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Using Rangeland Health Assessment to Inform Successional Management

Roger L. Sheley, Jeremy J. James, Edward A. Vasquez, and Tony J. Svejcar*

Rangeland health assessment provides qualitative information on ecosystem attributes. Successional management is a conceptual framework that allows managers to link information gathered in rangeland health assessment to ecological processes that need to be repaired to allow vegetation to change in a favorable direction. The objective of this paper is to detail how these two endeavors can be integrated to form a holistic vegetation management framework. The Rangeland Health Assessment procedures described by Pyke et al. (2002) and Pellant et al. (2005) currently are being adopted by land managers across the western United States. Seventeen standard indicators were selected to represent various ecological aspects of ecosystem health. Each of the indicators is rated from extreme to no (slight) departure from the Ecological Site Description and/or the Reference Area(s). Successional management identifies three general drivers of plant community change: site availability, species availability, and species performance, as well as specific ecological processes influencing these drivers. In this paper, we propose and provide examples of a method to link the information collected in rangeland health assessment to the successional management framework. Thus, this method not only allows managers to quantify a point-in-time indication of rangeland health but also allows managers to use this information to decide how various management options might influence vegetation trajectories. We argue that integrating the Rangeland Health Assessment with Successional Management enhances the usefulness of both systems and provides synergistic value to the decision-making process.

Key words: Rangeland health assessment, successional management, ecologically-based invasive plant management, EBIPM.

Land managers long have identified a need for a practical and effective framework for managing vegetation change, particularly in heavily degraded or invasive plant dominated systems (Cairns 1993; Clewell and Rieger 1997). Such a framework requires several key components, including methods to assess ecological processes leading to degradation, as well as a conceptual model based on ecological principles that allow managers to identify appropriate tools and strategies that alter ecological processes and mechanisms that allow plant communities to change in a favorable direction (Hobbs and Harris 2001; Hobbs and Norton 1996). Major advances in rangeland health assessment have been made over the past two decades. Likewise, conceptual models of successional management have been developed, tested, and refined (Pickett et al. 1987; Sheley et al. 2006, 2009). However, there has been little integration of these parallel advances. Integrating these advances is a critical step toward developing a holistic rangeland management framework that could be applied across a range of land management scenarios.

Rangeland health assessment is a heavily debated topic because it provides an indication of the ecological status of a critically important natural resource (Breckenridge et al. 1995; Pellant et al 2005; Reed et al. 2008). Historically, the Clementsian view of plant succession directed the collection of data for rangeland condition and trend analysis (Clements 1916; Dyksterhuis 1949; Sampson 1919). In 1994, a National Research Council panel advocated the use of multiple indicators to assess soil stability and watershed function, integrity of nutrient cycling and energy, and the resilience and resistance of a community to change that would provide an assessment of ecosystem health (NRC 1994). Since then, many indicators and assessment systems have been proposed as providing valuable insight into the ecological status and

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Interpretive Summary

Integrating the Rangeland Health Assessment with Successional Management enhances the usefulness of both systems and provides synergistic value to the decision-making process. Successional management provides a science-based management system based on the causes of vegetation dynamics. Rangeland Health Assessment provides a method for determining which causes of succession are most likely directing dynamics, and leads managers to those ecological processes most likely in need of repair. Thus, management can be tailored to specially address those causes and processes with the highest probability of directing vegetation on a favorable trajectory. Besides the clear economic advantage of lower management inputs associated with using the rangeland health assessment to identify which primary causes of succession are most likely directing dynamics, integrating Rangeland Health Assessment also has the advantage of avoiding unnecessary management inputs and has the additional advantage of minimizing unintended negative impacts on ecological processes.

trend in dynamics of rangelands at various scales (Miller and Heyerdahl 2008; Pyke et al. 2002; Reed et al. 2008). The primary objective of these assessment systems is to quantify rangeland ecological condition (Pyke et al. 2002). In most cases, ecosystem health assessment is not incorporated into a framework that allows managers to use the assessment information to develop comprehensive restoration strategies (except see Briske et al. 2005).

Over the past two decades, major advances of successional management models have been made (Sheley et al. 1996, 2006). These hierarchical models link ecological processes to the major drivers of plant community change. This allows managers to identify and manipulate the underlying causes of invasion, succession, and retrogression to achieve a desired plant community. This requires understanding the conditions, mechanisms, and processes that direct plant community dynamics enough to alter them to favor desired vegetation trajectories (Sheley et al. 1996). Successional management represents a shift toward ecosystem management strategies that modify ecological processes in need of repair (Gram et al. 2001; Swanson and Franklin 1992). Designing restoration programs based on successional management requires initial and periodic assessment of the ecological conditions across managed landscapes. Thus, Rangeland Health Assessment can provide information necessary to help implement effective successional management programs. Although we are not at a point where an exact diagnostic test can be conducted, it is possible to use the Rangeland Health Assessment to provide indications of causes of succession that are in need of repair (Sheley et al. 2006).

The broad objective of this paper is to provide an explicit description of how Rangeland Health Assessment and Successional Management can be integrated to form a holistic vegetation management framework. We first provide a brief discussion of the development of successional management and Rangeland Health Assessment (Pellant et al. 2005; Pyke et al. 2002) currently being adopted by land managers. We then detail methods to integrate these complimentary endeavors, providing a hypothetical and an actual example. We conclude by discussing how this holistic framework can improve our ability to identify causes of succession, retrogression, and invasion, and thus more effectively manage plant community dynamics.

Rangeland Health Assessment

Although a quantitative national assessment protocol is needed, Federal land management agencies sought a technique that could provide a rapid preliminary assessment of rangeland health in 1997. Using an iterative developmental process over several years, the current qualitative rangeland health assessment was developed and the technique is being widely adopted (Pellant et al. 2005; Pyke et al. 2002). The rangeland health assessment has six steps. The process involves identifying the evaluation area and confirming the ecological site, identifying an Ecological Reference Area used to develop expected indicator ranges, reviewing and modifying descriptors of indicators, rating the indicators, and using the information to determine the functional status of the three rangeland health attributes. Seventeen standard indicators were selected to represent components of the three attributes that are impossible to directly measure (Table 1; Pyke et al. 2002). Each of the indicators is rated from extreme to no (slight) departure from the Ecological Site Description and or the Reference Area(s). Once the indicators are rated, a summary table is created that provides a list of the indicators and their rating for each management unit (Table 2). Indicators are categorized by rating for the three rangeland health attributes (Soil/Site Stability: indicators 1 to 6, 8, 9, 11; Hydrologic Function: indicators 1 to 5, 7 to 11, 14; and Biotic Integrity: indicators 8, 9, 11 to 17). A summary table is created to provide a quality description of current rangeland health of a particular management unit. This rangeland health assessment is aimed at providing a rapid assessment of rangeland health at the management unit and to provide a communication tool with stakeholders regarding the status of ecosystem properties and processes (Pyke et al. 2002).

Successional Management

Over the past two decades, a conceptual model for successional management has been developed, tested, and refined (Table 3; Pickett et al. 1987; Sheley et al. 1996, 2006, 2010). Successional management proposes a hierarchical model that includes three primary causes of plant community change (site availability, species availability, and species performance), ecological processes that drive these causes,

Table 1. Potential quantitative measurements and indicators that we believe relate to the 17 rangeland health qualitative indicators from Pellant et al. (2005. For each quantitative indicator, we provide a potential explanation (interpretation) of the relationship between the qualitative and quantitative indicators. Taken from Pyke et al. 2002.

Qualitative Indicator	Quantitative Indicator	Measurement	Interpretation
1. Rills	None		
2. Water flow patterns	Percent basal cover	Line-point intercept	Basal cover is *negatively* correlated with water flow patterns because plant bases slow water movement.
	Proportion of basal gaps > 25, 50, 100, 200 cm	Basal gap intercept	Basal gaps are *positively* correlated with water flow patterns because water gains energy as it moves unobstructed across larger gaps.
3. Pedestals and/or terracettes	Standard deviation of pin heights	Erosion bridge (microtopography)	Pedestals and terracettes can be *positively* correlated with pin height standard deviation because increased microtopography is *sometimes* due to pedestals and terracettes.
4. Bare ground	Percent bare ground	Line-point intercept	Bareground is *positively* correlated with runoff and erosion
	Proportion of line in canopy gaps > 25, 50, 100, 200 cm	Canopy gap intercept	The bareground qualitative indicator is also *positively* correlated with canopy gaps because bareground in large gaps usually has a larger effect on many functions than bare ground in small gaps.
5. Gullies	Width-to-depth ratio and side slope angle	Channel profiles	Lower width-to-depth ratios and higher side slope angles both reflect more severe or active gully erosion.
	Headcut movement	Headcut location	Higher rates of headcut movement reflect greater gully erosion.
6. Wind-scoured areas	None		
7. Litter movement	Proportion of litter cover in inner spaces *vs.* under canopies	Line point intercept	Higher proportions of litter in the interspaces can be *positively* related to litter movement.
	Proportion of basal gaps > 25, 50, 100, 200 cm	Basal gap intercept	Basal gaps can be *positively* related to redistribution or loss of litter.
8. Soil surface resistant to erosion	Average soil surface stability	Soil stability kit (surface)	Surface aggregate stability is *positively* related to soil's resistance to wind and water erosion.
9. Soil surface loss or degreadation	Average soil sub-surface stability	Soil stability kit (sub-surface)	Sub-surface soil structure degrades and organic matter declines as surface soil is lost, thus sub-surface aggregate stability is *negatively* related to soil surface loss or degredation.
10. Plant community composition and distribution relative to infiltration and runoff.	Percent composition	Line point intercept or production	Changes in species composition can be related to changes in infiltration. For example, root and shoot morphology of tussock *vs.* Stoloniferous plants.
	Proportion of basal gaps > 25, 50, 100, 200 cm	Basal gap intercept	Changes in basal gaps can be related to changes plant distributions that relate to infiltration and runoff.
11. Compaction layer	Ratio of penetration resistance in the upper 15 cm (6 inches) between the evaluation and reference area	Impact penetrometer	Ratios of penetration resistance or bulk density above 1 can indicate the presence of a compaction layer.
	Ratio of mass-per-volume of soil in the upper 15 cm between the evaluation and reference area	Bulk density	
12. Plant functional or structural groups	Percent composition by functional or structural group and group richness	Line-point intercept Production	Composition and richness of functional or structural groups are *positively* related to plant functional or structural
13. Plant mortality or decadence	Proportion of live-to-dead canopy	Line-point intercept	The live-to-dead proportion is *positively* related to the plant mortality or decadence qualitative indicator.
14. Litter amount	Litter mass	Litter mass	The amount of litter mass and cover per unit area is related to litter amount
	Litter cover	Line-point intercept	
15. Annual production	Total annual production	Production	Productions relates directly with the qualitative indicator of annaul production.
16. Noxious and invasive plants	Density of invasive species	Belt tranect	Number of species and their densities or cover will directly relate to the qualitative indicator.
	Percent cover of invasive species	Modified Whitaaker cover plots	
17. Perennial plant reproductive capability	None		

Table 2. A hypothetical example of a completed Rangeland Health Evaluation Summary Worksheet, part 2 used in the rangeland health assessment for a site. Letters S, W, and B under the Attribute column refer to Soil, Water, and Biology, and indicate association of the indicator with the respective attributes, Soil or Site Stability, Hydrologic Function, or Biological Integrity. The comments section is used to help evaluators document their rationale for the specific rating of selected indicators. Taken from Pyke et al. 2002.

		Departure from Ecological Site Description/Reference Area(s)				
Attribute	Indicators	Extreme	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
S, W	1. Rills				√	
Comments						
S, W	2. Water Flow Patterns				√	
Comments						
S, W	3. Pedestals and/or Terracettes			√		
Comments - *Several plants along flowpaths have roots exposed, but site is not prone to frost heaving*						
S, W	4. Bare Ground				√	
Comments						
S, W	5. Gullies				√	
Comments						
S	6. Wind Scoured Blowouts and/or Deposition Areas					√
Comments						
W	7. Litter Movement					√
Comments						
S, B, W	8. Soil Surface Resistance to Erosion			√		
Comments - *The majority of soil samples from under canopies of plants tending to fall apart when placed in water*						
S, B, W	9. Soil Surface Loss or Degradation			√		
Comments - *A-horizon missing in interspaces; present under shrubs or larger grasses*						
W	10. Plant Community Composition & Distribution Relative to Infiltration & Runoff			√		
Comments						
S, B, W	11. Compaction Layer			√		
Comments - *Interspaces with platy structure at 2-3 cm depth & roots tending to grow horizontally at this point; No evidence under shrubs*						
B	12. Functional/Structural Groups	√				
Comments - *Tall and short C4 grasses not present; Midgrass C3 grasses restricted to one species; Forb components not present; Shrubs Dominate*						
B	13. Plant Mortality/Decadence		√			
Comments - *Many shrubs have died recently*						
B, W	14. Litter Amount		√			
Comments - *Only associated with shrubs; no litter around C3 mid-grasses*						
B	15. Annual Production	√				
Comments - *site should support 1800 kg/ha, but estimate less than 300 kg/ha*						
B	16. Invasive Plants					√
Comments						
B	17. Reproductive Capability of Perennial Plants	√				
Comments						

and factors that modify these processes. In this model, management tools and strategies are designed to target specific ecological processes that influence one or more of the three causes of succession. This links treatments a manager imposes to ecological processes driving plant community dynamics. For example, a manager might use biological control to reduce seed production, addressing species availability, and use sheep to preferentially graze invasive forbs, addressing

Table 3. Process-based ecologically-based invasive plant management (EBIPM) framework.

Causes of succession	Processes	Management factors
Site availability	Disturbance	Size, severity, time intervals, patchiness
Species availability	Dispersal	Dispersal mechanisms and landscape features
	Propagule pool	Land use, disturbance interval, species life history
Species performance	Resource supply	Soil, topography, climate, litter decomposition
	Ecophysiology	Growth rate, photosynthesis, nutrient uptake
	Life history	Allocation, reproduction timing and degree
	Stress	Climate, site history, natural enemies
	Interference	Competition, allelopathy, trophic interactions

species performance (Sheley et al. 1997). Because of the focus on treatment effects on weeds, the ecological processes they affect usually are not fully understood. Based on this ecological model, a range of tools can be identified, developed, and strategically imposed to direct vegetation trajectories. Most importantly, this model provides a way for managers to understand how to apply the appropriate combination of tools and strategies to address the underlying cause of invasion rather than simply controlling invasive plant abundance (Sheley et al. 2006).

The broad utility of a general successional model ultimately depends on how well it enables managers to select appropriate tools and strategies in heterogeneous environments. An understanding of the ecological conditions prior to implementation of management should provide critical insight into processes in need of repair. Disturbance regimes, propagule pressure, and factors affecting plant performance vary substantially across the landscape. As a consequence, we can expect the three general drivers of plant community change (Table 3) also to vary within a single management unit. An effective model would need to successfully incorporate this variation and allow managers to select and alter appropriate combination of treatments as they move across the landscape. We found that if appropriate assessments are used to inform our successional model, our probability of selecting the most effective combination of treatments for a particular portion of the landscape increased from 5% to over 60% (Sheley et al. 2009). These initial findings demonstrate how linking assessment to a processes-based model can yield a general approach for successional management applicable across a range of scenarios.

Integrating Rangeland Health Assessment with Successional Management

Regardless of the model used, it is widely recognized that rangeland management involves directing successional dynamics toward desired plant communities (Walker et al. 2007). This is the case especially where invasive species are invading into indigenous ecosystems (Sheley et al. 1996). Thus, identification of the causes of successional dynamics within a management unit likely is the first step toward identifying strategies for facilitating change. The Rangeland Health Assessment provides critical ecological information needed for successional management by helping to identify the general causes of succession that likely are directing dynamics and should lead managers to begin to identify those ecological processes in need of repair (Sheley et al. 2009).

To inform the successional management model, we used the most current ecological literature to categorize the 17 indicators from the Rangeland Health Assessment into the three general causes of succession (Table 4). Because many indicators are related to more than a single cause of succession, the primary and secondary causes of succession are identified for each indicator or group of indicators. We also combined range health indicators which would have similar impacts on individual causes of succession. For example, we combined rills, waterflow patterns, pedestals and/or terracettes, gullies, wind scoured, blowout depositions, and litter movement into a single category associated with high site availability because the proportion of bare ground and disturbance intensity is often positively associated with site availability (Turnbull et al. 2000). Similarly, we combined bare ground, soil surface loss or degradation, and soil surface resistance into a single category. A summary version for the group of these combined indicators can be used in these evaluations. Once the rangeland health indicators have been ranked, that information, combined with knowledge of whether the indicator is associated with a cause primarily or secondarily (based on literature), can be used to provide an indication of the relative importance of each cause in directing succession at the site level. This information is central to using the successional management model because it provides the initial link to identifying the ecological processes in need of repair for successful restoration (James et al. 2010; Sheley et al. 1996, 2006, 2009, 2010).

Rangeland Health Assessment mainly is qualitative. In most cases, the indicators can be measured, but the magnitude and degree to which they indicate that a

Table 4. Scientific literature supporting the categorization of rangeland health indicators into their associated cause of succession.

	Causes of succession				
Rangeland health indicators	Site availability	→ ←	Species availability	→ ←	Species performance
Rills, water flow patterns, pedestals, and/or terracettes, gullies, wind scoured, blowout depositions, litter movement	Velazquez and Gomez 2009; Velazquez and Gomez 2008; Wei et al. 2007; Papaik and Canham 2006				
Bare ground, soil surface loss, or degradation	Benkobi et al. 1993; Cerda 1999; Walker and del Moral 2009; Warren et al. 1986; Wright and Clarke 2009; Sheley et al. 2006				Mata-Gonzalez et al. 2008; Foster et al. 2007
Plant community composition			Egler 1954; Lanta and Leps 2009; Bischoff et al. 2009; Li et al. 2008; Wright and Clarke 2009; Galatowitsch 2006; Mata-Gonzalez et al. 2008		Peltzer et al. 2009; Mahaming et al. 2009; Luzuriaga and Escudero 2008
Compaction layer	Burke 2008; Pranagal 2007; Bonis et al. 2005				Burke 2008; Pranagal 2007; Bonis et al. 2005
Functional/structural groups			Koniak and Noy-Meir 2009; Dzwonko and Loster 2008; Holdaway and Sparrow 2006; Bezemer et al. 2006, Symstad 2000; McIntyre et al. 1995		
Plant mortality/ decadence	Li et al. 2005				Baeten et al. 2009; Barnes et al. 2006; Midoko-Iponga et al. 2005; McKinley and Van Auken 2005
Litter amount					Sheley et al. 2009; Donath and Eckstein 2008; Vasquez et al. 2008; Wilby and Brown 2001
Annual production					Castro and Freitas 2009; Kremer et al. 1996; Suman 2008
Invasive plants			Dodge et al. 2008; Kulmatiski 2006; Vosse et al. 2008; Sheley et al. 2006		
Reproductive capacity of perennial plants			Kardol et al. 2008; Vosse et al. 2008; Knapp and Rice 2011; Yurkonis and Meiners 2006		Korner et al. 2008

Table 5. Summary table of rating for indicators organized by the primary (solid-box) and secondary (dashed-box) causes of succession for the hypothetical case.

Rangeland Health Indicators	Causes of Succession														
	Site Availability					Species Availability					Species Performance				
	Extreme	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight	Extreme	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight	Extreme	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
Rills, water flow patterns, pedestals, and/or terracettes, gullies, wind scoured, blowout depositions, litter movement			√	√√√√	√√										
Bareground, soil surface loss or degradation			√√	√											
Plant Community Composition								√					√		
Compaction Layer			√										√		
Functional/Structural Groups						√									
Plant mortality/decadence		√										√			
Litter Amount												√			
Annual Production											√				
Invasive Plants										√					
Reproductive Capacity of Perennial Plants						√					√				

particular cause is driving successional dynamics is highly variable. It might be most useful to consider this assessment as a relative indication of the primary causes of succession. As the number of indicators in the extreme and moderate to extreme rating increases, it is reasonable to suspect that those causes are in need of attention because they deviate far from the conditions of the Reference Area. Additionally, this evaluation should be used with other information, such as site history, observations, and land managers' experience working on the management unit. This information should be used to focus on a starting point in the identification of ecological processes that appear to be in need of repair. By using the successional management framework, managers can strategically work their way through a thought process that can lead to the development and implementation of a truly ecologically-based management system.

Table 6. Summary table of rating for indicators organized by the primary (solid-box) and secondary (dashed-box) causes of succession for the actual case.

	Causes of Succession														
Rangeland Health Indicators	**Site Availability**					**Species Availability**					**Species Performance**				
	Extreme	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight	Extreme	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight	Extreme	Moderate to Extreme	Moderate	Slight to Moderate	None to Slight
Rills, water flow patterns, pedestals, and/or terracettes, gullies, wind scoured, blowout depositions, litter movement			√												
Bareground, soil surface loss or degradation	√										√				
Plant Community Composition						√						√			
Compaction Layer			√										√		
Functional/Structural Groups						√									
Plant mortality/decadence											√				
Litter Amount													√		
Annual Production											√				
Invasive Plants						√									
Reproductive Capacity of Perennial Plants							√					√			

Examples of Integrating Rangeland Health Assessment with Successional Management

A Hypothetical Case. This approach was developed as a tool for using the Rangeland Health Assessment described by Pyke et al. (2002) and further amended for use by Pellant et al. (2005) to provide an initial indication of the primary causes of successional dynamics in managed systems, especially those dominated or under the threat of dominance by invasive weeds. This information, combined with experience and observations about the past and present land uses, can provide much insight into understanding the causes of successional dynamics on a particular site. Understanding the primary causes of succession is the first step to developing management strategies that address the underlying causes of invasion.

In this example, we applied the results of a hypothetical example of a completed Rangeland Health Evaluation

Summary Worksheet from Pyke et al. (2002) to the Assessment of Causes of Succession worksheet (Table 5). Using the assessment information in this manner suggests that site availability is not a primary cause of retrogression in this system because the indicators suggest it only moderately deviates from the reference area. Conversely, both species availability and species performance tended to deviate from the reference area moderately to extremely. From this assessment, it appears that the primary causes of retrogression are related to those processes associated with species availability and species performance. Management efforts aimed at modifying these processes could provide the most positive response in directing the plant community on a desired trajectory. However, this could involve manipulating site availability if necessary to establish desired species because they are low in abundance.

An Actual Case. Using data collected in 2002, we retrospectively assessed a highly degraded site described in a test of Augmentative Restoration (Sheley et al. 2009) to provide an actual example of how the rangeland health assessment could inform successional management. The rangeland health assessment suggested that site availability was moderate to extreme, mainly because of the high degree of bare ground (Table 6). The availability of desired native species deviated extremely from the reference areas. Species availability was very low and the functional groups were largely changed from grasses to perennial invasive broadleaved plants. The three indicators of species performance suggested that species performance also was extremely altered. Desired plant mortality was high and annual production by those species was very low. Additionally, desired species reproductive capacity appeared somewhat limited.

In this case, many ecological processes appeared in disrepair. As we predicted based on the assessment, modifying species availability by seeding desired species and species performance by adding water produced the highest desired species establishment. The assessment indicated a high amount of bare ground; thus, we anticipated that safe sites were likely already available for desired seedling estab lishment and growth on this site. Amending site availability did not improve establishment on this site. In this study by using the variables collected in the rangeland health assessment with the successional management framework to identify ecological processes in need of repair improved the management outcome by 66% over traditionally used techniques (Sheley et al. 2009).

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