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Aspen Status Report and Recommendation for the Book Cliffs

Paul C. Rogers

Cody M. Mittanck

Ronald J. Ryel

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Aspen Status Report and Recommendations for the Book Cliffs

Prepare for:

Vernal Field Office, Bureau of Land Management, Utah

12/6/2013

Prepare by:

Paul C. Rogers

Cody M. Mittanck

Ronald J. Ryel

Western Aspen Alliance,

Wildland Resources Department

Utah State University

Contents

Summary

Regionally quaking aspen (*Populus tremuloides* Michx.) forests are experiencing numerous impediments to resilience. In the West, recent drought, fire suppression, insects, diseases, climate trends, inappropriate management, and ungulate herbivory are impacting these high biodiversity forests. We conducted a landscape assessment of aspen communities in the Book Cliffs region, Vernal Field Office of the Bureau of Land Management, for the purposes of determining landscape-level status of aspen and making recommendations for future management of these forests. The study area consists of 268 distinct aspen polygons totaling approximately 70 ha (174 acres) of aspen forest surrounded by much larger tracts of pinyon-juniper, sagebrush, grassland, and riparian types. This relatively small coverage amplifies the importance of moist aspen forests as oases of biodiversity in much larger landscapes of arid systems.

We implemented a comprehensive monitoring plan to test novel measures linking plant-animal interactions, compare crucial functional differences in aspen types, and make appropriate restorative recommendations based on the outcome of these assessments. Seventy-seven one hectare plots were sampled for forest structure, composition, regeneration and recruitment, landscape elements, browse level, and herbivore use. Use was determined by counting the number of pellet groups by ungulate species at each sample location. We tested the efficacy of a visual stand condition rating system when compared to objective metrics. A series of non-parametric analyses were used to compare functional aspen types and stand condition groups by key variables. An ordination analysis, nonmetric multidimensional scaling (NMS), allowed us to explore all our data to find the most critical measures of aspen stand conditions for the purpose of better informing future aspen monitoring. Results indicate that plots differed significantly by seral or stable aspen functional types, stand condition rating, and browse species use. NMS revealed that regeneration level and herbivore use were the strongest objective indicators of aspen stand conditions, while the stand condition rating proved a valuable subjective index of forest status. While ungulate herbivory of aspen is problematic throughout western North America, our results show acute impacts where moderate slopes, relatively low water availability, and intense browsing predominate in the Book Cliffs. We stress a range of options to target specific Book Cliffs aspen situations: seral aspen require periodic disturbance and post-disturbance browse protection, while stable aspen will need more immediate and long-term protection from browsers to restore resilient, multiple aged, stand structures. Overall, aspen in our study landscape is highly vulnerable to collapse due to narrow physiographic and climate limitations, plus elevated browse levels. Without herbivory reduction, future aspen management in the Book Cliffs will be strained and widespread system failure may occur. Systematic and ongoing monitoring of both passively and actively treated aspen stands is imperative to measure future progress and setbacks.

I. Introduction

Purpose and Need

For many years personnel within the Vernal Field Office have noted the declining state of aspen communities in the highest, southern, portion of the Book Cliffs management area. A landscape-level, scientifically defensible, assessment of aspen in this region would provide status and causality to support or refute claims of aspen decline. Numerous causes for this deteriorating state of aspen in the Book Cliffs have been advanced: fire suppression, grazing livestock, wildlife herbivory, forest succession, past management actions, and drier/warmer climate trends. The present field and remote survey was commissioned to quantitatively assess aspen conditions and their underlying causes at the landscape scale and make recommendations for ongoing monitoring and management of this valuable forest resource.

Objectives

1. Conduct a scientifically defensible landscape assessment of aspen status across the Book Cliffs.
2. Evaluate usefulness of aspen condition indicators and make recommendations for future monitoring protocols.
3. Address the role of wild and domestic herbivory in the greater Book Cliffs aspen community.
4. Make appropriate restorative recommendations based on aspen functional types (i.e., seral, stable, riparian) in the Book Cliffs.

Overview of Quaking Aspen and Ungulate Herbivory

Quaking aspen (*Populus tremuloides*) forests of western North America provide unique resources where they are often the lone deciduous component of vast coniferous expanses. Aspen are valued for their rich flora and fauna (Edenius and Ericsson 2007; Kuhn et al 2011). These biodiverse communities, however, are regionally threatened by practices such as logging and fire suppression which favor conifers, and by overabundance of either domestic or wild herbivores (Kota and Bartos 2010; Edenius et al 2011). Additionally, climate will be a key component of future quaking aspen management where it is thought that these forests are at or near their moisture resource margins (Rehfeldt et al 2009; Martin and Marin 2012). Stressors on aspen landscapes that augment climate limitations, therefore, are of high concern to those addressing forest system resilience.

In western North American there are numerous recent studies documenting both declines (Di Orio et al 2005; Worrall et al 2008) and expansions (Manier and Laven 2002; Kulakowski et al 2004) of aspen forests. These works document cover change at a variety of spatial and temporal scales, therefore it is difficult to make direct comparisons between results. Moreover, recent authors have pointed out distinct aspen functional types (Shepperd et al 2006; Rogers et al in review) which would be expected to respond differently to short- and long-term perturbations. For example, aspen competing with conifer species for resources over long periods are thought to "behave" much differently than aspen stands where there are effectively no other tree species. Similarly aspen in uplands thrive with different soil properties and water availability than do those near streams. More

broadly, aspen cover change has been attributed to fire suppression and conifer encroachment, past logging, climate variability, settlement period burning, and browsing by wild and domestic ungulates (Kulakowski et al 2004; Shepperd et al 2006; Rogers et al 2011). Some results have indicated positive and negative cover change within the same landscape (Kulakowski et al 2004; Sankey 2009), lending further support to the concept of varying aspen functional types. Given that aspen forests have undergone modest-to-large change over the past 150 years—often where human actions combine with stochastic disturbances—practitioners have become concerned about the future of these forests under current management regimes. Contemporary thinking holds that "managing for resilience" will afford the best hopes for sustainable quaking aspen (as in most systems). Forest managers are therefore interested in sustaining or creating resilient aspen communities with a foundation of state-of-the-science knowledge and adaptive practices. Where plant-animal interactions are paramount, a barrier to such goals has been a lack of effective communication between federal forest and state wildlife practitioners in both scientific and applied realms.

While aspen is highly valued for its' biodiversity, in some locales herbivores are having undue impact on the ability of these systems to maintain ecosystem functions. Aspen shoots and leaves provide valuable nutrition to several species, especially early and late in the growing season when diversity of browse is limited (Jones et al 2005; Beck et al 2006). In the western United States, browsing cattle (*Bos* spp.), sheep (*Ovis* spp.), North American elk (*Cervus elaphus*), and mule deer (*Odocoileus hemionus*) in many areas are severely inhibiting stand renewal via repeated aspen sprout consumption (DeByle 1985; Zeigenfuss et al 2008; DeRose and Long 2010; Rogers et al 2010). This phenomenon seems particularly acute where wild elk populations are thought to be beyond "historical range of variation" levels due to aggressive reintroduction programs (e.g., Bailey et al 2007; Stritar et al 2010) and relatively low levels of predation (Beschta and Ripple 2009). Though reduced elk numbers from predation may lead to successful aspen recruitment in some areas (Fortin et al 2005), there is some dispute over whether commensurate alterations of browsing patterns wrought by fear of predation are further influencing regeneration success (Kauffman et al 2010). In most of the western U.S., however, significant predation of wild and domestic ungulates is absent as recent reintroductions of a critical carnivore, the gray wolf (*Canis lupus*), are limited to specific geographic zones. Cougar (*Puma concolor*) apparently do prey on younger or smaller elk, though their primary ungulate prey appear to be adult mule deer (Matson et al 2007). Overall, the impact of large herbivores on aspen communities may be reduced to three key factors: nutrition, population, and frequency of movement. Browsers who require specific nutrient content of aspen leaves or bark (continuously or seasonally) and who are present in large numbers for extended periods may reduce long-term system resilience (Beck et al 2006; Martin and Marin 2012). Presence of multiple aspen-browsing species will only amplify this phenomenon.

Within the Book Cliffs study area, past work (Sexton, et al., 2006) and anecdotal observations suggest a strong link between deteriorating aspen stands and large ungulate browsing. While cattle grazing has been a constant source of browse consumption for many decades, addition of rising state-level elk populations since the 1970s (Utah Division of Wildlife Resources, 2010) may be causing lasting damage to aspen regeneration and recruitment. In the present study, we were not only interested in status and causes of aspen deterioration, but also in the geographic extent of this phenomenon. Is cessation of recruitment localized or landscape-wide? What about environmental features such as slope, aspect, and aspen functional type? Our aim was to pinpoint landscape features that may encourage or discourage stand health, not only in terms of understory browse, but in light of entire stand sustainability, including stand density, growth/volume, cover, age, structural diversity,

and competition (where seral conditions exist). With these issues and questions in mind, we undertook a landscape-level survey of aspen condition and resilience across the southern Book Cliffs.

II.   Data Collection

Our study area consists of 268 distinct aspen polygons scattered across ~18 000 ha of the Book Cliffs in Utah and Colorado. Polygons were identified using three bands, including near-infrared, of National Agriculture Imagery Program (NAIP) imagery. Images were enhanced to allow a linear stretch across three standard deviations of the spectral data. This process increases contrast between vegetation types allowing easier interpretation. An earlier aspen stand assessment in this same area yielded a photo interpretation accuracy level of 88% (Mittanck 2012). The primary criterion used to delineate aspen polygons was if the area was contiguously forested with an aspen component. Polygons greater than 50% aspen cover and more than 0.5 ha were randomly selected for sampling. The completed procedure resulted in an initial selection of 100 sample polygons, of which 77 were field sampled (Figure 1). Sixteen polygons were inaccurately identified as meeting our species/cover criteria and seven were eliminated due to access and time constraints.) In sum, we sampled 29% of the total polygon population within the study area, enabling us to make strong inferences about the overall Book Cliffs aspen landscape.

Figure 1: Map of the study area shows all aspen locations as identified with aerial imagery and aspen sample plot locations. Inset depicts the Book Cliffs study area within the Rocky Mountain region, USA.
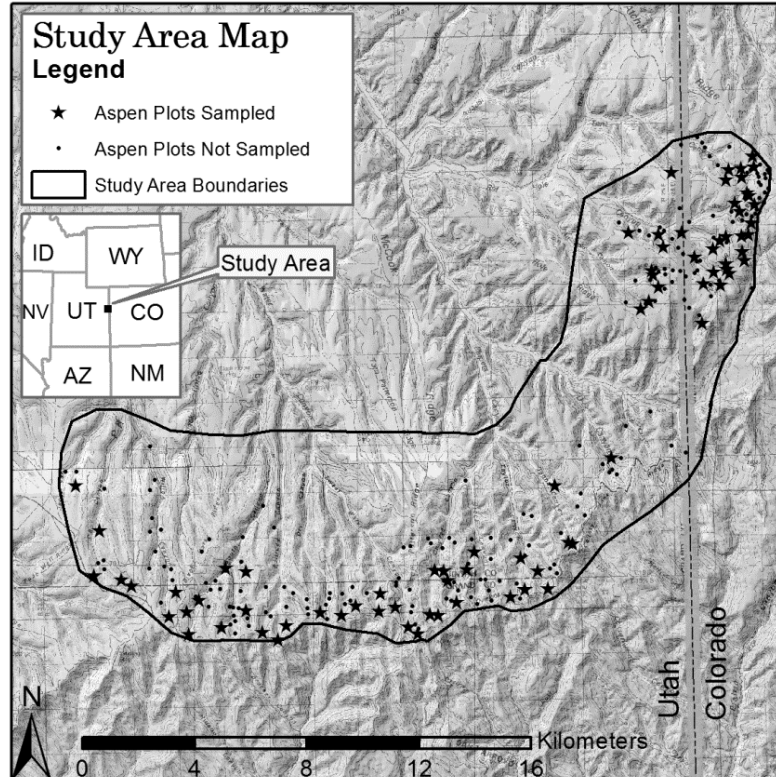
The prime sample unit for this study consists of a ha^{-1} area, henceforth called the "plot," at the centroid of each polygon. Plots were sampled only if they were at least 50% aspen and entirely within a forested area. With these requirements—along with the random polygon selection and systematic centroid location—plot data are assumed to represent mean conditions for each polygon. At each plot, visual estimates of aspen and conifer cover were made for the entire polygon with the aid of aerial photos. A walk through the ha^{-1} sample area was made to gain an overall rating of stand conditions using criteria defined in Table 1, an estimate of discrete vertical "layers" of aspen, and the dominant understory cover by plant group (i.e., shrub, trees, grasses, forbs). Each plot was assigned an aspen stand type, either seral or stable (Harniss & Harper 1982). We define seral aspen as containing more that 10% conifer cover or, if major disturbance within past three decades, the potential to exceed this cover. Stable aspen implies < 10% conifer cover and long-term "stability" in a single species state (i.e., $\geq$ 100 years). In most instances the distinction between seral and stable plots is immediately evident as there are either no conifers or many conifers within an aspen forest. Geographic coordinates were obtained and four plot photos were taken to document understory composition and structure.

Table 1: Ranking of stand condition based on visual estimates of overstory, regeneration/recruitment, and browse of young aspen suckers. A stand must meet all the criteria for either "Good" or "Poor" condition, otherwise it is rated as moderate. "Mortality" is defined as standing dead mature trees. Browse includes branch tips, buds, and leaves missing, as well as presence of multi-stemmed ("bushy") aspen regeneration.

Code	Descriptor	Overstory Mortality/disease	Vertical Stand Layers	Visible Browse Impacts
1	Good	Minimal overstory mortality and stem disease present (< 5%)	Several aspen layers ($\geq$ 3)	Browsing impacts on regeneration uncommon (< 25%)
2	Moderate	Does not fit 1 or 3	Does not fit 1 or 3	Does not fit 1 or 3
3	Poor	Overstory mortality and/or stem cankers common (> 25%)	layering absent or minimal ($\leq$ 2)	Browsing impacts clearly evident (> 50%) on regeneration.

At each plot center, two perpendicular 30 x 2 m transects were established and the following field measures were taken: percent aspen, conifer, and sagebrush cover; regeneration (< 2 m height), recruitment ($\geq$ 2 m height, < 8 cm diameter breast height [dbh]), and mature tree ($\geq$ 8 cm dbh) counts by species; mature tree counts by three diameter classes (8-15 cm; 16-25 cm; >25 cm dbh); and fecal pellet counts by groups (deer and elk) and individual feces (cattle). Pellet groups were defined as any assemblage of feces consisting of three or more pellets from the same defecation (Bunnefeld et al, 2006). Pellet groups give relative frequency of species' visits (use) of aspen stands; they are not direct measures of browse intensity. Two mature representative, healthy, aspen and two conifer (if present) were aged at breast height to determine overall stand age. Finally, field personnel recorded

recent disturbances, if applicable, across the sample ha^{-1}. All transect data were expanded to represent conditions on a ha^{-1} basis for analytical purposes.

III.   Analysis

Analytical efforts for this work were exploratory in nature, meaning our intent was to determine the most important measures among a suite of environmental variables. First, we wished to combine proven aspen landscape survey methods (Rogers et al. 2010) with experimental techniques designed to simplify monitoring methods for future work. Thus, we were in search of key metrics, or "indicators," of aspen conditions. Two non-parametric tests were used to address indicators individually. The two-sided Wilcoxon-Mann-Whitney U test was used to evaluate field variables for differences between seral and stable aspen stands to establish whether such a delineation was ecologically meaningful. The Kruskal-Wallace test, a non-parametric equivalent to analysis of variance, was the primary means of assessing the usefulness of the stand condition ranking. Direct measures of aspen mortality, condition and amount of regeneration and recruitment, and level of browsing (Table 1) were not considered independent of stand condition, therefore they were removed from these tests of group differences. We evaluated the remaining field variables for group effects based on their overall rating of good, moderate, or poor stand condition. The Kruskal-Wallace test does not provide a between-groups test of significance, thus further evaluation of stand condition, as well as other field measures, would be addressed with a broader statistical approach using the entire data set in distance matrix analyses.

Nonmetric multidimensional scaling (NMS) is an ordination technique that provides a robust method of understanding salient structure within ecological data sets which are expected to be nonnormal and discontinuous in their nature (McCune et al. 2002). Our goal in using NMS was to seek out critical measures of aspen stand conditions within our data set to provide a basis for evaluating the entire Book Cliffs landscape. The wide variation in data types (e.g., counts, ratings, digitally generated location data, measures, cover estimates) required a flexible and defensible analytical approach such as NMS (Peck 2010). An initial outlier analysis was performed to check of data anomalies (Peck 2010). We used the PC-ORD software to conduct NMS and produce related graphic outputs (McCune & Mefford 2006). The ordination was initiated with a random start number upon 250 runs of the actual data set. We assessed final NMS solution dimensionality by plotting stress as a function of number of dimensions or axes. Where two consecutive dimensions were $\leq$ 5points of stress apart the lower dimension was selected as our optimum solution (McCune et al. 2002). A Monte Carlo test was then run on the lowest stress solution using 250 randomized runs to evaluate the probability of our result being greater than chance occurrence. For all analyses in this study results were considered significant when reaching the 95% confidence interval (i.e., p-value $\leq$ 0.05).

IV.   Results

Two-thirds (66%) of our survey locations were considered stable aspen and the remaining one-third were seral to conifer species. We found several significant differences in environmental variables by these two primary aspen stand types (Figure 2). Overall, stable plots were at higher elevations ($Z = -2.69$; $p = 0.007$), with lower slope angles ($Z = 3.78$; $p < 0.001$), had greater

regeneration (Z = -2.95; p = 0.003), and more trees ha^{-1} (Z = -2.21; p = 0.027). Seral aspen in the Book Cliffs were significantly older than stable aspen forests (Z = 2.09; p = 0.039). Stable stands are experiencing heavier levels of browse (Z = -2.21; p = 0.038; box plot not shown) which likely relates to higher scat counts among cattle (Z = -3.85; p < 0.001), elk (Z = -3.59; p < 0.001), and the total scat (Z = -4.41; p < 0.001). Deer pellet counts were not significantly different between stand types (Z = -1.13; p = 0.257). Elk feces accounted for 67% of the total scat count, with cattle and deer at 22% and 11%, respectively.

Figure 2: Wilcoxon-Mann-Whitney U test results displayed in box plots showing significant differences between seral and stable aspen types by plot-level indicators across the study landscape. Wilcoxon mean scores are shown on the Y-axis. Whiskers show minimum and maximum values, boxes represent 25-75% data ranges, horizontal lines within boxes are medians, and diamond symbols are means. Only results with > 95% confidence intervals are shown.

Elk Scat

Z = -3.59
p < 0.001

Cattle Scat

Z = -3.85
p < 0.001
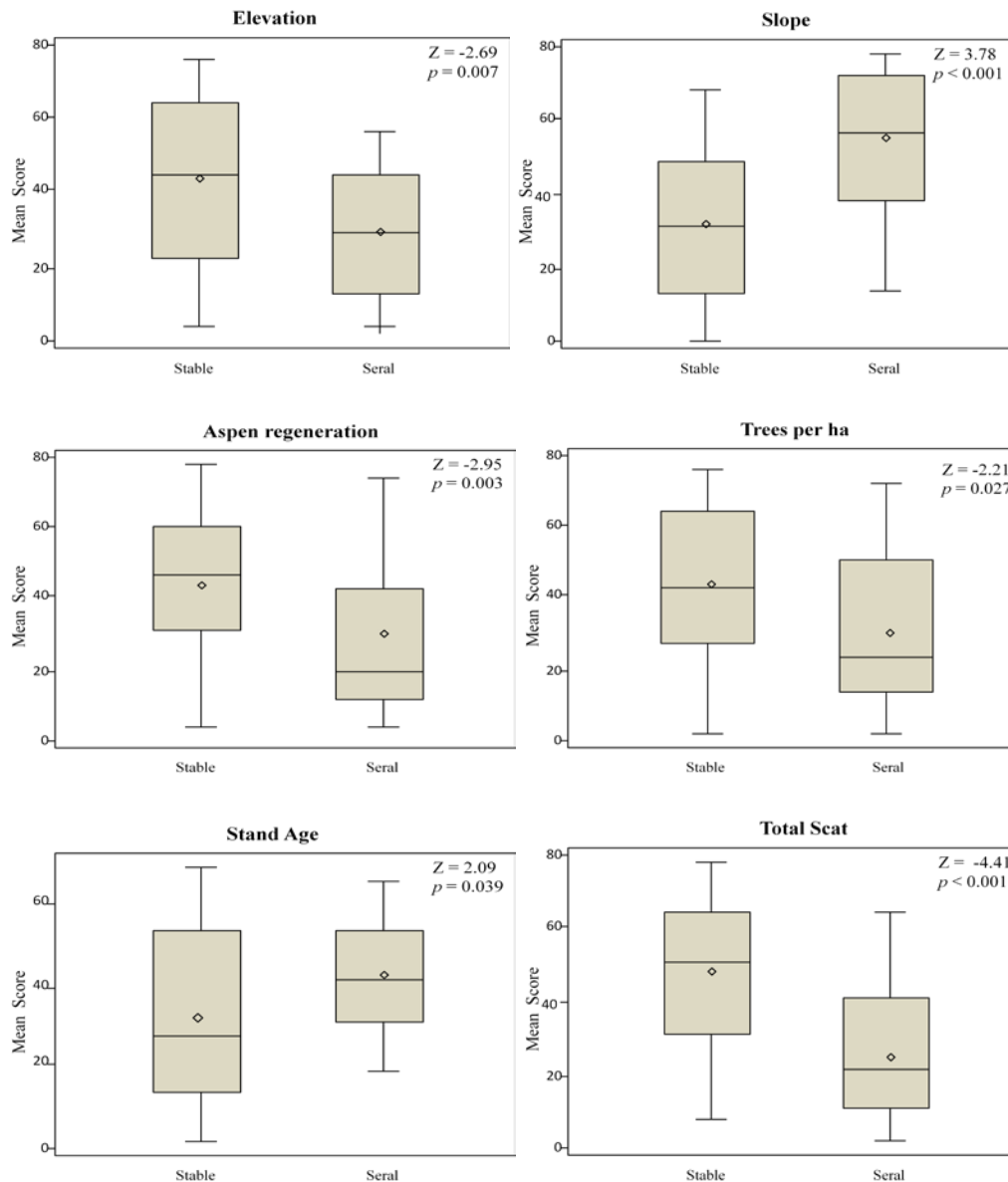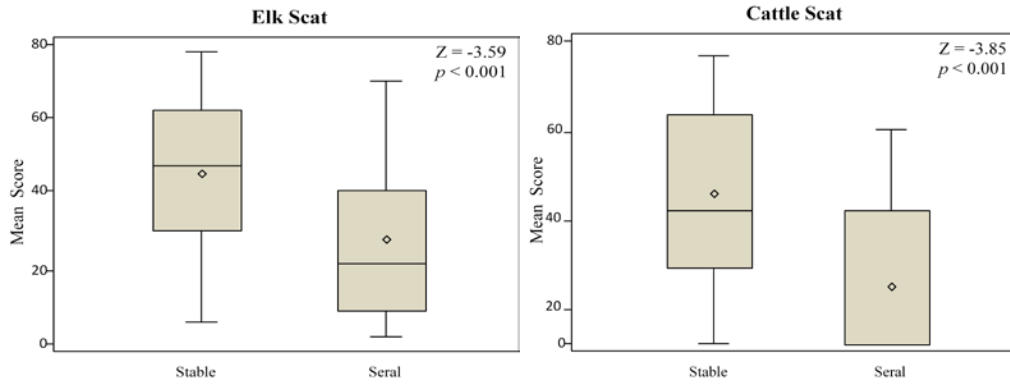
Recruitment levels were equally low in seral and stable aspen communities across our study area. Only three of 77 sampled plots contained greater than 500 recruitment stems ha^{-1}, a suggested minimum threshold for stand replacement (O'Brien et al. 2010). Given that many sample plots had fewer than 500 mature trees ha^{-1} we took a closer look at aspen recruitment based on local conditions. Using a more site-driven approach, we calculated live recruitment as a percentage of total mature trees ha^{-1} with the logic that 100% would support complete immediate stand replacement and 50% ample recruitment for gradual (i.e., gap-phase) replacement. Even this conservative consideration yielded very poor recruitment across the Book Cliffs landscape (Figure 3). Ninety-four percent of sample plots had a fewer than 50% recruitment based on total mature trees ha^{-1}. Fifty-five of the total 77 aspen stands had zero recruitment.

Figure 3: Histogram depicting the number of sample plots by the ratio of recruitment stems (> 2 m height) to overstory aspen trees ha^{-1}. Ninety-four percent of sample plots in the study area had less than 50% of the overstory stem count. The majority of aspen stands had zero recruitment.

n = 77
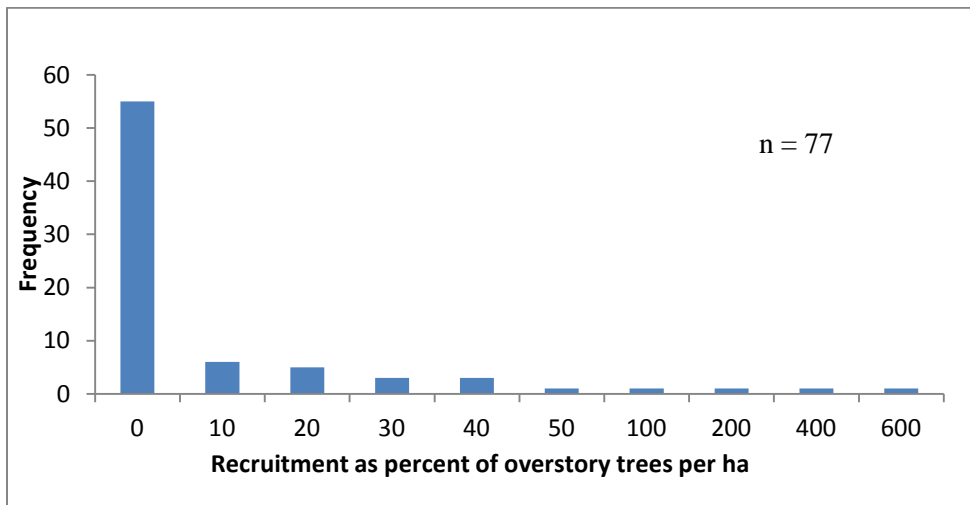
In addition to a number of objective field-based metrics of aspen forest conditions, we tested the efficacy of a subjective stand condition rating system. We found several significant group trends

along our stand condition continuum (Figure 4). Aspen polygons in both poor and good condition were at higher elevations than those with moderate visual impacts; stands in the worst condition were found at the highest elevations ($\chi^2 = 7.62$; $p = 0.019$). As expected, as stands age their condition deteriorates ($\chi^2 = 9.60$; $p = 0.007$). Basal area ($\chi^2 = 10.58$; $p = 0.004$) and trees ha^{-1} ($\chi^2 = 20.15$; $p < 0.001$) decreased as stands condition declines. As an indirect measure of browsing impact, there were significant increases in elk scat ($\chi^2 = 20.09$; $p < 0.001$) and total scat ($\chi^2 = 17.68$; $p < 0.001$) as stand condition deteriorates. Both cattle ($\chi^2 = 3.95$; $p = 0.138$) and deer ($\chi^2 = 4.59$; $p = 0.106$) failed to show significant relationships to stand condition. Overall, these data provide significant and visually compelling trends, but do not specify differences between each group. To pursue this further, we explored overall dataset structure using more powerful analytical tools.

Figure 4: Kruskal-Wallace test results are displayed in box plots showing significant differences between aspen condition classes across the study landscape. We intentionally did not test variables directly related to condition class elements (Table 2) in an effort to independently assess the value of the rating system. Wilcoxon mean scores are shown on the Y-axis. Whiskers show minimum and maximum values, boxes represent 25-75% data ranges, horizontal lines within boxes are medians, and diamond symbols are means. Box plots display general trends between three classes; test results apply only to an overall group difference. Only results with > 95% confidence intervals are shown.
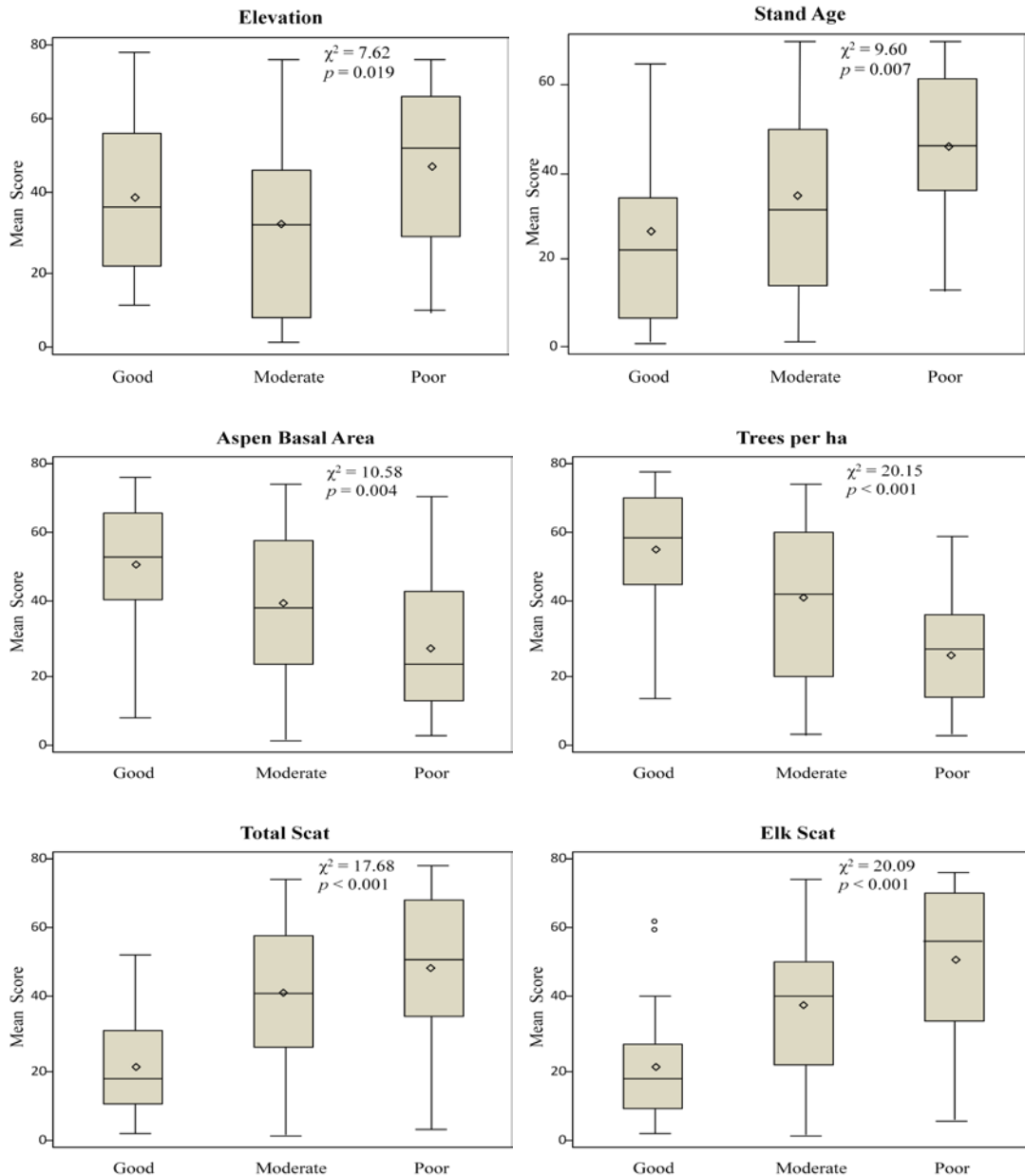
Nonmetric multidimensional scaling (NMS) provided a parsimonious method for exploring distance relationships by ordination of all variables in "sample plot space." No data or plots were eliminated in outlier analysis. NMS ordination produced a 2-dimensional (i.e., axes) solution with a

12

final stress of 12.03 (instability < 0.000). We assessed stability by plotting a graph of stress versus number of iterations. Stability was reached at 54 iterations from a maximum of 500 runs of our "real" dataset. Monte Carlo test results indicate that the two-axis solution using real data was significant (p = 0.004). Two axes explain nearly all of variability in the Book Cliffs aspen dataset (Axis 1: r^2 = 0.61; Axis 2: r^2 = 0.31; total r^2 = 0.92, orthogonality = 97.3%). Cumulatively, the degree of stability, randomization results, and variability explained by the two-axis solution indicate a highly significant final NMS result (McCune et al. 2002). An ordination joint plot and the categorical variable "stand condition class" were overlaid on the results of the NMS (Figure 5). Axis 1 strongly represents aspen regeneration ha^{-1} and to a lesser degree aspen recruitment. Axis 2 displays a robust alignment with overall scat ha^{-1}, as well as to individual browsing species; dominantly elk. All environmental variables are presented here in terms of Pearson's coefficient (r) values as they relate to the primary axes identified in NMS (Table 2).

Figure 5: Nonmetric multidimensional scaling results are shown in a joint plot which highlights prominent indicators within the total Book Cliffs data set. Vectors with > +/- 0.5 Pearson's coefficient (r) value (Table 2) are displayed in relation to "plot space". The length of vectors corresponds to their r-value ("as_regen" = aspen regeneration; scat_ha = total scat; elk_ha, cow_ha, deer_ha = species scat counts). Aspen stand condition ratings are superimposed within plot space to depict general relationships to the primary axes. Axis 1 displays general trends in regeneration, recruitment, aspen basal area, and aspen trees ha^{-1}. Axis 2 corresponds to animal presence, prominently elk, polygon-level aspen cover (+) and conifer cover (-), and percent of regeneration browsed.
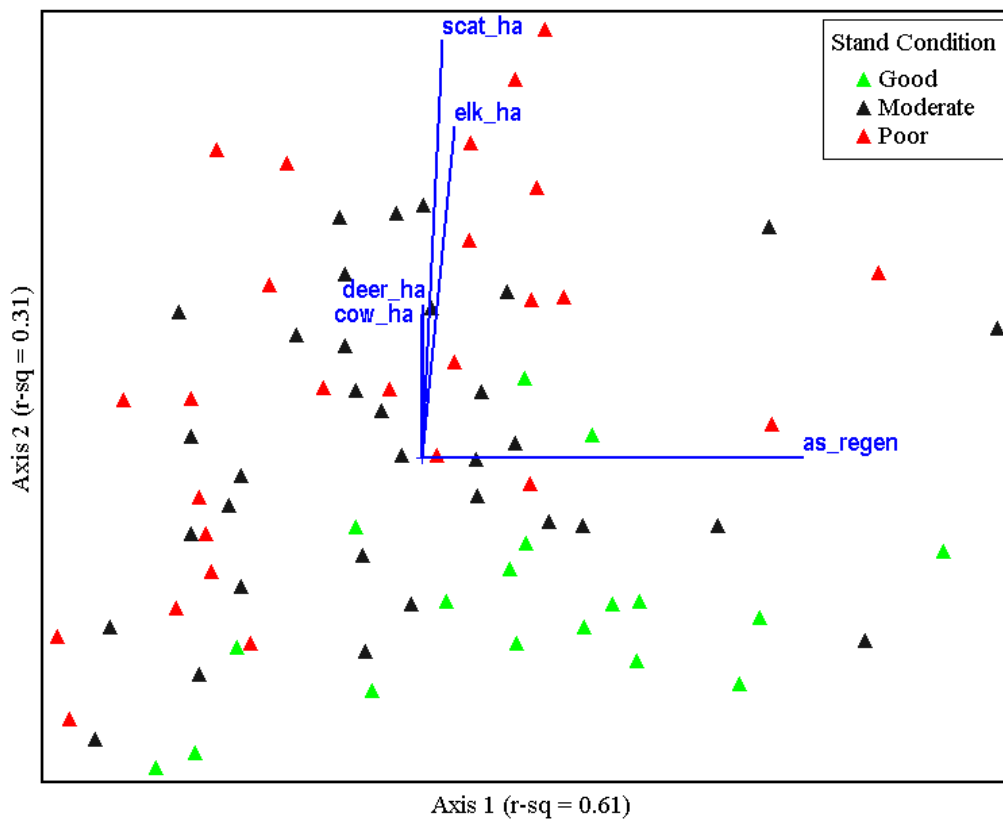
Table 2: Pearson's coefficients (*r*) between environmental variables and primary ordination axes. The strongest response variables are in bold type where *r* > 0.5 or < -0.5.

Variable name	*r* - value Axis 1	Axis 2
Elevation	0.361	0.225
Aspect	0.137	0.083
Slope	-0.169	-0.271
% Polygon aspen	0.334	0.515
% Polygon conifer	-0.244	-0.488
Aspen stand age	0.051	-0.112
Total scat per ha	0.206	**0.943**
Cattle scat per ha	0.011	**0.551**
Elk scat per ha	0.264	**0.839**
Deer scat per ha	0.043	**0.570**
Aspen cover ha	0.255	0.042
Conifer cover ha	-0.101	-0.282
Sagebrush cover ha	0.005	0.261
Total tree cover ha	0.165	-0.145
Aspen regeneration	**0.900**	0.046
% regeneration browsed	0.315	0.388
Live aspen recruitment	0.343	-0.233
Small tree BA	0.236	-0.147
Medium tree BA	0.213	0.033
Large tree BA	0.019	0.080
Total aspen BA	0.296	-0.023
Aspen trees per ha (TPA)	0.339	-0.091
Recruitment as % of TPA	0.328	-0.226

V. Discussion: Indicators and Herbivore Impacts

Key Indicators for Future Monitoring of Aspen in the Book Cliffs

We set out to conduct a landscape assessment of aspen communities in the Book Cliffs of eastern Utah. In order to accomplish this, we sought to establish key measures of aspen conditions within a relatively efficient (i.e., a goal of > two hours per stand assessment) field-based protocol. Our random sample of nearly one-third of all stands in the area showed an overall aspen population under moderate-to-high threat. Stable aspen make up two-thirds of the Book Cliffs aspen landscape, thus continuous recruitment is crucial to long-term forest vigor. Only 23% aspen polygons were rated as being in good condition based on visual assessments of stand mortality, regeneration and recruitment, and browse levels (Table 1). While 27% of sample sites contained minimum required regeneration levels, just three of 77 stands contained adequate levels of recruitment (O'Brien et al. 2010). Whether aspen produces many or few suckers over time is less important than survivorship above browse

level. Once above this height, understory stems can eventually fill canopy gaps as the relatively short-lived canopy trees die. In fact, resilience, particularly in stable aspen, depends on a diverse height and age profile. In an effort to gain appropriate measures of recruitment based on site-specific data, which include relatively low water resource availability (Mittanck 2012), we looked at recruitment as a proportion of actual live mature stems (Fig. 3). Even with this more conservative adjustment, landscape-level recruitment was very low indicating a great majority of aspen stands with little resilience to future drought or disturbance. Ordination of all physical, mensuration, browse, and scat data gives us a strong indication of what factors are responsible for this poor level of aspen recruitment.

Teasing apart causality among multiple domestic and wild herbivores continues to be a vexing problem for forest, range, and wildlife ecologists. Standard measures of animal and tree populations occur at widely varying scales and browsers may not exhibit predictable movement and feeding patterns from year to year. Moreover, in areas of limited predation and accessible aspen terrain the combined effects of herbivory are severely limiting to aspen recruitment (Beschta & Ripple 2010; Rogers et al. 2010). In the current work, we sampled scat on the same scale (i.e., transects) as forest structure data. To our knowledge, this spatial symmetry has not been attempted elsewhere and may help overcome previous barriers in understanding effects of widely roaming herbivores at stand-levels. Browse levels were moderate-to-high across most of the study area as reflected by a 51% average browse level combined with very low levels of recruitment. Olmstead (1979) suggests that more than 30% aspen sucker utilization by elk lead to declines in stand density. Others suggest a more conservative guideline where > 20% annual browse of aspen leaders will result in decreases in stand density (Jones et al. 2005). Further connections between elk use, browse level, and recruitment success are presented for the Book Cliffs landscape through ordination (Fig. 5; Table 2). In NMS analysis, Axis 1 positively represents aspen regeneration, as well as moderate correspondence to recruitment and trees ha^{-1}. Axis 2 relates most strongly to elk scat counts, but also to deer and cattle scat. Additionally, axis 2 corresponds with percent aspen canopy cover (negative to conifer cover) and heightened browse levels (Table 2). This indicates greater impacts and use of stable aspen stands by all herbivores likely due to their generally moderate terrain.

Our study used scat counts to represent herbivore use of aspen habitat and indirectly level of aspen browse. Use of scat counts as surrogates for habitat use have been criticized by some (Smart et al. 2004), but favored by others when compared to animal radio-telemetry data (Borkowski 2004; Bunnefeld et al. 2006). The central advantage of the scat count method was a direct correspondence of site and scale of sampling. Studies using radio-telemetry cannot be easily calibrated to our stand-level sample units and thus would be very difficult to understand as we attempted to measure landscape conditions and habitat use based on these ha^{-1} measures. A disadvantage when comparing between species is that each feces occurrence cannot *a priori* be assumed to mean the same level of use. We feel, however, that nominal differences between elk—two-thirds of all scat; > 3x cattle and > 5x deer—and other herbivore scat counts provide proximate evidence for elk's primary role in limiting aspen recruitment on this landscape. Ordination results (Fig. 5; Table 2) confirm a dominant role of elk among all herbivores and only elk and total scat counts related significantly to our stand condition rating system (Fig. 4).

Our chief motivation for developing an aspen stand rating system was efficiency. Degraded aspen communities in our region are commonplace (Binkley 2008; Worrall et al. 2008; Rogers et al, 2010), therefore a quick and credible means for managers to assess conditions across very large landscapes is desirable. We pitted several objective measures of aspen systems against our subjective

stand condition and confirmed the utility of this measure as a surrogate for overall condition, as well as aspen mortality, stand structure, regeneration/recruitment, browse, and (independently) animal use. We consider the high correspondence to scat ha^{-1} (Fig. 5) an independent estimate of herbivore use, as there are no direct elements of scat or animal visitation in our stand condition classes (Table 1). Where resources are low and there is need for widespread aspen monitoring we suggest use of stand condition ratings alongside key site measures, such as regeneration, recruitment, and browse counts, to glean meaningful information with minimum expenditure.

Large Herbivore Impacts to Aspen Ecosystems in the Book Cliffs

Consumption beyond replacement level of understory plants, and in particular juvenile trees, by large herbivores is common globally (White et al. 1998; Gill 2006; Edenius & Ericsson 2007; Takatsuki 2009; Tanentzap et al. 2009). In areas dominated by conifers in the western United States aspen provide unique habitat and high levels of biodiversity (Kuhn et al. 2011). As a keystone species (Campbell & Bartos 2001; Edenius et al. 2011), loss or reduction of aspen communities has cascading effects on dependent biota (Bailey et al. 2007; Rogers & Ryel 2008; Kuhn et al. 2011) including target herbivores (Beck et al. 2006). In the Book Cliffs, we consider aspen forests to be of relatively low resilience to environmental changes due to low water availability and generally moderate- to low-angle slopes (Mittanck 2012; Sexton et al. 2006). A basic definition of *ecological carrying capacity* (Beck et al. 2006, p.283) simply states "an equilibrium between populations of plants and herbivores in the absence of harvest." Evidence presented here suggests that browsers, particularly elk, are beyond carrying capacity for the Book Cliffs aspen landscape and are having long-term effects on this landscape. Potential for significant aspen cover loss is high with consequent effects on dependent species. With continued heavy browsing, we should expect to see stand decline and loss of entire age cohorts that coincide with noted increases in large herbivore populations (Binkley 2008; Beschta & Ripple 2010). Furthermore, sites at lower elevations in accessible terrain may be most vulnerable to predicted warming climates via reduced snow cover which carries the dual negative impacts of decreased water resources and increased winter access by browsers (Martin & Maron 2012).

VI.   Field and Remote Surveys: A Comprehensive Look at Book Cliffs Aspen

Supplementary Mapping Project

A key output of Cody Mittanck's work in remote sensing and mapping of aspen stands is a greatly refined estimation of total aspen coverage, as well as a more accurate depiction of all aspen stand locations, within the Book Cliffs. The report titled, "Book Cliffs Aspen Study: Supplementary Mapping Project, Uintah County, Utah" is on file with the Vernal Field Office of the BLM. The report contains detailed documentation of methods used, a map showing all aspen polygons greater than 0.5 ha having more than 50% aspen cover, and a "map book" of each polygon at 1:5,000 scale with polygon centroid coordinates. Based on these the polygon criteria above, we mapped a total of ~70 ha (174 acres) in 268 aspen polygons. The 2012 field monitoring indicates about 66% of the locations are stable and the remaining 34% seral aspen, although this mapping project found a higher percentage of mixed types (though with greater error expected). The map book also includes the

following key plot summary data for each aspen polygon field sampled in 2012: stand type, condition rating, number of aspen layers, regeneration and recruitment per hectare, percent regeneration browsed, fecal counts by species, and photo IDs for the four cardinal directions. Both the map book and the reference photos from sample plots are meant to provide an ongoing resource for specific polygon/plot conditions for land managers. It was our intention to provide the BLM with practical aerial photo/remote sensing-based products that, overall, supplement the detailed field data collection of aspen conditions. This supplementary report allows application of results in the main report to the entire Book Cliffs aspen resource.

2013 Roadless Area Aspen Study

Cody Mittanck, CNL Environmental Consultants, contracted with the Utah Division of Wildlife Resources (UDWR) and the BLM in 2013 to conduct an aspen survey of the roadless portion of the Book Cliffs region (west of the current study area). There were three prime differences that the 2013 study incorporated: 1) a much greater proportion of seral aspen, 2) a large wildfire burned area, and 3) a lack of cattle grazing allotments. This work titled, "Book Cliffs Roadless Area Aspen Study 2013: Grand & Uintah Counties, Utah" is on file with the UDWR and BLM Vernal Field Office. A promising result from this survey was the strong aspen regeneration and recruitment response within the burned portion of the study area. It is unclear whether this positive response is due to steeper terrain, higher elevations, size of the burned area, or differences in elk numbers, movements, or browse habits. There was no clear result showing that the lack of cattle in the 2013 survey area produced lower browse in aspen, however the author did notice less herbaceous forage across the 2012 sites where cows were present; perhaps greater availability of forage in the 2013 study area allows more aspen sprouts to survive (i.e., forage "shifting" by elk), particularly following wildfire. However, while we might expect to see differences in regeneration levels given the high (72%) of seral aspen stands, there was little difference in poor recruitment levels when measured as a percent of live overstory aspen. The percent of plots with zero recruitment was 71% in 2012 and 69% in the 2013 survey. Nearly all of the 2013 locations with strong levels of recruitment were found in the burned area. There was evidence to suggest that these burned sites contained dense enough recruitment to inhibit elk access and further regeneration browse. Overall, the level of seral communities in the western portion of the Book Cliffs allows greater options for treatment of imperiled aspen communities. Land and wildlife managers may use a combination of silviculture, prescribed fire, wildland fire, and wildlife manipulation to rectify poorly reproducing aspen. However, this doesn't nullify the prominence of stable aspen, particularly in the east (66%) though also in the west (18%), and the strong need to address the lack of structural diversity wrought by repeated browsing in these communities (see recommendations below).

VII.   Management Recommendations

Aspen Functional Types as a Starting Point

Our findings clearly show two distinct aspen types occupying different realms of key environmental variables (Fig. 2). This overall picture generally fits that of the Colorado Plateau stable and montane seral functional types described by Rogers et al. (in review), although the Book Cliffs appear to be within the lowest elevation and precipitation niche for western aspen (Sexton et al.

2006; Mittanck 2012). With these results in mind, future management should focus on functional distinctions for appropriate treatments and monitoring. Recommendations in this and the following section on herbivory rely on type-specific distinctions and actions that emulate ecosystem processes.

Within the study area, a novel finding is that seral aspen occupy relatively lower elevations, unlike other locations where stable aspen is common on the Colorado Plateau (Rogers et al. 2010). We do find, however, that pure aspen types often occur on lower slope angles which make them more vulnerable to herbivores (Harniss & Harper 1982). Our results confirm use on lower angle slopes as heavier levels of elk and cattle occupancy occurred in stable aspen forests. It appears that deer use both seral and stable habitat equally, though at lower overall levels.

In terms of stand structure measures, we also found evidence of distinct functional groupings between seral and stable aspen. Where aspen are seral to conifers, stands are generally older than pure sites (Fig. 2; Rogers et al. 2010), although clear indication of stand age is sometimes difficult in healthy uneven-aged stable aspen. Seral stands in the Book Cliffs contained less mature aspen trees ha^{-1} than the upland stable type. Greater aspen regeneration on upland stable sites corresponds to overall tree counts. Although there is more regeneration in stable forests, it appears an insignificant number of stems in either functional category are surviving to a recruitment stage (Fig. 3). Thus, where stable aspen (particularly) should exhibit multiple stand layers, we found only about one-third (35%) of such vertically diverse locations in the Book Cliffs. The low overall tally of recruitment (Fig. 3) amplifies the lack of vertical diversity and high level of concern at the landscape-scale.

A note on riparian aspen: We did not independently assess riparian aspen communities due to the often narrow/small size not fitting our survey methods. This should not undermine their unique characteristics as a distinct aspen functional type (Rogers et al., 2014). For example, these narrow corridors may attract even greater biodiversity and transient wildlife use. Riparian aspen may well engender a more resilient type due to their proximity to above- and below-ground water. Adding further complexity, riparian aspen may be either of seral or stable nature and are often contiguous to upland seral or stable types. Thus, a single "stand," as sampled in the current survey, may require nuanced management actions where riparian and upland aspen types are adjacent to each other.

Recommendations Herbivore Impacted Aspen Communities

We recommend restoration of aspen forests based on appropriate aspen functional type (Rogers et al. in review). In the current work we have highlighted key environmental differences between seral and stable aspen. With a view toward restoration, we favor emulating ecological processes that have shaped these aspen systems for centuries. While seral aspen depends on irregular fire and other stand-replacing disturbance, stable communities are driven by small group- and tree-level mortality and continuous or episodic recruitment (Harniss & Harper 1982; Kurzel et al. 2007). Thus, commonly prescribed burning or clear-felling are in many cases appropriate for seral aspen and inappropriate for stable types. Once browse pressure is removed, or reduced to a sustainable level, stable aspen often need little or no stimulus to rejuvenate their stand structure. If herbivory cannot be curtailed stable stands will eventually die-off and seral stands may be overtopped by conifers. In fact, Edenius et al. (2007), working in European aspen (*P. tremula*), found that heavy browsing in the absence of disturbance—either human-caused or natural—will accelerate succession toward conifer dominance to the detriment of remaining mature aspen. In smaller stands, or specific environmental situations (e.g., riparian or recreational locations), aspen may be protected by temporary fencing from browsers. However, this protection strategy is not feasible for large landscapes where fencing is cost prohibitive. Finally, we encourage allowance for natural or prescribed burns to increase changes of

genetic diversity through aspen seedling establishment. This strategy is more appropriate for seral types that burn more readily, than for stable aspen that are generally not susceptible to fire (Shinneman et al. 2013). While it is now accepted that aspen establishment by seed is more common than previously thought (Long & Mock 2012), we have little understanding of mechanisms of occurrence in stable types where evidence suggests high genetic diversity, too (Mock et al. 2008). In the end, both seral and stable aspen will require significantly reduced browsing, thus elk population reduction should be considered a core strategy where heavy browsing, such as in the Book Cliffs, can be credibly documented. Secondarily, seral types may require complementary conifer disturbance to create forest openings and facilitate both seedling and sucker regeneration (Long & Mock 2012; Rogers et al. in review).

Monitoring Recommendations

Monitoring is often a task relegated to lower priority. Following the "Guidelines for Aspen Restoration…" (O'Brien et al. 2010) we strongly discourage this approach. Without vigilant monitoring the likelihood of repeating past resource stewardship errors of omission and commission are high. Pre- and post-treatment monitoring using a scheme similar to the one tested here is required to further understand if actions are having desired restorative effects. For example, use of fenced exclosures, while appropriate for demonstrative purposes, raise concerns when prescribed as a landscape-level management option. Past exclosure studies have shown that aspen will respond heartily to complete protection (Kay & Bartos 2000; Kay 2001). Monitoring within and outside exclosures will give reliable measures of sprouting ability and no-browsing protection, respectively, but provide little useful information regarding reduced herbivory in the context of stand- or landscape-level aspen restoration. For this reason, the current study area as well as locales with similar browse issues, will require documentation of active (stimulus) and passive (reduction or removal of browsers) management effects. While we fully expect confounding factors (i.e., climate, disturbance, human impacts), our overall objective with monitoring and adaptive management is to facilitate future aspen community resilience. In a setting such as the Book Cliffs that is predisposed to low resilience, managers should focus resources toward increasing the systems' capacity to rebound under expected stresses. Ongoing monitoring for treatment and environmental effects, positive and negative, is precedent setting in terms of making appropriate, data-based, adjustments as conditions change.

We recommend adoption of the aspen stand condition rating system used here to evaluate, with little resource investment, general conditions in aspen stands of this area. Visiting as many of the 268 polygons shown in the "Book Cliffs Aspen Study: Supplementary Mapping Project" and performing the rating based on methods described herein will give BLM managers the most robust aspen landscape assessment available. Additional key measures that should be gathered include, at minimum, counts of regeneration and recruitment, regeneration browse level, condition of overstory (live, dead, and disease presences), and animal presence assessment. We recommend a scat count such as the one used here. A survey including the rating system only can be completed in under 20 minutes, additional "minimum" measures listed here would add another 30-60 minutes, and the complete inventory used to conduct the present report takes a total of 1.5-3 hours depending on conditions. Even more detailed stand exams or forest inventory monitoring methods are available, though we felt it was more important to include as many aspen polygons as possible rather than gained detailed measures at fewer sample sites.

Commonly resource managers address proposed actions, such as those needed to restore Book Cliffs aspen, in terms of a range of prescriptions from no action to intensive management. We agree with the recommendations of the "Guidelines for Aspen Restoration…" (O'Brien et al. 2010) that, while multiple actions may aid the restorative process, the greatest effort should be taken to address *the cause* of the problem. In the Book Cliffs there chief cause of aspen degradation is herbivory by wild elk and domestic livestock. Secondarily, long-term fire suppression may be having some effect on seral aspen, though this cannot be assumed without further pointed research. If no action is taken to address these the number and movement of browsers we can expect continued, and perhaps accelerated, landscape-level aspen deterioration. Similarly, as demonstrated in the 2013 survey, allowance for as much wildfire in seral aspen communities as possible will have likely have positive outcomes for aspen rejuvenation, provided that post-fire stands are not heavily browsed. Moderate actions, such as limited fencing, may only serve to shift ungulates to adjacent communities or other aspen stands. In effect, fencing as a management strategy relocates, but doesn't really address, the problem of stymied reproduction.

In the absence of predators, increased hunting, sterilization, or translocation of overabundant elk may provide options for recovery. Published findings suggest a minimum of 30% reduction in elk numbers (Seager et al. 2013) and/or no more than 20% annual browse (Jones et al. 2005) can provide initial guideposts toward sustainable aspen management. An alternative to wildlife culling is fertility manipulation via contraception: either temporary or permanent control agents may be employed. One study, using modeling techniques to predict future population trends, found that temporary fertility control yielded better results than herd culling or permanent contraception (Bradford and Hobbs 2008). Any herbivore management scheme is contingent upon consistent follow-up monitoring to test management practices. Previous and current work, reinforces the critical nature of monitoring of recruitment and animal presence (at a minimum) in aspen ecosystems where ungulate browsing is affecting resilience (Seager et al. 2013).

We recommend solutions using a combination of approaches focusing on symptoms and causes: ecologically appropriate protection of select stands in conjunction with active initiation of new aspen stems, while also curtailing landscape-scale herbivore numbers and sedentary time in WCR aspen. The "Guidelines for Aspen Restoration…" (O'Brien et al. 2010, p. 28-29) provides a long list of potential management tools or "responses" for specific situations. We should also consider focusing additional resources on better understanding why elk are heavily using some areas while only lightly browsing others. Aspen treatments should initially be limited and carefully monitored for financial, ecological, and conservation reasons. The highest priority should be placed squarely on reducing elk populations or changing their behavior to decrease their impact on the ranch. Other actions will have limited benefit without reduction in browsing intensity. Protection of regeneration in targeted stands should be used as long as elk numbers remain high, though there is potential for elk impacts to simply be relocated and concentrated outside fenced areas. Stimulation of additional regeneration in protected stands should be considered experimental or used when monitoring indicates that a stand will not be capable of regenerating itself at levels that lead to stand-replacing recruitment.

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