critical to understanding outcomes that translate into ranch management (stocking rates, rotations, timing of turnout, etc). Additionally, decision-making complexity stays dynamic. As such, it is the arena for identifying the source and origin of motivations, commitment thresholds, and social-psychologic triggers influential to conservation practices and ecological outcomes along the R&R gradient. As the *de facto* stewards of much of the sagebrush biome in question, ranch owners, managers, and staff have significant and disproportionate impact on species outcomes in a public- and private-lands matrix. In this context, a relatively small pool of landowners and managers have substantive impact from direct day-to-day actions. Decisions that determine those actions relate back to information availability, connectivity to social networks, and attitudinal commitments.

*Core measures / indicators*. Measures of social heterogeneity will stem from the following categories:  1) natural, human, social, and financial capitals within the community capitals framework; 2) constituency scale; and 3) nature and extent of interactional ties. The community capitals framework emphasizes a suite of measurable concepts that combine to provide broad indicators of collective capacities (Emery and Flora 2006). In the R&R framework, community capitals will inform where system-level resources are stronger or weaker to navigate the complexity of factors affecting sage-grouse habitats and grazing (Gutierrez-Montes et al. 2009, Mueller et al. 2020). A constituency scale analysis will complement the capitals’ framework components in order to incorporate the range of local-to-regional scales of socio-economic organization and analyzing impacts within corridor geographies. Constituency scales will operationalize decision-making patterns for landscape management that translate along a continuum of social coordination (ranging across a two-dimensional matrix with axes of cooperation and conflict).

*Data collection methods*. To develop primary sociological data for incorporation into the agro-economic modeling effort, a series of semi-structured interviews will occur across the selected community corridor geographies. An initial cluster sampling approach will identify rural community areas by category within the R&R gradient (Table 1). Use of secondary data will develop a profile of community areas for ongoing site selection. Multiple geographies within the overall sage-grouse habitat region will be selected to represent the R&R categories across multiple management zone contexts. An estimated 10-15 interviews per corridor will provide qualitative data toward a larger survey design effort to be administered within the community areas. Sub-categories for interviewees will include livestock producers, industry representatives, community leaders, and conservation partners. We will group livestock producers per the typology of Gosnell and Travis (2005): traditional ranchers who receive a significant portion of their income from the ranch; part-time ranchers who receive more income off-ranch than on; amenity buyers who hire ranch managers or lease their property; and corporate ranchers who have a large network of several ranches with one or more ranch managers. The social survey approach will utilize a team of on-the-ground researchers to implement a digital questionnaire via tablet devices. Using a Qualtrics (or similar) platform, modified drop-off / pick-up methodology (Trentelman et al. 2016) protocols will be used to facilitate respondent recruitment, real-time recording of responses, and efficient compilation of aggregated data. Digital-recording platforms will be connected and integrated within each survey to augment data collection questions and details from respondents to enable qualitative complexities that may elaborate survey responses. Survey sampling designs will use field-based enumeration protocols with randomized cluster sampling based on ratios of community size, number of household units, and with replacement records implemented after three attempts. (Jackson-Smith et al. 2016).

*Social data analysis approaches*. The approach for analyzing the primary social interview data will include analysis of responses to a concourse of statements to which respondents provide viewpoints and subsequently get categorized across the set (Cooper and Wardropper 2021) based on digital member-checking follow-ups. Survey analyses will be conducted on aggregated datasets by corridor as well as the overall region to allow for corridor-comparative analyses. Statistical analyses will use *R* as a base platform for data management and preliminary analyses prior to data integration across the economic and ecological modeling efforts.

**Objective 3 (Ecosystem Health): Quantify how the tradeoffs, feedback loops, and threshold effects of sage-grouse population viability translate to ecological resilience at multiple scales and identify linkages with social and economic resilience as affected by energy development, exurban development, and climate change.**

To address this Objective, we will build and evaluate integrated population models to evaluate the linkages between sage-grouse population viability (i.e., ecosystem health), socio-economic, and ecological resilience, and project how population viability may change under future climate scenarios. To accomplish this, we will address four sub-objectives:

1. Identify the key population vital rates influencing population growth and whether sensitivities vary spatially in relation to ecological resilience,

2. Evaluate whether the effects of climate on sage-grouse demography vary spatially,

3. Forecast population responses to climate change over a gradient of ecological resilience.

4. Quantify the proportion of variation in sage-grouse population abundance and growth rates explained by climate, energy and exurban development

Extensive and rich data have been collected across much of the range of greater sage-grouse. Data have been collected from numerous independent studies to inform demographic processes for nearly every stage in their life cycle (e.g., Blomberg et al. 2012, Dahlgren et al. 2016, McCaffery and Lukacs 2016, Gibson et al. 2018). In addition to demographic data, standardized lek counts are conducted annually across the range of sage-grouse. Although demographic data and lek count data are collected to address different management questions and research hypotheses, combined the data contain information on spatial and temporal trends in abundance, and the demographic processes that regulate those trends. Objective 3 is to leverage these disparate data, in a cohesive modeling framework to examine spatio-temporal sage-grouse demographics, how those demographics relate to environmental stressors and may change under future conditions of climate and rural socioeconomics. We will use publicly available data to characterize community corridors of socio-ecological resilience and classifying them based upon the following covariates: exurban development, local public finance changes and energy development associated with our 39 study sites and resources.

**Objective 4. Engage local communities in research and outreach**

1. The team will actively engage stakeholders within the rural communities during the relevant phases of research activities. Initially this will be in areas where active field research is being planned and conducted. We will meet with key stakeholders such as private and public land management agencies, state and federal wildlife agencies, county and community government, and interest groups. To engage the stakeholders directly in the research process requires incentivized and structured formats to elicit input within participatory and co-designed processes on questions being investigated, appropriate research locations, and means to mitigate concerns they may have. Once the research is underway, we will continue to engage those groups and others to ensure a transparent and mutually beneficial outcome.
2. If the opportunity arises, we will work to develop a citizen-science component to this objective.  Ideas may be solicited from the community as to the need and practicality of implementation. Successful efforts in this include but are not limited to a national plant phenology network (USA National Phenology Network at <https://www.usanpn.org/>) and various weed mapping activities (for example, *cal-ipc.org/symposia/archive/pdf/2010/1Brigham.pdf* describes a phone app). There may be opportunities for local communities to be involved with installing treatments or continual monitoring of locations. Competitions with restoration (Wyoming Cheatgrass Challenge, <https://www.facebook.com/WYrestorationchallenge/>) or management (Adaptive Grazing Management Experiment, <https://www.ars.usda.gov/plains-area/fort-collins-co/center-for-agricultural-resources-research/rangeland-resources-systems-research/docs/range/adaptive-grazing-management/research/>) techniques have also been successful in engaging the community.  These kinds of activities can provide a sense of ownership by the community in the research and provide researchers with resources they may not otherwise have.

The Cooperative Extension component of this project will play a key role in leading these efforts.  In most cases, the local Extension educator or specialist will have the contacts and relationships with the key stakeholders. Researchers will be relied upon to participate in all activities.

**Measurement of Progress and Results**

**Outputs**

1. Integrated conceptual model that depicts the complex relationships among ecological, economic, and socio-cultural aspects of sagebrush management and policy- and knowledge gaps between the ecological and economic interface

2. Assessment of existing data, consolidated database, and identify data gaps

3. Identification of funding targets and generate extramural proposals

4. Publications (refereed journal articles, extension bulletins, synthesis papers)

5. Presentations and outreach activities (local, regional, and national venues; e.g., workshops, field tours)

**Outcomes or Projected Impacts**

1. Increased capacity and availability of social-ecological science and integrated research efforts about ecosystem health in sagebrush systems

2. A framework for defining indicators, operationalization of conservation measures, and identification of relationships within and integrated conceptual model

3. Improve the transfer and use of science from land grant universities to agencies and policy makers, as well as information flow to local communities and stakeholders

4. Improve effectiveness of local-to-national land management / policies

**Milestones**

1. Internal symposium to present on our existing data and finalize conceptual model. June 2024.
2. Proposals to funding agencies based on conceptual model. Strategic presentations / networking (on going-- NSF DISES to be submitted Nov 2023).
3. Potential grant work if successful (NIFA funded work underway). Symposia (in year 2026 or 2027) and individual papers at Ecological Society of America, Society for Range Management, The Wildlife Society, International Symposium on Society and Resource Management, The North American Fish & Wildlife Conference, Association of Fish and Wildlife Agencies, or others.Strategic presentations / networking (1 annually starting in 2024).
4. Potential grant work if successful. Strategic presentations / networking. Publications (2024-2025).

**Projected Participation**

[View Appendix E: Participation](https://www.nimss.org/appendix_e/project?id=18509)

**Outreach Plan**

We will use existing Extension programs such as local working groups or focus groups to reach sagebrush stakeholders more efficiently. These existing Extension networks will include landowners, state and federal agency personnel and county extension faculty. This will allow for quick and easy dissemination of findings from our group and it will also provide a readily available source for input on social economic impacts. Results will be disseminated to research and extension constituents through peer-reviewed or refereed publications; presentations at state, regional and national professional meetings, webinars, and social media.  Examples of the professional meetings include state and national conferences in natural resource management (e.g., Society for Range Management, The Wildlife Society) and natural resource policy (e.g., North American Wildlife and Natural Resource Conference).

Results from collaborative research will be vetted by various stakeholders at local and regional workshops.

**Organization/Governance**

The workgroup will be comprised of members with a diverse scientific backgrounds from land-grant universities located throughout the sagebrush biome. All members will be active participants. The organizational structure consists of a chair, vice-chair, and secretary who will be nominated and elected annually by the members of the workgroup. The chair and vice-chair will appoint subcommittees to complete specific tasks. Conference calls will be held as needed and at least one annual meeting will occur to discuss progress.

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Table 1. Summary of 39 study sites to evaluate socio-ecological systems in the sagebrush biome. Years of sage-grouse research conducted, nearest community, and percentage of each resistance & resilience (RR) category within each community region Low (L-RR), Medium (M-RR) and High (H-RR) Resistance and Resilence.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Study ID | Years | Community | L-RR | M-RR | H-RR |
| Atlantic Rim, WY | 2007-11, 2020-21 | Baggs, Dixon, Rawlins, Savery WY | 0 | 100 | 0 |
| Baker, OR | 2019-2021 | Baker City, OR | 68 | 18 | 11 |
| Bighorn Basin, MT | 2011–2015 | Bridger, MT | 6 | 81 | 13 |
| Hyattvile, WY | 2011–2015 | Hyattville, WY | 100 | 0 | 0 |
| Shell, WY | 2011–2015 | Shell, WY | 96 | 0 | 4 |
| Box Elder, UT | 2005-2020 | Grouse Creek and Park Valley, UT | 45 | 35 | 20 |
| Bridger, MT | 2018–2020 | Bridger, MT | 56 | 44 | 0 |
| Bully Creek, OR | 2019-2021 | Harper, OR and Vale, OR | 93 | 0 | 7 |
| Chapman Bench, WY | ??-2021 | Cody, WY and Powell, WY | 81 | 19 | 0 |
| Clear Lake, CA | 2019-2021 | Klamath Falls, OR | 62 | 12 | 0 |
| Collett Creek, WY | 2008-2011 | Kemmerer, WY | 0 | 60 | 40 |
| Cow Lakes, OR | 2019-2021 | Jordan Valley, OR | 57 | 6 | 36 |
| Crawford, WY | 2008-2011 | Kemmerer, WY and Randolf, UT | 0 | 78 | 12 |
| Crocker's Point, WY | 2008-2011 | Kemmerer, WY | 0 | 73 | 26 |
| Crowley, OR | 2019-2020 | Juntura, OR and Crane, OR | 46 | 0 | 54 |
| Dry Creek, WY | 2008-2011 | Mountain View, WY | 0 | 69 | 31 |
| Glasgow, MT | 2018-2020 | Glasgow, MT | 0 | 100 | 0 |
| Hampton, WY | 2008-2011 | Kemmerer, WY and Lyman, WY | 0 | 100 | 0 |
| Hart Mountain, OR | 1988-08, 2013-16 | Adel, OR (Plush too) | 0 | 70 | 29 |
| Jeffrey City, WY | 2011–2019 | Jeffrey City, WY | 0 | 94 | 5 |
| Little Muddy, WY | 2008-2011 | Kemmerer, WY and Lyman, WY | 0 | 100 | 0 |
| Massacre PMU, NV | 2013-2019 | Cedarville,CA | 84 | 16 | 0 |
| Meadow Springs, WY | 2008-2011 | Lyman, and Mountain View, WY | 0 | 100 | 0 |
| Mud Lakes, WY | 2008-2011 | Kemmerer, WY | 0 | 33 | 67 |
| Lance Field, WY | 2019–2021 | Pinedale, WY | 0 | 89 | 8 |
| Parker Mountain, UT | 1998-2009 | Loa, UT | 0 | 49 | 51 |
| Polecat Bench, WY | 2016-2021 | Powell, WY | 99 | 0 | 0 |
| Red Desert, WY | 2018–2020 | Baggs, WY | 0 | 100 | 0 |
| Roundup, MT | 2011-2016 | Roundup, MT | 0 | 97 | 0 |
| Seven Mile Hill , WY | 2009–2014 | Hanna, WY | 0 | 100 | 0 |
| Sheldon NWR, NV | 2013-2019 | Denio, NV | 7 | 93 | 0 |
| Soldier Creek, OR | 2019-2021 | Jordan Valley, OR | 7 | 77 | 14 |
| Stewart Creek, WY | 2008-11, 2017-20 | Bairoil, WY | 0 | 100 | 0 |
| Trout Creeks, OR | 2012-2021 | Fields, OR - McDermitt, NV | 11 | 65 | 25 |
| Vya PMU, NV | 2013-2016 | Cedarville,CA | 60 | 35 | 2 |
| Warners, OR | 2010-2021 | Lakeview, OR (Adel, OR) | 47 | 27 | 4 |
| Vya, NV | 2018-2021 | Cedarville,CA | 55 | 27 | 17 |
| YU Bench, WY | ??-2021 | Meeteetse, WY and Cody, WY | 84 | 16 | 0 |