Management innovations for resilient public rangelands: Adoption constraints and considerations for interagency diffusion

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ABSTRACT

Maintaining healthy rangeland ecosystems requires adaptive co-management at the landscape scale. Because the majority of western rangelands are publicly owned, it is critical that federal land management agencies work together in generating and sharing information. Promotion and communication of rangeland management innovations among agencies is one means of sharing information. Two rangeland management innovations, the Weather-Centric Restoration Tool, and Interpreting Indicators of Rangeland Health, were studied in order to better understand agency adoption decisions and barriers to diffusion of the innovations across agencies. Using a mixed qualitative methodology, we interviewed land managers across the floristic Great Basin and in Southeastern Utah responsible for making or advising rangeland management decisions. Using thematic analysis of participant interviews and land managers' social networks in Southeastern Utah, we were able to identify variables at the innovation, individual, organization, and external system levels that affect innovation adoption and diffusion across agencies. In line with previous research, desirable innovation traits were related to five constructs: complexity, relative advantage, compatibility, trialability, and observability. Inter-agency siloing was found to be the biggest factor affecting individual and organization-level adoption decisions. External socio-political factors were also found to create organization-level barriers including funding streams, legal considerations, and differing institutional cultures between agencies. While management innovations are hindered by these hurdles, innovations also serve as promoters of institutional change that reshape these constraints. However, overcoming barriers to innovation requires the presence of innovation champions who can influence both incremental bottom-up and top-down processes.

Keywords: Innovation adoption, adaptive co-management, institutional change, social capital, social-ecological systems

Introduction

Resilience-based management of rangelands is required to ensure sustained production of range-based ecosystem services in an era of rapid social-ecological system (SES) change (Bestelmeyer and Briske, 2012). Because of changing climatic conditions, rangelands are facing stressors that will require adaptation and transformation of SESs. Resilience-based management strategies are proposed as a means to maintain rangelands' use for human well-being through the adaptation and transformation process. However, our limited knowledge of how the ecological system will respond to different management approaches and, reciprocally, how the social system will react to ecosystem changes, poses a challenge to resilience-based management.

Adaptive management was proposed as a response to this challenge as early as the 1970s. Assuming incomplete knowledge, adaptive management uses iterative experimental management, reassessment, and refinement as a means to produce best practices (Holling, 1978). Resilience scholars now often refer to adaptive co-management, focusing more on the social aspects of the management process (Bodin et al., 2011). In adaptive co-management it is key that land managers collaboratively develop strategies that improve the SESs capacity to adapt or transform in response to change (Brunson, 2012; Walker et al., 2006). One way to promote adaptive co-management is to build social networks that improve information flow and subsequent innovation so that ecological thresholds are detected before they're crossed (Brunson, 2012). However, there are barriers to building and transferring information and management tools across networks of land managers. In fact, fragmentation of information and knowledge is one of five factors enumerated in studies of agency characteristics limiting adaptive co-management (Ascher, 2001; Pinkerton, 2007; Yaffee, 1997). In this research we explored how such characteristics, combined with attributions of the innovations themselves, affect inter-agency diffusion of innovations that can improve adaptive capacity.

Rangeland Management Innovations

The innovations examined here were the Weather-Centric Restoration Tool (WCRT) (Moffet et al., 2019) and the Interpreting Indicators of Rangeland Health (IIRH) protocol (Pellant et al., 2005). Both the WCRT and IIRH are directed at assessing current or past rangeland conditions to inform future management and could serve as common tools between agencies that would facilitate communication about landscape condition. Rangeland ecosystems can shift into multiple vegetation states depending on natural events, such as fire and weather, and human activities, such as management practices (Briske et al., 2008, 2005). Invasive species and increasing wildfire events are stressors that can rapidly shift landscapes into another ecosystem state (Balch et al., 2013; Chambers et al., 2014; Dennison et al., 2014). Invasive plant species alter ecosystem function by reducing biodiversity and habitat for native plants and wildlife (D'Antonio and Vitousek, 1992). Due to climate change, wildfires in the western United States have increased in frequency and intensity (Balch et al., 2013; Dennison et al., 2014). Changing fire regimes and invasive plants are serious challenges to managers trying to maintain native plant and animal diversity on rangelands. For example, cheatgrass is an invasive annual species that is part of a positive feedback loop with fire (Germino et al., 2016). Landscapes dominated by cheatgrass burn easily, cheatgrass takes advantage of increased resource availability after the fire to seed, and the cycle repeats (Germino et al., 2016). Cheatgrass' effects on fire cycles postfire restoration are made more complex when factoring in unpredictable weather conditions. Climatic variables are often a significant limiting factor in management opportunities in rangeland ecosystems (Hardegree and Van Vactor, 2004).

Managers are tasked with gauging the potential of a landscape unit to transition to a more desirable state but they need tools in hand to assess that potential (Hardegree et al., 2019). The Weather-centric Restoration Tool is an attempt to fill this gap and provide a resource tool that facilitates the incorporation of short-term climate data into management decisions. Similarly, the IIRH protocol is a tool for manager's to quickly assess landscape condition and determine whether further action is required. Both innovations are intended to add to the managerial toolbox and promote protection of rangelands and were selected for study because of their generalizability to various agencies managing rangelands and their subsequent compatibility to act as conduits of information within and between agencies. The WCRT and IIRH showcase different stages of the adoption/diffusion process for rangeland management innovations. By studying multiple innovations, all stages of the innovation design and adoption/diffusion process were able to be studied in a relatively short time frame. In the case of the WCRT, the researchers documented the tool's progression from design to early implementation and examined factors impacting adoption of the WCRT. Examining the IIRH allowed the researchers to see another stage of innovation adoption, full implementation and continuing adaptation, and research factors impacting diffusion of the IIRH within and across agencies. This allowed the researchers to assess (1) attributes of the WCRT impacting managers' adoption decisions, (2) inter-agency diffusion potential for the IIRH, (3) organizational constructs impacting adoption and diffusion of both innovations, and (4) how the external socio-political system could impact adoption of the WCRT. Studying two rangeland management innovations at varying stages of the adoption/diffusion process gave the researchers a broader inference span to apply to similar innovations.

Weather-Centric Restoration Tool (WCRT) Description

The Weather-Centric Restoration Tool (WCRT) is a web-based application designed to offer managers help in developing best management practices for restoration under the highly variable weather conditions in the western US. The website contains a number of weather-centric restoration planning and analysis tools. It was developed in cooperation with the Great Basin Fire Science Exchange, and can be accessed at http://greatbasinweatherapplications.org. The WCRT currently provides a retrospective assessment of seedbed microclimatology that helps managers understand how past weather patterns at a localized scale might have affected past seeding success. It can also be used to inform adaptive management and long-term restoration strategies (Hardegree et al., 2019, 2018). This innovation was selected because we could track the WCRT’s evolution from design, which began in 2014, to implementation in 2018.

Interpreting Indicators of Rangeland Health (IIRH) Description

To understand how an already established rangeland management innovation had diffused throughout a network of managers in one geographic region, adoption of the Interpreting Indicators of Rangeland Health (IIRH) Technical Reference Version 4 was also examined (Pellant et al., 2005). The IIRH reference was jointly created by the Bureau of Land Management (BLM), United States Geological Survey (USGS), Natural Resources Conservation Service (NRCS), and Agricultural Research Service (USDA-ARS). The IIRH protocol provides a standardized qualitative method for assessing a moment-in-time status of rangelands.

Evaluators use seventeen indicators to assess three ecosystem attributes (soil and site stability, hydrologic function, and biotic integrity). The protocol uses observable indicators to interpret and assess rangeland health, which could provide early warning signs of problems. The IIRH has undergone multiple iterations since its inception in 1997. At the time of data collection IIRH Version 4, released in 2015, was the most recent iteration. IIRH Version 5 was released August 2020 and is available as a downloadable PDF at https://www.landscapetoolbox.org/manuals/iirhv5/ (Pellant et al., 2020).

Rangeland Innovation Adoption Constructs

Innovation-adoption constructs provide a framework for systematically researching the above objectives. An innovation can be defined as anything material or conceptual that constitutes a new idea, or an idea perceived to be new by the social system. Diffusion is then a form of communication about that new 'idea' among members of the social system (Rogers, 2010). While it is easy to think of diffusion as a one-way process, that is rarely the case. Characteristics of both the adopters and the innovation are changing throughout the process as more information is made available. As such, it is difficult to pinpoint how any innovation is adopted and diffuses through a social system, but the problem can be clarified by understanding the characteristics of the (1) innovation, (2) individual potential adopters, and (3) organizational and (4) external system in which adoption decisions are being made. Figure 1 displays these four levels of adoption constructs, and examples within each, as they will be outlined below.

[insert Figure 1 here]

1. Innovation traits

Key to understanding the adoption of innovations are five perceived innovation attributes: relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2010) (Figure 2).

[insert Figure 2 here]

The bulk of innovation adoption studies have focused on these five attributes and have been applied to campaigns as varying as marketing birth control to promoting farmers' use of hybrid seed corn (Rogers and Kincaid, 1981). Most innovation studies related to land use have focused on farming innovations (Pannell, 2003) and few on rangeland management. Within the context of rangeland management, studies have focused on adopter attributes (Bruno et al., 2020; Didier and Brunson, 2004; Lubell et al., 2013); however, studies of rangeland management innovation attributes themselves are limited.

2. Individual-level adoption constructs

When there is a flow of resources, such as information, across a social structure, some actors are better situated than others to receive this resource. An individual's position in their social structure can impact their social capital – i.e., features such as trust, norms, and networks that facilitate coordinated action among individuals and organizations (Putnam, 2001) – and thus their access to information and power to diffuse knowledge. There are three main types of social capital: bonding, bridging, and linking (Burt, 2000; Coleman, 1990). *Bonding* social capital arises from the connectivity of members of a cohesive social group and arises due to homophily, the tendency to associate with similar others (McPherson et al., 2001). Bonding social capital fosters the generation of trust, creation of common norms, and facilitation of communication (Borgatti et al., 1998; Burt, 2000; Coleman, 1990). *Bridging* social capital, arises from connectivity across social groups and develops in response to information and innovation seeking (Lin, 2017). Bridging social capital promotes interactions across heterogeneous groups that create opportunities for the generation of new knowledge (Reagans and McEvily, 2003). *Linking* social capital facilitates relationships between entities who are interacting across an institutionalized power gradient (Woolcock, 2001). Finding a balance between bridging, bonding, and linking social capital is important for the governance of natural resources. Too much bonding social capital can lead to homogeneity and stagnation; too much bridging social capital can dissolve trust and efficient communication; and too much linking social capital can lead to nepotism and corruption (Bodin and Crona, 2009; Onyx et al., 2007). In theory, ideal collaboration occurs when there is a balance of bonding, bridging, and linking social capital within the network (Bodin and Crona, 2009; Woolcock, 2001).

3. *Organizational-level adoption constructs*

When innovation-adoption decisions are made within organizations, individuals have additional factors to consider. An organization is a "stable system of individuals who work together to achieve common goals through a hierarchy of ranks and a division of labor" (Rogers, 2010). In the context of this paper, organizations are primarily land management agencies. Within these agencies many factors can impact adoption, including institutional culture, legal obligations, funding streams, incentive systems, and systems of academic training (Briske, 2012; Koontz and Bodine, 2008). For example, historically, funding timelines for Emergency Stabilization and Rehabilitation (ESR) have not been compatible with the impact of weather variability and long-term restoration goals (Hardegree et al., 2019, 2018). Iterative-contingency restoration, a potential organizational-level change promoting a shift to more proactive management, would be facilitated by innovations which detect transition to another ecological state (Hardegree et al., 2019). Another organizational-level adoption construct occurs when agencies, or programs within agencies, become siloed and communication between systems is limited or absent. Siloing, the isolation of one program or agency from another, impedes information flow and innovation diffusion, and hinders the potential for adaptive co-management across agency boundaries (Cortner and Moote, 1999). The more agency siloing is present, the less potential there is for disparate agencies to co-develop and utilize rangeland management innovations promoting proactive management. The centralized, hierarchical structure of most land management agencies is also a recognized impediment to resilience-based management (Bestelmeyer and Briske, 2012). Hierarchical structuring restricts lateral communication within agencies. This barrier to knowledge sharing across disciplines can hinder full adoption of rangeland management innovations and, in turn, landscape-scale adaptive management.

4. *External system-level adoption constructs*

At an even larger scale, there is an external system - the larger socio-political system – driving organizational traits (Wisdom et al., 2014). Social and political pressures locally, regionally, and nationally impact agencies structurally and operationally. For example, in Wright's (2010) study of impediments to the use of 'best science' in fire management, federal fire and fuels managers cited the influence of 1) high-level political priorities, 2) public interest groups, 3) the general public, 4) and the role of human values in management decisions among the top five barriers to innovation. Innovation adoption decisions do not occur in a political vacuum, rather they are tempered by the larger socio-political system of the time.

By exploring these four levels of adoption constructs through the lens of two rangeland management innovations, the Interpreting Indicators of Rangeland Health protocol and Weather-centric Restoration Tool, we aim to understand constraints and opportunities for information sharing within and between rangeland managers.

Methods

Study Areas

The floristic Great Basin and the portion of the Colorado Plateau located in southeastern Utah served as our study areas. The WCRT is designed to assist managers throughout the Great Basin; thus, interviews were conducted with individuals from across this region. The IIRH protocol is specific to rangelands but not limited to the study area we selected. We chose to study diffusion of the IIRH protocol in southeastern Utah for the practical reason of limiting the potential sample size so we could reach response saturation.

Survey & Interview Protocol

To understand how land managers make innovation adoption decisions, we chose a mixed qualitative methodology composed of key informant interviews, online and print surveys, and one focus group. A snowball sampling methodology (Noy, 2008) was used to identify additional participants after conducting initial interviews. The interview protocols were reviewed and approved by the Institutional Review Board at Utah State University as protocols #4683 and #8630. For the WCRT data gathering, eligible participants constituted individuals responsible for making or advising rangeland management decisions in the floristic Great Basin. In relation to the WCRT, from October 2014 to March 2018, twenty-five individuals responsible for making or advising rangeland management decisions within the Great Basin participated in semi-structured interviews, print/email surveys, or a focus group. WCRT interviewees and focus group attendees were private ecological consultants as well as employees of federal and state agencies and military entities (Table 1). Survey data for the WCRT were obtained anonymously so affiliation/agency is unknown. These surveys were administered following three training sessions introducing the tool to agency professionals; thus, the authors have high confidence the participants were providing an informed opinion. These semi-structured interviews, surveys, and focus group dialogic interactions were focused on gathering information on potential innovation traits and managers' barriers to adoption of the WCRT: "1) In what ways do you currently use online resources to inform your decisions on rangeland restoration following wildfire or non-native plant invasion? 2) How usable and reliable are the online resources you've seen for informing rangeland restoration decisions? 3) If new weather-related online management tools were available to you, are there factors that might hinder your ability to use them?" (For the full set of WCRT interview questions, please refer to Appendix A.). Data was gathered until no new themes were observed from additional data, thus reaching saturation.

For the IIRH data gathering, eligible participants constituted individuals responsible for making or advising rangeland management decisions in Southeastern Utah. For the more targeted IIRH study, we conducted eleven semi-structured interviews from June-August 2017. With the exception of two email interviews, all subjects were interviewed in-person. IIRH interviewees were employees of the Bureau of Land Management (BLM), U.S. Forest Service (USFS), and National Park Service (NPS) (Table 1). Because the IIRH has been implemented over a decade, these semi-structured interviews did not focus on desirable innovation traits, but rather on managers' barriers to inter-agency use of the IIRH: "1) What would you say is the leading factor that led to adoption of the IIRH? 2) Do you perceive your agency adopts innovations from other agencies? Explain." For the IIRH data gathering, we also asked managers about whom they seek for rangeland management advice for the purpose of creating a social network to elucidate potential barriers to communication. (For the full set of IIRH interview questions, please refer to Appendix B.) Saturation was also achieved for this portion of the study because there were few agency employees within the study area that fit our eligibility requirements and a significant portion of that study population was contacted. This high degree of saturation was intentional and necessary for social network formation.

[insert Table 1]

The focus group and interviews were conducted using an interview protocol and script but were semi-structured so that data not previously thought of could be explored. The interviews and focus group were also audio-recorded with consent of the participants and transcribed for coding.

Data Analysis

Thematic analysis was used to assess participants' desired innovation properties for the WCRT, adoption status and social network data for the IIRH, and professed barriers to adoption of the WCRT and inter-agency diffusion of the IIRH. Thematic analysis is commonly used in qualitative research as an inductive method to systemically discover and then examine themes in the data (Braun and Clarke, 2013). Using thematic analysis, we were able to better understand the broader context in which managers are making decisions, adding depth to the understanding of our research questions by providing answers to questions that cannot be reduced to binary terms. Once themes were identified in the data, they were ranked in order of their frequency of occurrence. A social network visualization was formed from the data gathered in relation to the IIRH interview participants. Because of the small sample size, social network analysis metrics were unnecessary to interpret the data.

Results

Across the WCRT and IIRH study participants, common themes emerged that further understanding of how innovation adoption and diffusion impacts knowledge exchange within and between land management entities. Results are presented in the context of the innovation adoption constructs framework, such as: innovation traits, individual social capital, and organization constraints as impacted by external socio-political power.

Innovation Traits

The Weather-centric Restoration Tool (WCRT) was in its design phase in 2014 when data gathering on land managers' perceptions of the potential tool began. As such, it was the ideal time to research what innovation traits land managers would find desirable in the WCRT so those ideas could be incorporated in the innovation's design. Analysis of innovation traits pertain more to adoption than diffusion; thus, we focus on the incipient WCRT for this construct. For any innovation to be successful it requires a set of traits that make its adoption worthwhile for the user. All five of Rogers' innovation attributes - complexity, relative advantage, observability, compatibility, and trialability - were identified as being important for land managers' adoption of the WCRT.

Complexity

The number one factor that participants mentioned as affecting their potential adoption was related to the complexity of the innovation. Participants desired the WCRT to be user-friendly with minimal complexity; as one anonymous survey respondent expressed, "I have tried using systems like PRISM and the steps and output are too convoluted. To have a program where I can input site-specific variables and receive weather data and advice in a user-friendly format would be much appreciated." The WCRT was created with this feedback in mind. To generate a full site report, all that is needed is the latitude, longitude, and soil texture of the site of interest.

Participants who expected to adopt the tool desired it to be a freely accessible online tool that was regularly maintained and provided ample technical support options. They desired something similar to NRCS's Web Soil Survey, citing its user interface and output that can be understood with minimal training. Participants agreed that if the tool were an expensive software program that required extensive training, their likelihood of adoption would be much lower. For example, one ecological consultant stated that "if it's the sort of thing that you could play on the web for nothing for thirty minutes, figure out how to do, and try it out, that will probably sell itself. If you have to buy it and be trained to use it, it's going to have really limited utility."

Relative advantage

The second factor most often cited by land managers related to the WCRT's relative advantage over current decision-making processes. Specifically, some participants were wary of the predictive ability of the WCRT. There is a large degree of year-to-year variability in rangeland weather which greatly affects the success of management practices (Hardegree et al., 2016, 2012a, 2012b). The WCRT is designed to help identify those years in which you have a greater chance of success in establishing a significant proportion of seed mix species. This would help managers limit their expenditures in bad years and channel their expenditures to good years, given they had the flexibility to decide which year to plant. However, the probability of success is not readily calculable. For several participants this uncertainty was a hindrance to its perceived advantage over status quo management decisions. As one BLM Idaho employee put it, “We’ve always tried to stress ‘what’s the reliability?’ Understandably, the reliability is better than tossing a coin. Otherwise, why do it? But I think most managers would say, ‘Well, if it’s 60% versus 40% and we’ve got funding and need to apply it or lose it, that’s not going to be enough incentive to say we better hold off on the project.’” Other factors, such as distrust of models and inflexible funding streams, discussed below, also contribute to perceptions by some that the WCRT would lack a relative advantage.

We investigated the IIRH protocol after agency’s adoption of the tool, and thus did not specifically collect data on desirable traits. Regardless, several interviewees brought up their perception that the IIRH lacked a relative advantage over other, more quantitative, options. The qualitative nature of IIRH was cited as a deterrent to its adoption by three of the eleven interviewees. These individuals perceived the qualitative indicators to be too subjective and simplistic to stand up in court if contested. Interviewees who explicitly claimed that quantitative data would need to supplement the IIRH perceived no relative advantage to using IIRH. Rather, multiple individuals mentioned the BLM’s Assessment, Inventory, and Monitoring (AIM) strategy as a tool that is in the process of replacing IIRH. Indeed, one of the key changes to Version 5 of the IIRH, released in 2020, is to add emphasis on the use of quantitative measures to support evaluations and the document specifically mentions keeping standardized core methods consistent with BLM’s AIM strategy (Pellant et al., 2020).

Observability

Observability of the WCRT at work was the third most cited factor. Managers desired to test the WCRT using historical data, whereby past conditions are estimated and compared to actual data from that time period. One BLM Idaho employee suggested "Going out to some sites and backcasting the model to show 'Here's what it looks like today. Based on the weather conditions that we could have predicted and the management outcomes, would you change actions you took in the past?' I think that would be a pretty valuable way to demonstrate the utility." This is also aligned with a previously mentioned innovation attribute: relative advantage. Before adoption, managers want to be able to observe the innovations' advantage over 'business as usual' management. Generally, managers' thoughts echoed that of this BLM Nevada employee: "I'd want [the WCRT] to show how predictions come through to prove that there's value in it, that actual predictions did come true."

Compatibility

The fourth factor most often cited by land managers relates to how compatible the WCRT is with land managers' needs, particularly in matching the scale of the output with that of their projects. Managers desired a tool where they could input the ZIP code or latitude and longitude coordinates and receive immediate output at a scale similar to that of their project. Adding seasonal weather forecasting, wind erosion potential, and detailed seedbed microclimate data to current WCRT output products could improve the amount of available science at their disposal but could also complicate the output beyond usability. Providing data at a very fine scale was perceived by some as potentially convoluting the decision-making process. To make comparisons, some participants related the WCRT to Ecological Site Descriptions. A military ecological specialist voiced that “if you are new to [Ecological Site Descriptions] they are confusing unless you’re helped. If you start adding additional information onto that you could get it so convoluted it’s not usable.” On the other end of the spectrum, several land managers mentioned how Ecological Site Descriptions are often too coarse-grained and lacking detail; as one ecological consultant explained: “On a lot of sites we work on there is a fine scale of variability that is absolutely critical from our restoration perspective that isn’t captured and will just be mapped as a mix of several soil types.” Generally, respondents desired a balance between fine scale results and increased complexity.

Also associated with the perceived compatibility of the WCRT with current management norms was distrust of using climate model output in making management decisions. As previously mentioned, any forecasts produced with the WCRT would be probabilistic in nature. Several participants either expressed their disapproval of models or said they had co-workers that distrusted models. Models were perceived as “unproved predictions” and highly error prone. As one BLM Nevada employee put it, “I just don’t know how effective it would be. You can’t predict the weather a month from now, let alone next spring.” For some, failures in the past using model output made them dubious of future model applications. For example, a BLM Idaho employee observed that “There’s been enough models that haven’t worked as well as expected so I think that would be one hurdle to overcome.” For others, disciplinary differences influenced their impression of the WCRT’s compatibility with their needs. These participants did not distrust modelling as much as they perceived it to be a separate discipline from their own; Thus, they did not see model output informing their own management decisions.

Trialability

The fifth tool trait relates to the trialability of the innovation. Participants reported that if the WCRT was made mandatory at their agency it would have an overall negative effect, because some adaptability in decision-making and management would be taken away. A military ecological specialist felt that "if now all of a sudden this is a required tool to use, it takes my flexibility away." Managers want an option to try the tool but not an edict that it's required. This challenge pertains to a variety of issues stemming from the fine balancing act between centralized governance structures and retention of flexibility at the local level.

These findings suggest that land managers prefer rangeland management decision-making tools that are user-friendly, complex enough to be scale-appropriate but not so much to convolute the data, compatible with their needs, providing observable sufficient relative advantage over status-quo management regimes, and allowing flexibility in decision-making.

Individual-level adoption constructs

The social capital available to individuals within the organization is particularly relevant to the diffusion potential of rangeland management innovations. To understand how diffusion of the IIRH protocol and subsequent knowledge exchange could be related to the social capital of land managers, a network of agency individuals was created based on whom they solicit ideas or advice from in making land management decisions (Fig. 3). Fourteen individuals, in addition to the eleven interviewed land managers, were identified and are also represented in the social network. Figure 3 shows that the individuals within this study in the BLM, USFS, and NPS sought rangeland management advice and ideas from within their agency, but not from individuals at the other two federal agencies.

[Insert Figure 3 here]

Furthermore, the thematic analysis revealed the network to be hierarchical in nature; in other words, many referred to their bosses and supervisors as their only contact in making decisions. These findings suggest that, within this context, land managers may have bonding and linking but not bridging social capital. Even within the BLM, the rangeland specialists and the fuels specialists reported using different methods to assess rangeland condition. The range specialists were required to adopt the IIRH protocol while the fuels specialists used a separate assessment protocol, the Utah Fuels Monitoring Strategy, leading to fragmentation even within the BLM. As Figure 3 shows, individuals' social capital is held within discrete agencies (bonding and linking), with no advice connections between agencies (bridging). Indeed, each agency adopted the IIRH independently of each other.

Organization-level & External system-level adoption constructs

While interviewing land managers about their potential or actual use of the WCRT or IIRH, major institutional barriers to adoption and diffusion came to light. Agency siloing, funding streams, and political pressures were most frequently cited as constraints for innovation adoption and subsequent inter-agency information diffusion.

Agency Siloing

Agency siloing, driven by institutional cultural, legal considerations, incentive structures, and systems of academic training, was the number one mentioned barrier to inter-agency diffusion of innovations. Hierarchical structuring in agencies keeps communication within the agency and even sometimes restricts communication between disciplines within an agency (see BLM in Fig. 3). For example, one Utah BLM employee stated, “I think if there was a [discipline] related question that I didn’t know, I would ask my supervisor. If he didn’t have the answer, I would ask the state [discipline] lead.” Whether the symptom, or the cause, agency siloing was also related to fear of legal action for information sharing outside agency borders. Fear of legal repercussions were mentioned as a barrier to adopting any innovation originating elsewhere. As one Utah BLM employee put it, “The BLM must follow its own protocols and guidance for sound management decisions that are defensible in court.” Especially because the IIRH protocol is often used to assess whether grazing permits should be renewed, agency participants mentioned how carefully they implement the IIRH protocol according to agency guidelines. Three of the eleven participants cited agency policy as stifling their ability to adapt the IIRH to local conditions. Generally, threats of litigation for operating outside of agency policy led managers to stay within their own agency when communicating about a management tool or approach.

Differences in training, or at least perceptions of differences, was also a factor promoting agency siloing in this context. For example, in speaking of inter-agency communication between the NPS and BLM, a Utah NPS employee saw major differences in management style: “We don’t speak the same language. We don’t speak the same management style. They have a completely different opinion of everything. After [x] years, I still haven’t got them [BLM] to understand NPS policy. We’ve been trying to educate them to a certain extent but they tend to forget after awhile. They look at things in terms of multiple use and they never met a cow they didn’t like.” Application of the IIRH protocol particularly suffers from agency siloing. Many, if not most, land managers receive training on how to assess different condition departures from a reference state; however, over time, managers' perception of departure begins to align with the mission of their individual agency. For instance, individuals from the BLM and the NPS viewed each other as having differing views on indicators that should be objective. One Utah NPS employee stated that "where [inter-agency collaboration using the IIRH] tends to break down is in how we interpret the data that we collect or how we evaluate what the effect will be on the landscape of a certain action." This finding may be a result of individuals staying within their own agency for advice. As shown in Figure 3, the advice network of individuals interviewed about the IIRH protocol is highly fragmented between agencies, and even within one agency. In response to a question concerning this lack of inter-agency communication, a Utah NPS employee summed it up saying, "It boils down to different cultures and a lack of staff and money."

Funding Streams

Rigid funding streams can hinder the adoption of decision-making innovations, because management decisions are already locked in place. In studying the potential adoptability of the WCRT, funding streams, especially for Emergency Stabilization and Rehabilitation (ESR), were viewed as restrictive to adoption of innovations facilitating adaptive management. A Nevada BLM employee stated that "as far as Emergency Stabilization and Rehab, you have a short window and you need to get in there and plan on implementing right away." Furthermore, participants interviewed about the WCRT mentioned that while the WCRT could promote proactive management, set timelines and funding for restoration work would limit managers' flexibility in using the tool. A military ecological specialist explicitly mentioned how funding streams restrict their decisions: "The [WCRT] would probably be better at deciding whether or not I'm going to do a prescribed burn or control of invasive species, something I can control as opposed to something restrictive. If we've had a burn, I've got the money for that year. I have to dump the seed down regardless of what the climate model says." One interviewee with the Nevada USFS expressed concerns about using the WCRT for mining reclamation: "We have a lot of mining reclamation and we have to tell them almost a couple years in advance what they are going to do." Whether management plans have to be decided years in advance, in the case of mining reclamation, or that season, in the case of ESR, interviewees felt constrained in what management actions they could implement using the WCRT. As previously mentioned, the WCRT requires the user to have some flexibility in deciding what year to seed. As long as agency policy limits ESR activities to 1-2 years after disturbance, use of the WCRT, or tools like it, is limited to restoration projects outside the context of ESR. While funding streams could impact inter-agency diffusion of established tools like the IIRH, funding streams impact on adoption of new innovations was more apparent and readily expressed in interviews.

Political Pressures

An external system-level adoption constraint that impacted managers' adoption decisions concerning the WCRT was political pressure, particularly concerning grazing resumption after treatments. As one BLM Nevada employee puts it, "Grazing is always an issue, being able to allow rest for re-establishment for perennials as well as seeded species. There's political pressure not to close [allotments]." There was the perception that regardless of seasonal weather predictions and the resulting probability of success, seeding and 'working the land' are actions that make the agency look good. There is pressure to spray herbicide and/or seed immediately after a wildfire event so that the land is available for grazing as soon as possible. Thus, participants mentioned that seeding the first fall after a fire, regardless of whether climatic conditions will be favorable to seedling establishment, is preferable because it is perceived as an active, rather than passive, management approach. Looking forward, political pressure could be a hindrance to the WCRT if the output contradicts societal demands. An ecological consultant summed this up by saying, “Whether or not [the WCRT’s] going to be used probably relates more to economics, politics, and organizational factors.” External system-level constructs, such as political pressure, are almost certainly impacting diffusion processes because they influence all four of the other adoption constructs; however, the connection is indirect and harder to explicitly capture. As such, external pressures are an indirect barrier to established innovations like the IIRH but were not explicitly studied here.

Suggestions for enhanced adoption and diffusion of rangeland management innovations

Working within these constraints of siloing, funding, and politics, participants still mentioned opportunity for adoption of rangeland management innovations given the presence of an ‘innovation champion’ to promote its use and overcome any resistance or indifference to the innovation. Agencies require champions to seek out and promote innovations they find useful to furthering their agency’s mission. These champions do not have to be individuals at the top of the agency hierarchy. In fact, personnel at regional field offices will likely be more motivated to seek and promote methodological/technological innovations like the WCRT and IIRH. For example, one Utah BLM employee interviewed about the IIRH stated that “The BLM has its own protocols. But, personally, I want to see anything new that comes up and how it works. When I see stuff I send it up to the state office. They go through it and start this whole process, but it’s got to start on this level [field office]. If we hear something then we have to start kicking it up so they are aware of it, because most of the Salt Lake and Denver people don't get into the field so they don't see this kind of stuff."

Another participant saw hope that inflexible funding streams and one-size-fits-all agency policy could be changed if a few managers were able to implement an innovation and show success as a result: "We aren't going to go that direction about being a little more proactive about considering climatic conditions to help guide restoration until we have something that can help us. Our policies are going to lock us in, but maybe this [WCRT] could help inform changes in our policy as well if it's successful."

Discussion

Both the WCRT and IIRH facilitate a change from reactive to proactive management. The IIRH protocol gives a moment-in-time assessment of rangeland health which can provide an early indication that lands should be monitored so that critical thresholds of ecological change are not reached. The WCRT gives land managers a chance to align future management with predicted climatic conditions. In addition, both innovations facilitate inter-agency communication. Thus, a deeper understanding of the innovation adoption processes underlying the WCRT and IIRH was required. This research, while context specific, provides an extensive view into the constraints and opportunities present for widespread rangeland management innovation adoption and diffusion.

To understand barriers to adoption and implementation of rangeland management innovations, we studied characteristics of the (1) innovation, (2) individual potential adopters (social capital), and (3) organizational and (4) external system in which adoption decisions are being made (Fig. 1). These adoption constructs are not independent of each other. In fact, these variables have a successive impact upon each other. The external socio-political environment affects the organization (agency), which in turn impacts individual land managers' adoption decisions. However, optimizing innovation traits is the first and the most readily controllable step in creating a successful rangeland management innovation.

In the innovation design phase, it is important that decision support tools facilitate easy application of the information they provide. Innovations that are compatible with management needs, are user-friendly, have an observable relative advantage over current processes, and can be adopted without loss of flexibility are more likely to be successful. Additionally, as we further advance into an era of increasing technological advancement, freely available online tools will likely have an advantage over the majority of expensive licensed software and programs.

At the individual and organizational-level, it became apparent that vertical communication to superiors within agency (linking social capital) was common, horizontal communication within agency (bonding social capital) was sometimes lacking, and communication outside of the interviewee's agency (bridging social capital) was far less common. Bonding social capital may be increasing though. Our results from the IIRH interviews showed a disconnect within the BLM concerning use of monitoring/assessment protocol, namely the parallel use of the IIRH protocol and Utah Fuels Monitoring Strategy. It should be noted that the BLM created the Utah Fuels Monitoring Strategy partially because they found little to no monitoring/assessment cooperation between specialists in fuels and resources. The Utah Fuels Monitoring Strategy is largely built from BLM AIM methods, previously mentioned as supporting information for IIRH Version 5, released in 2020. Over time there is potential for complementarity within these innovations, at least within the BLM. However, at the time of data collection Version 4 was the most recent iteration of the IIRH and participants were not yet viewing the Utah Fuels Monitoring Strategy as a complementary approach. Regardless, potential complementarity of once disparate innovations within the BLM does not resolve fragmentation between agencies. Insufficient bridging social capital between agencies can lead to stagnant information pools not conducive to innovation, impeding evolution of existing innovations and greatly slowing diffusion of nascent innovations. Without bridging social capital, divergent evolution of innovations within agencies can occur. As differences in implementation accrue, the potential of an innovation to serve as a means of inter-agency information diffusion is hindered.

One possible explanation for this lack of bridging social capital, and subsequent inter-agency innovation diffusion potential, is strict agency policies that require employees to follow agency protocols precisely. Legal restrictions that promote existing program policies to the exclusion of other approaches suppresses innovation diffusion. Hierarchical decision-making structures can also limit innovation because practices that are a departure from the norm must be institutionalized at a state or nation-wide level. When this lack of bridging social capital is combined with hierarchical decision-making structures, innovation diffusion is often impeded. Additionally, rigid funding timelines and external barriers, such as political pressure to open grazing allotments, hinder the adoptability of innovations promoting adaptive management (flexibility) and reduce their intended ecosystem effects. This reduction in flexibility in turn hinders managers' capacity for inter-agency communication and adaptive co-management. However, optimal innovation traits in combination with land managers that act as innovation champions can reverse the direction of these successive impacts such that the organizations (agencies) and external environment are affected by the innovation.

Implications

Applying the innovation adoption constructs framework to the Weather-Centric Restoration Tool (WCRT) and the Interpreting Indicators of Rangeland Health (IIRH) protocol has revealed barriers to agency adoption and diffusion that could stymie information exchange and proactive management. While there is no panacea to these barriers, there are ways forward. Agencies need to better utilize the information-sharing potential of tools like the WCRT and IIRH. Bestelmeyer & Briske (2012) identified shared knowledge systems as a key element of resilience-based rangeland management because generating and then sharing knowledge that guides adaptation is crucial to resilience. The IIRH protocol promotes standardized condition assessment measures, and thus multi-agency understanding of landscape condition. However, in practice, the IIRH was used separately by agencies. In fact, a couple of interviewees expressed concern with how others in different agencies were using the IIRH indicators. This finding suggests that promoting an innovation does not ensure that results are being shared in a productive way. Those developing inter-agency monitoring tools should not just promote diffusion of the innovation but also forums for those users to share knowledge gains.

Further, to facilitate innovation adoption, support should be provided to individuals within land management agencies who decide to be innovation champions. Large-scale institutional changes to such issues as agency siloing, funding streams, and inflexible policies all appear to be intractable problems from the perspective of the individual. Certainly, administration shifts, as influenced by the current socio-political system, can have rapid and drastic top-down impacts on institutional-scale issues like those mentioned above. However, there is a role for the individual to change agency culture through emergent bottom-up processes. For an innovation or collaboration to be successful, it requires at least one champion, and that's something that cannot be dictated via top-down processes. Ultimately, collaborations are between individuals, not agencies. Developing and maintaining trust with others across agencies is an obtainable step the individual can take to incrementally change their agencies' culture.

Much rangeland management research is focused on supporting land managers' decision making and improving adaptive management. Therefore, it is very important to research how rangeland managers decide to use new information and tools. This research identified desirable innovation design traits, barriers to adoption or diffusion, and suggested potential approaches for lessening these constraints in the future. However, widespread adoption and diffusion of rangeland management innovations facilitating adaptive co-management is likely to require continued research into potential solutions that may only be foreseeable from the contexts of the future.

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References

Ascher, W., 2001. Coping with Complexity and Organizational Interests in Natural Resource Management. Ecosystems 4, 742–757. https://doi.org/10.1007/s10021-001-0043-y

Balch, J.K., Bradley, B.A., D'Antonio, C.M., Gómez-Dans, J., 2013. Introduced annual grass increases regional fire activity across the arid western USA (1980-2009). Glob. Chang. Biol. 19, 173–183. https://doi.org/10.1111/gcb.12046

Bestelmeyer, B., Briske, D., 2012. Grand Challenges for Resilience-Based Management of Rangelands. Rangel. Ecol. Manag. 65, 654–663. https://doi.org/10.2111/REM-D-12-00072.1

Bodin, Ö., Crona, B.I., 2009. The role of social networks in natural resource governance: What relational patterns make a difference? Glob. Environ. Chang. 19, 366–374. https://doi.org/10.1016/J.GLOENVCHA.2009.05.002

Bodin, Ö., Ramirez-Sanchez, H., Ernstson, H., Prell, C., 2011. A social relational approach to natural resource governance, in: Bodin, Ö., Prell, C. (Eds.), Social Networks and Natural Resource Management: Uncovering the Social Fabric of Environmental Governance. Cambridge Univ. Press, Cambridge, UK, pp. 3–28.

Borgatti, S., 2002. NetDraw: Graph visualization software.

Borgatti, S., Jones, C., Everett, M.G., 1998. Network measures of social capital. Connections 21, 27–36.

Braun, V., Clarke, V., 2013. Successful Qualitative Research a practical guide for beginners. Sage.

Briske, D.D., 2012. Translational Science Partnerships: Key to Environmental Stewardship. Bioscience 62, 449–450. https://doi.org/10.1525/bio.2012.62.5.2

Briske, D.D., Bestelmeyer, B.T., Stringham, T.K., Shaver, P.L., 2008. Recommendations for

Development of Resilience-Based State-and-Transition Models. Rangel. Ecol. Manag. 61, 359–367. https://doi.org/10.2111/07-051.1

Briske, D.D., Fuhlendorf, S.D., Smeins, F.E., 2005. State-and-Transition Models, Thresholds, and Rangeland Health: A Synthesis of Ecological Concepts and Perspectives. Rangel. Ecol. Manag. 58, 1–10. https://doi.org/10.2111/1551-5028(2005)58<1:SMTARH>2.0.CO;2

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. Rangel. Ecol. Manag. 73, 181–193. https://doi.org/10.1016/j.rama.2019.10.005

Brunson, M.W., 2012. The Elusive Promise of Social-Ecological Approaches to Rangeland Management. Rangel. Ecol. Manag. 65, 632–637. https://doi.org/10.2111/REM-D-11-00117.1

Burt, R.S., 2000. The Network Structure Of Social Capital. Res. Organ. Behav. 22, 345–423. https://doi.org/10.1016/S0191-3085(00)22009-1

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, 360–375. https://doi.org/10.1007/s10021-013-9725-5

Coleman, J.S., 1990. Foundations of social theory. Harvard University Press, Cambridge, MA.

Cortner, H.J., Moote, M.A., 1999. The Politics of Ecosystem Management. Island Press, Washington, D.C.

D'Antonio, C.M., Vitousek, P.M., 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annu. Rev. Ecol. Evol. Syst. 23, 63–87.

Dennison, P.E., Brewer, S.C., Arnold, J.D., Moritz, M.A., 2014. Large wildfire trends in the western United States, 1984-2011. Geophys. Res. Lett. 41, 2928–2933. https://doi.org/10.1002/2014GL059576

Didier, E.A., Brunson, M.W., 2004. Adoption of range management innovations by Utah ranchers. Source J. Range Manag. 57, 330–336. https://doi.org/10.2111/1551

Germino, M.J., Belnap, J., Stark, J.M., Allen, E.B., Rau, B.M., 2016. Ecosystem Impacts of Exotic Annual Invaders in the Genus Bromus. Springer, Cham, pp. 61–95. https://doi.org/10.1007/978-3-319-24930-8_3

Hardegree, S.P., Abatzoglou, J.T., Brunson, M.W., Germino, M.J., Hegewisch, K.C., Moffet, C.A., Pilliod, D.S., Roundy, B.A., Boehm, A.R., Meredith, G.R., 2018. Weather-Centric Rangeland Revegetation Planning. Rangel. Ecol. Manag. 71. https://doi.org/10.1016/j.rama.2017.07.003

Hardegree, S.P., Cho, J., Schneider, J.M., 2012a. Weather variability, ecological processes, and optimization of soil micro-environment for rangeland restoration, in: Monaco, T.A., Sheley, R.L. (Eds.), Invasive Plant Ecology and Management: Linking Processes to Practice. CAB International, Wallingford, Oxon, UK, pp. 107–121.

Hardegree, S.P., Schneider, J.M., Moffet, C.A., 2012b. Weather Variability and Adaptive Management for Rangeland Restoration. Rangelands 34, 53–56. https://doi.org/10.2111/RANGELANDS-D-12-00048.1

Hardegree, S.P., Sheley, R.A., Brunson, M.W., Taylor, M.H., Moffet, C.A., 2019. Forum: Iterative-Adaptive Management and Contingency-Based Restoration Planning in Variable Environment. Rangel. Ecol. Manag. 72, 217–224. https://doi.org/10.1016/J.RAMA.2018.09.006

Hardegree, S.P., Sheley, R.L., Duke, S.E., James, J.J., Boehm, A.R., Flerchinger, G.N., 2016. Temporal Variability in Microclimatic Conditions for Grass Germination and Emergence in the Sagebrush Steppe. Rangel. Ecol. Manag. 69, 123–128. https://doi.org/10.1016/J.RAMA.2015.12.002

Hardegree, S.P., Van Vactor, S.S., 2004. Microclimatic Constraints and Revegetation Planning in a Variable Environment1. Weed Technol. 18, 1213–1215. https://doi.org/10.1614/0890-037X(2004)018[1213:MCARPI]2.0.CO;2

Holling, C.S., 1978. Adaptive environmental assessment and management. John Wiley & Sons, Ltd, Toronto.

Koontz, T.M., Bodine, J., 2008. Implementing Ecosystem Management in Public Agencies: Lessons from the U.S. Bureau of Land Management and the Forest Service. Conserv. Biol. 22, 60–69. https://doi.org/10.1111/j.1523-1739.2007.00860.x

Lin, N., 2017. Building a network theory of social capital, in: Social Capital. Routledge, pp. 3–28.

Lubell, M.N., Cutts, B.B., Roche, L.M., Hamilton, M., Derner, J.D., Kachergis, E., Tate, K.W., 2013. Conservation Program Participation and Adaptive Rangeland Decision-Making. Rangel. Ecol. Manag. 66, 609–620. https://doi.org/10.2111/REM-D-13-00025.1

McPherson, M., Smith-Lovin, L., Cook, J.M., 2001. Birds of a Feather: Homophily in Social Networks. Annu. Rev. Sociol. 27, 415–444. https://doi.org/10.1146/annurev.soc.27.1.415

Moffet, C.A., Hardegree, S.P., Abatzoglou, J.T., Hegewisch, K.C., Reuter, R.R., Sheley, R.L., Brunson, M.W., Flerchinger, G.N., Boehm, A.R., 2019. Weather Tools for Retrospective Assessment of Restoration Outcomes. Rangel. Ecol. Manag. 72, 225–229. https://doi.org/10.1016/J.RAMA.2018.10.011

Noy, C., 2008. Sampling Knowledge: The Hermeneutics of Snowball Sampling in Qualitative Research. Int. J. Soc. Res. Methodol. 11, 327–344. https://doi.org/10.1080/13645570701401305

Onyx, J., Edwards, M., Bullen, P., 2007. The Intersection of Social Capital and Power: An Application to Rural Communities. Rural Soc. 17, 215–230. https://doi.org/10.5172/rsj.351.17.3.215

Pannell, D.J., 2003. Uncertainty and adoption of sustainable farming systems, in: Babcock, B.A., Fraser, R.W., Lekakis, J.N. (Eds.), Risk Management and the Environment: Agriculture in Perspective. Springer, Dordrecht, pp. 67–81.

Pellant, M., Shaver, P., Pyke, D., Herrick, J., 2005. Interpreting indicators of rangeland health, Version 4. Technical Reference 1734-6.

Pellant, M., Shaver, P.L., Pyke, D.A., Herrick, J.E., Lepak, N., Riegal, G., Kachergis, E., Newingham, B.A., Toledo, D., Busby, F.E., 2020. Interpreting indicators of rangeland health. Version 5. Technical Reference 1734-6.

Pinkerton, E., 2007. Integrating holism and segmentalism: overcoming barriers to adaptive co-management between management agencies and multi-sector bodies, in: Armitage, D., Berkes, F., Doubleday, N. (Eds.), Adaptive Co-Management: Collaboration, Learning, and Multi-Level Governance. University of British Columbia Press, Vancouver, pp. 151–171.

Putnam, R., 2001. Social Capital: Measurement and Consequences. Can. J. policy Res. 2, 41–51.

Reagans, R., McEvily, B., 2003. Network Structure and Knowledge Transfer: The Effects of Cohesion and Range. Adm. Sci. Q. 48, 240. https://doi.org/10.2307/3556658

Rogers, E.M., 2010. Diffusion of innovations. Free Press, New York, NY.

Rogers, E.M., Kincaid, D.L., 1981. Communication networks: Toward a new paradigm for research. Free Press, New York, New York, USA.

Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., Schultz, L., 2006. A Handful of Heuristics and Some Propositions for Understanding Resilience in Social-Ecological Systems. Ecol. Soc. 11, art13. https://doi.org/10.5751/ES-01530-110113

Wisdom, J.P., Chor, K.H.B., Hoagwood, K.E., Horwitz, S.M., 2014. Innovation Adoption: A Review of Theories and Constructs. Adm. Policy Ment. Heal. Ment. Heal. Serv. Res. 41, 480–502. https://doi.org/10.1007/s10488-013-0486-4

Woolcock, M.M., 2001. The place of social capital in understanding social and economic outcomes. Can. J. Policy Res. 2, 11–17.

Wright, V., 2010. Influences to the success of fire science delivery: perspectives of potential fire/fuels science users.

Yaffee, S.L., 1997. Why Environmental Policy Nightmares Recur. Conserv. Biol. 11, 328–337. https://doi.org/10.1046/j.1523-1739.1997.95204.x

Tables

Participants' Affiliation by Innovation of Interest		
Agency / Affiliation	**WCRT Number of Respondents**	**IIRH Number of Respondents**
Bureau of Land Management	3	6
U.S. Forest Service	2	2
State Department of Natural Resources	2	0
Environmental Consulting Service	3	0
Military	1	0
National Park Service	0	3
Anonymous	14	0
TOTAL:	25	11

Table 1. Agency affiliations of study participants for both the WCRT and IIRH innovations. Survey data for the WCRT were gathered anonymously so affiliation is unknown.

Figure Captions

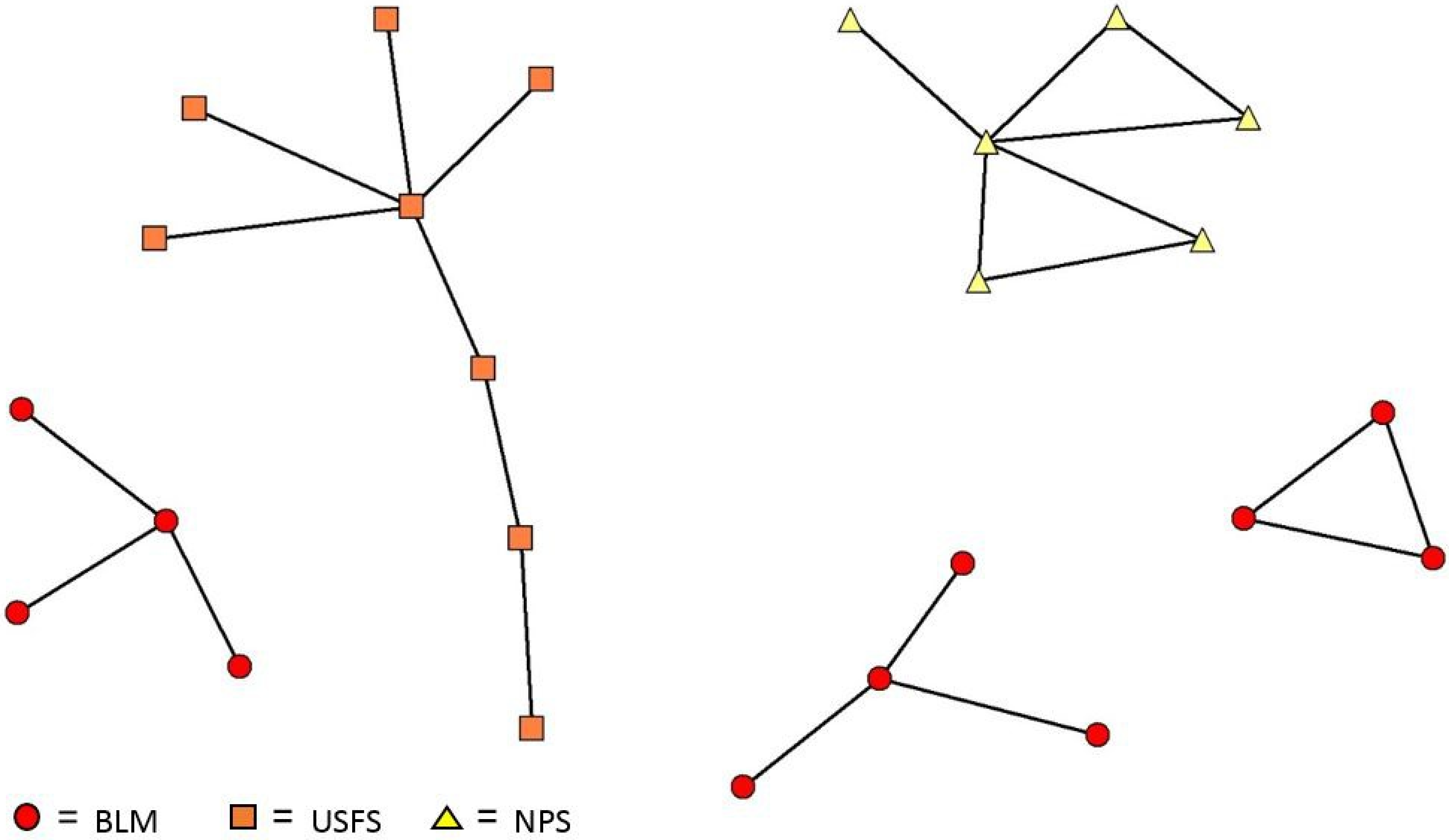
Figure 1. Inter-related variables impacting innovation adoption and/or diffusion, innovation studied for each process, and examples of each variable within the context of this study.

Figure 2. Summarization of Rogers's (2010) five innovation attributes

Figure 3. Social network of rangeland managers in southeast Utah based on advice connections. Nodes are individuals within each of the three agencies. Black lines are connections between land managers and are undirected. NetDraw (Borgatti, 2002) was used for visualizing the network of land managers. This figure displays siloing between agencies and within the BLM in terms of rangeland management advice connections.

INNOVATION ADOPTION CONSTRUCTS	PROCESS STUDIED	INNOVATION OF INTEREST	EXAMPLE
Innovation traits	Adoption	WCRT	Complexity, relative advantage, compatibility, trialability, observability
Individual level	Diffusion	IIRH	Bonding/linking/bridging social capital
Organizational level	Adoption	WCRT	Funding streams
	Diffusion	IIRH	Agency policy & siloing
External system level	Adoption	WCRT	Political pressure

INNOVATION TRAITS	
Relative Advantage	The degree to which the innovation is perceived as better than what it is replacing or improving upon.
Compatibility	How much the innovation already fits your needs and aligns with your norms, values, and beliefs.
Complexity	The measure of usability of the innovation.
Trialability	How easily the innovation can be tried without much investment.
Observability	The visibility of the innovation's results to potential adopters.


= BLM
= USFS
= NPS