2013

Wolf Creek Ranch Aspen Monitoring Report

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Wolf Creek Ranch Aspen Monitoring Report

September 2013

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EXECUTIVE SUMMARY

Project Summary: In the summer of 2012 we undertook a landscape assessment of aspen forest conditions at Wolf Creek Ranch (WCR) near Kamas, Utah. Using a geographic information system (GIS) coverage of predicted aspen coverage, fifty systematically selected field "plots" were located and mapped with aspen stands around WCR. Seven plots were eventually discarded from our survey due to lack of aspen cover. Volunteer field crews, mostly WCR homeowners, collected aspen data documenting tree sizes, height/age groups, diameters, reproduction, mortality, browse levels, and browse animal use levels.

Aspen Conditions: Young aspen, growing primarily from established roots as "suckers" (not from seeds), are a key measure of forest resilience to future deterioration. On nearly half of the 43 plots with aspen cover, we found that "recruitment" (trees 6 ft to 20 ft tall) of new aspen stems was insufficient for stand replacement. We documented high levels of browsing on young aspen and correlated several elements to elk use of the area, suggesting that low levels of aspen recruitment correspond with elk browsing. Low detection rates of sheep and deer suggest that these animals have little effect on aspen recruitment in the study area. Aspen mortality in mature trees at WCR is reflected in general thinning of canopy cover and possibly drying out of understory vegetation where shrub cover is replacing formerly lush grass and herb cover.

Spatial Patterns: We found forests on the east side and central portion of the ranch to be experiencing higher levels of damage. There was a moderate relationship between lower slope angles and heavier elk use and browse levels. We found no direct correlations to elevation, likely due to the relatively small differences in this measure across the study area.

Causes: The chief cause of deteriorating aspen as WCR is elk browsing. While past sheep grazing and current deer browsing likely contribute to current lack of recruitment, there is little doubt that moderate-to-high elk numbers pose the greatest concern.

Recommendations: High elk numbers, as well as their relative lack of movement must be addressed to improve aspen conditions at WCR. Elk may be reduced by hunting, relocation, fertility prevention, or experimental combination of these approaches. Elk movement may be enhanced with harassment via noise making, non-lethal shooting, or guard dogs. Stimulation of new aspen recruitment using selective tree cutting or girdling, root ripping, or light burning may supplement browser deterrence, if passive regeneration is insufficient for stand-replacing recruitment. Fencing in targeted areas will assist recruitment, but may be cost prohibitive across large landscapes. Monitoring of both successes and failures is crucial to sustainable aspen management.
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INTRODUCTION

Overview and Objectives

We undertook a landscape assessment of aspen forest conditions at Wolf Creek Ranch (WCR), Utah. The systematic, quantitative, monitoring design used here allowed us to assess the aspen forests here in a scientifically defensible manner. This assessment gave us a more informed picture with which to identify and implement actions required to sustain a desirable aspen landscape. Stakeholders at WCR should understand that preservation of dynamic ecosystems like these aspen forests does not imply lack of change. Rather, we hope to preserve these forests in a landscape influenced mainly by forces of nature, and secondarily by human actions, with the goal of a sustainable ecosystem that includes aspen. Aspen forests are among the most biodiverse vegetation types in Rocky Mountains, and a large number of plant and animal species depend on the preservation of these forests. These aspen forests also have great aesthetic, recreational, economic, and intrinsic value for the WCR property owners. The great effort that has gone into this project shows our high regard for the WCR landscape.

Objectives: In July 2012 data collection commenced for monitoring aspen forests at WCR. Data compilation and analysis took place through the winter and spring of 2012-13. This effort had three objectives:

1. To provide a scientifically credible assessment of conditions across the entire aspen landscape at WCR.
2. To test the feasibility of data collection by "citizen scientists" (primarily WCR property owners) for forest indicators representing broad conditions. Specifically, we measured environmental parameters, stand structure, regeneration and recruitment, visual condition, browse level, and ungulate use (i.e., sheep, deer, elk) in aspen stands at WCR.
3. To make recommendations based on this assessment for sustainable management of future aspen forests at WCR.

Quaking Aspen in the West: Background

Aspen communities are often considered biodiversity “oases” surrounded by dominant conifer or meadow types in western settings (Mueggler 1985, Griffis-Kyle and Beier 2003, Rogers et al. 2007, Kuhn et al. 2011). While aspen forests are highly valued for their flora and fauna, in some locales herbivores are having a great impact on the ability of these systems to properly function and maintain high biodiversity. Specifically, browsing ungulates—both wild and domestic—in many areas are inhibiting regeneration as they consume aspen sprouts (DeByle 1985, Zeigenfuss et al. 2008, DeRose and Long 2010, Rogers et al. 2010). This phenomenon seems particularly acute where wild ungulate populations are thought to be above historical population levels, where ungulates have been introduced (e.g., Bailey et al. 2007, Stritar et al. 2010), or where predation is minimal or hunting is not allowed (Beschta and Ripple 2009). Though in some locations reduced elk numbers from wolf predation allow successful aspen recruitment (Ripple et al. 2001), there is some dispute over whether this changes browsing patterns enough to influence regeneration success (Kauffman et al. 2010). Also moose, elk, deer, and other smaller mammals may severely damage mature trees by debarking portions of boles as they eat the bark or, in the case of large ungulates, as they rub bark off during rutting (Hinds and Krebill 1975, DeByle et

Similar to wild herbivores, domestic ungulates will browse sprouts, particularly where preferred forage is depleted (DeByle, 1985; Rogers et al., 2010). The long-term effects of repeated heavy browse of regeneration include single-story stable aspen and elimination of aspen understory in seral systems. In both cases dying mature trees may lose the physiological reserves required to continue producing the next generation of aspen, resulting in the loss of stands as a maturing overstory eventually dies-off.

Aspen, as a pioneer species, is favored by forest disturbance. Following removal of mature forest canopies, via any number of natural or human mechanisms, aspen may produce thousands of root sprouts per hectare (DeByle 1983, Shepperd 2001). Stable aspen types, absent conifer competition, diverge from classic seral forests in their "functional ecology" (Rogers et al., 2013). Where stable (single tree species) aspen predominates gap-phase disruptions drive age and structure diversity. While current management of aspen favors strategies that result in a strong asexual sprouting response following wildfire, increasing evidence suggests that successful sexual regeneration of aspen is important to very long-term spread, survival, and genetic diversity (Mock et al. 2008, Long & Mock, 2012; Callahan et al., 2013). Both large and small fire events have historically played an important role, along with favorable climatic conditions, in aspen’s long-term persistence on landscapes (Kulakowski et al. 2004, Rogers et al. 2011). Conversely, lack of disturbance facilitated by cool and moist climate, promotes conifer domination of shade-intolerant aspen (Rogers et al., 2011).

In areas with limited predation on wild ungulates, wildfire is thought to provide a “window of opportunity” for successful aspen recruitment. Further, it is believed that future climate warming will invoke larger, more frequent forest fires, along with increasing complexity of multiple disturbance types—a scenario favorable to aspen persistence if herbivory of post-disturbance recruitment is limited (Kulakowski et al., 2013). An idea has been advanced by numerous state and federal wildlife and forest managers that scale of disturbance is key to successful aspen recruitment. The theory suggests that if wildfires or other disturbance agents impact enough potential aspen habitat, the large amount of sprouting over a large area will effectively “swamp” herbivore consumption rates, thereby allowing some percentage of successful aspen recruitment. This theory has not been tested to date. Better understanding of the interactions of disturbance scale, intensity, and ungulate consumption patterns following wildfire, will greatly inform future management decisions toward building aspen resilience under future climate scenarios.

**METHODS**

**Area description**

The WCR study area is located in northeastern Utah near the intersection of the Wasatch and Uinta Mountains, adjacent to the headwaters of both Little South Fork or the Provo River and the Lake Creek Fork of the Provo River (Figure 1). The study area consists of an aspen-conifer topped plateau that descends to the north down to the Provo River. Thirty separate soil types can be found on WCR, most being dominated by loams, in a variety of terrains. Overall, the soils of the study area
resemble those typically found in forested landscapes in this region. The elevation of WCR ranges from 6,400 ft. to over 9,000 ft., however most of the aspen on the property can be found between 7,200 and 9,000 ft. The closest rain gauge (SNOTEL #330) recorded an average annual precipitation of 27 inches (694 mm) between 1987 and 2012. Most precipitation occurs as snow between November and February, with June and July being the driest periods. Over the considerable elevational range of WCR, aspen forests vary substantially in clonal characteristics and have in abundance of understory vegetation, having a greater understory brush component at lower elevations (Abraham 2013). In general, aspen and conifer stands at WCR are bounded by mountain big sagebrush (Artemisia tridentata ssp. vaseyana) on adjacent dry sites and, as elevation decreases, maple (Acer grandidentatum) woodlands. Most forested uplands at WCR are dominated by stable aspen communities, with steeper north and east facing slopes occasionally exhibiting Douglas-fir (Pseudotsuga menziesii).

The importance of study design and statistics

It is important to understand the underlying principles of the 2012 WCR aspen survey design in order to appreciate the robustness of the results presented here (see also detailed methods description). To test our perception of aspen decline without bias we devised an objective and statistically defensible means of assessing conditions. Thus, we avoided bias and opinion creeping into our conclusions. We went out of our way to sample the entire aspen landscape systematically. If we chose only locations that
were known to be damaged (or not) or easily accessible, than our results may be called into question. We selected (originally) 50 sample locations with likely aspen forest cover governed by a systematic grid designed and imposed in an office setting. Then at each plot location, designated by geographic coordinates, we aligned our sampling transects in a standardized manner regardless of slope, aspect, or vegetation conditions on the ground. These simple precautions allow us to make credible statements about overall aspen conditions on this landscape. Each of the final plots (43 after non-aspen dominated forests were eliminated) represent about 134 acres of aspen forest in this survey.

Citizen science

A unique aspect of the WCR aspen monitoring project was that data collection was conducted by volunteer (homeowner) field technicians. This so-called "citizen science" is now commonly being used across the nation for natural resource monitoring efforts (Cohn 2008). When science incorporates non-professionals in study implementation there are naturally advantages, and a few cautions, that should be noted (Cohn 2008, Dickinson et al. 2010). Dickinson et al. (2010) emphasize the use of citizen scientists for monitoring rather than experimentation or identifying detailed ecological patterns. Often, though, broad scale descriptive patterns may be derived from ecological monitoring. Volunteer field personnel clearly help cut field expenses, but there is also an educational benefit as participants 'learn by doing' about natural history while taking field measurements and managing data. Citizen scientists are often vested in the areas they volunteer to monitor, thus they bring natural enthusiasm to sometimes mundane tasks. However, innate attraction to landscapes may inadvertently promote measurement bias (e.g., data gatherers may favor "good" or "bad" outcomes). Where basic scientific principles are communicated and adhered to, along with training in measurement procedures, past citizen science efforts have resulted in credible data at landscape-, regional-, and even continental-scales (Dickenson et al., 2010).

Study design, field measures, and analysis

Landscape monitoring procedures are commonly delineated into two general steps: study design and field methods. The study design is the broad-scale layout of sample units (i.e., survey plots) in a scientifically defensible manner. WCR has about 13,300 acres with an estimate 5,765 acres in aspen-dominated forests. Our WCR study design began with a digital map overlay of all forested lands, consisting primarily of aspen, and a 500 m sample grid (i.e., x/y coordinates at intersecting grid lines define potential sample points). Once this base grid was established, we randomly selected 50 points from this potential plot pool for the field survey. In this manner, plots were selected independent of any survey bias and were distributed across the WCR landscape to incorporate system variability. Of the original 50 field plots, 43 actually met our stand definition of dominance in aspen coverage (i.e., ≥ 50% aspen). At each field plot, we subsampled a one-acre area using two perpendicular 6' x 100' belt transects. At each sample plot two types of data were collected: estimates of conditions and transect-based measures of vegetation and wildlife attributes. Plot-level estimates of environmental and forest conditions normally preceded transect data collection. Field personnel noted the number of distinct vertical aspen layers, percent aspen and other species' canopy cover, stand disturbance, and overall stand condition. Stand condition provides a subjective ranking system of the state of various forest attributes in aspen stands (Table 1).
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 a "Good" rating, and at least two criteria for a "Poor" condition, otherwise it is rated as moderate. "Mortality" is defined as standing dead or recently downed mature trees. Browse includes branch tips, buds, and leaves missing, as well as presence of multi-stemmed ("bushy") aspen regeneration.

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Overstory Mortality/disease</th>
<th>Vertical Stand Layers</th>
<th>Visible Browse Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Minimal overstory mortality and stem disease present (&lt; 5%)</td>
<td>Several aspen layers (≥ 3)</td>
<td>Browsing impacts on regeneration uncommon (&lt; 25%)</td>
</tr>
<tr>
<td>Moderate</td>
<td>Does not fit 1 or 3</td>
<td>Does not fit 1 or 3</td>
<td>Does not fit 1 or 3</td>
</tr>
<tr>
<td>Poor</td>
<td>Overstory mortality and/or stem cankers common (&gt; 25%)</td>
<td>layering absent or minimal (≤ 2)</td>
<td>Browsing impacts clearly evident (&gt; 50%) on regeneration.</td>
</tr>
</tbody>
</table>

This ranking is designed to favor moderate conditions, where either "good" or "poor" values are more difficult to achieve. Field crews were trained to see distinct vertical layers. Where this could not be determined (i.e., continuous layering) they were instructed to record the maximum value of "4" layers. Estimations of canopy cover were taken by subtracting the amount of sky visible when looking up at several points around the one-acre sample plot. This gives a gross estimate of aspen coverage. Stand disturbances include damage to trees, vegetation, or forest floor that significantly affect the condition of the stand (e.g., > 50% of area or trees affected). Disturbances include such things as recent fires, heavy grazing or browsing, insect or disease infestations, other animal damage, or weather damage such as frost or heat scald. Additional environmental variables, such as location, elevation, aspect, and slope, were determined for each plot from digital databases after the field work.

Along the belt transacts we measured aspen regeneration (< 6 ft. height), recruitment (≥ 6 ft. - ≤ 20 ft.), and mature canopy trees (> recruitment). Other height and diameter sub-classes of trees were collapsed into mature group post-field. Each aspen regeneration stem was tallied and we noted whether there was any browse in the upper six inches of the branches. If so, this stem was considered browsed. Live aspen recruitment trees were also tallied for this same area. Mature trees, both live and dead, were counted based on three diameter classes: 3-6 inches, >6-10 inches, and > 10 inches. Estimates of average canopy height were taken for the tallest layer of trees using a Biltmore stick. Also along transects, field crews counted distinct ungulate fecal piles (Bunnefeld et al. 2006). Individual piles were distinguished as having at least three pellets per defecation. The primary species pellet counts were for mule deer, elk, and domestic sheep. Per acre means or totals were calculated for each plot after error checking and compilation. For example, transect data were expanded to a per acre values and tree diameter classes were used to calculate basal area per acre.

Our analytical approach involved a series of steps to systematically evaluate the data. First, we looked for patterns as data were charted. Second, we looked at each field variable for whether there were statistically significant differences between groups as defined by our qualitative aspen condition rating.
system. In general, we employed non-parametric statistics, such as the Kruskal-Wallace test for group difference, as few variables in our data set met distribution and variance standards required for parametric tests (this would be similar for many ecological data sets). We used SAS software to conduct group tests and were guided by statistical theory in Zar (1999). Third, preliminary evaluations were followed by non-metric multidimensional scaling (NMS), an ordination procedure used to extract ecological patterns from diverse data sets (McCune et al. 2002). NMS provides a mechanism for visualizing prominent variables (i.e., indicators), their relationship to each other in terms of strength and direction, and their relationship to individual plots; meaning all data for each plot are oriented in statistical "plot space." We ran the NMS with and without location variables (elevation, GPS coordinates) to find the best results. Ordination procedures were implemented using PC-ORD software (McCune and Mefford 2006). The ordination was initiated with a random start number upon 250 runs of the actual data set using Sørensen distance measure. We assessed final NMS solution dimensionality by plotting stress as a function of number of dimensions or axes. Where two consecutive dimensions were ≤ 5 points 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 ≤ 0.05). Finally, we displayed significant variables found in NMS in maps of WCR to evaluate the results geographically, better understand distributions, and target potential follow-up actions.

RESULTS

We examined conditions on the WCR aspen landscape using several approaches: descriptive statistics, tests for group differences, exploratory ordination with many measures, and map displays of the strongest statistical measures. We track each of these approaches below for significant trends.

Descriptive Statistics

The purpose of descriptive statistics is to give a preliminary overview of key elements in the data set. A preliminary survey conducted on four test plots in 2011 indicated, at some locations, that browsing of regeneration (aspen suckers < 6 ft. tall) may be problematic at WCR. This initial survey did not specifically measure recruitment, though this has since been pointed out to be a key indicator of aspen conditions where browsing may be a concern (O'Brien et al. 2010, Rogers et al. 2013a, Rogers and Mittanck 2013).

A histogram depicting the number of plots (of 43 total) in regeneration classes is shown here (Fig. 2). O'Brien et al. (2010) suggest that aspen stands containing less than 500 regeneration stems per acre are not self-replacing, while those with 500-1000 pose some concern. Though aspen forests in good condition, or following severe disturbance, commonly have several thousand stems per acre, O'Brien et al. (2010) conservatively recommend that those with > 1,000 suckers per acre are self-replacing and therefore not of immediate concern. At WCR 46% of stands sampled are not self-replacing and an additional 19% are between 500-1,000 stems per acre (i.e. "marginal").
For each aspen sample location, we calculated percent of aspen regeneration stems that were browsed by ungulates (sheep, deer, or elk). We did not attempt to determine which ungulate species was responsible for observed browse. Previous research describes annual browse levels of greater than 20 percent as being too high for aspen stands to maintain themselves over time (Jones et al. 2005). In the current survey we found that 72 percent of aspen stands included more than the 20 percent browse threshold (Fig. 3).

Recruitment is both a measure of structural diversity—particularly important to avian diversity—and longer-term browse patterns. Previous work shows that decadal fluctuations in ungulate populations can be traced to survival of young aspen suckers to recruitment and subsequent mature stages (Larsen and Ripple 2003). Using O'Brien et al. (2010) as a generalized guideline for WCR, we found that 51 percent of our locations did not meet the minimum recruitment standards (500 stems per acre) to be considered self-replacing (Fig. 4). A more sensitive approach bases recruitment success on the number of aspen present in the canopy at each site (Rogers and Mittanck, 2013). The logic behind this measure is that
environmental conditions control the number of trees that can grow at each location and that recruitment should at least be equal to the number of mature trees (i.e., 1:1 ratio). Taking this approach, WCR aspen overall fared a bit better with 41 percent of locations having less than 100 percent of canopy tree recruitment (Fig. 5).

**Figure 4:** Aspen recruitment per acre by number of plots. Red line represents minimum per acre threshold for self replacement (O'Brien et al., 2010).

![Figure 4](image)

**Figure 5:** Aspen recruitment as a percentage of live mature trees per acre. Red line represents percent of mature trees required for self-replacement of the stand over time (Rogers and Mittanck, 2013).

![Figure 5](image)

Mortality trees are those that have recently died, but are still standing. This is a common indicator of stand "health" in all types of forests (Keyes et al. 2001). A histogram of mortality per acre as
a percent of live overstory trees is shown below (Fig. 6). Exactly half of our WCR aspen sample locations had greater than 20 percent mortality. While this is not an unusually high number, combined with a moderate-to-high level of browse, this may be an early sign of stands beginning to degrade from "above" and "below."

**Figure 6:** Aspen mortality as a percent of live canopy trees at Wolf Creek Ranch, Utah

![Mortality as percent of total mature trees](image)

**Testing for Group Differences**

We were interested in understanding how well stand condition ratings replicated actual measured conditions on the WCR aspen survey plots. If objectively collected indicators show significant differences between subjective, visually estimated, condition classes then we feel confident in using such as system as a future metric of overall aspen stand conditions. The Kruskal-Wallace test provides a non-parametric measure of significant difference between stand condition groups (Fig. 7). This statistic is unable to pinpoint how individual groups affect the overall group difference. As opposed to results presented thus far (i.e., descriptive graphics), these tests offer actual statistical evidence of aspen stand conditions. Additionally, these results give a general understanding of important aspen indicators which may supplement use of the condition rating system.

All box plots shown in Fig. 7 depict statistically significant differences between groups, with the exception of elk pellets per acre (7G). Numerous measures of stand conditions were taken that did not prove significant in these tests. Aspen canopy cover (7A) shows a continuous decrease with stand condition, while canopy height (7B) appears to only change significantly between moderate and poor groups. Stand aspect (the general compass direction of a sloped sample site) was transformed from a 360° scale to a logarithmic scale (0-1) representing a moisture index from dry (southwest) to wet (northeast) aspects (Roberts and Cooper 1989). Thus, the box plot below (7C) appears to show a significant decline in aspect (moisture) with decreasing stand condition, particularly from the moderate to poor classes. Aspen regeneration per acre declines continuously as stand condition worsens (7D). Recruitment per acre (taken as a percent of canopy trees) displays a nearly identical pattern as
regeneration (7E), while mature tree mortality, as might be expected, increases as stand conditions decline (7D). Taken as a whole, these significant results indicate a strong ability of the stand condition rating system to gage actual field measures of overstory and stand structure (layers) conditions, as well as browse impacts. While we did see a loose trend of increasing elk pellets per acre as aspen conditions declined (7G), this result was not considered statistically significant.

Figure 7: Box plots based on results of Kruskal-Wallace non-parametric tests for differences between stand condition groups (1= good, 2= moderate, 3= poor) for: A) percent aspen canopy cover, B) canopy height, C) stand aspect, D) aspen regeneration per acre, E) recruitment as a percent of overstory stems, F) mortality trees as a percent of live overstory tree count, G) elk pellet groups per acre. See Table 1 for group explanations. 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. Results are considered significant where a Monte Carlo simulated Chi-square test using 10,000 runs produced an estimated $p$-value of > 0.05 (i.e., 95 percent confidence of a true group difference).

![Box plots](image.png)
Seeking Key Aspen Indicators through Ordination

We used an ordination technique called non-metric multidimensional scaling (NMS) to explore the WCR aspen data set for the most important indicators of overall stand conditions. The most important indicators were those associated with the greatest variability in overall plot measures. We removed location variables (elevation and geographic coordinates) to glean a clearer picture of important factors affecting aspen conditions at WCR (but see Spatial Distribution discussion below). Results from this “grand test” of our data are shown in Fig. 8. Technically known as a “joint plot,” the NMS results effectively display a WCR aspen data “landscape”; meaning the strength of the data by indicator are arranged within “plot space.” This is not geographic space; it is data space. For ease of interpretation, we have overlaid stand condition rating scores and the most significant variables expressed as vectors showing the direction and strength (length of line) of individual aspen condition indicators. The axes move in positive (up and right) and negative (down and left) directions from the vector centroid. Vectors moving in direct opposition to each other, namely elk presence and recruitment indices, carry inverse relations.
Figure 8: Non-metric multidimensional scaling (NMS) joint plot depicting an ordination of all final WCR aspen indicator variables. Colored symbols represent stand condition ratings of individual survey plots in data space. Vectors show only indicators with Pearson’s $r$ values greater than 0.5 (Table 2). Vectors describe indicator direction and strength (length of line). Amount of the total data set explained are shown as $r^2$ values along each axis. Generally, Axis 1 is defined by recruitment (+) and elk presence (-). Axis 2 corresponds most directly to live trees per acre. From left to right, indicators are: elk_ac = elk pellets per acre; live_tpa = live mature aspen trees per acre; p_acov = percent aspen cover; regen_ac = aspen regeneration per acre; recrt_di = recruitment as defined by diameter; recrt_ac = recruitment (by height) per acre; recrtptr = recruitment (by height) as a percent of live aspen trees per acre.

Numerous interpretations of our overall data collection and analysis efforts can be made from this NMS joint plot and corresponding values (Table 2). Visually we see that all three plots rated as “good” stand condition are all in upper-right portion of the graphic (Fig. 8). Separation of stand condition classifications (poor, moderate, good) in ordination space reinforces actual differences as measured with all the other objective plot variables combined. “Poor” stand condition plots fall almost exclusively on the left, signifying our objectively impacted stands, but several plots also appear to have relatively high number of trees per acre, but low recruitment and frequent elk visitation. The majority of stands, at least from a visual rating standpoint, are spread across the data landscape (as we might expect) in the very broad “moderate” category. In terms of indicator strength and direction, the most notable trend is the inverse relationship between recruitment and elk pellets per acre (axis 1). (While our between group tests [Fig. 7G] described a trend that was statistically not significant, the more rigorous NMS ordination revealed a clear negative correlation between elk pellets and aspen regeneration and recruitment [Table 2].) Axis 2, representing significantly less of the explanatory power of the NMS, pretty clearly describes
mere presence of mature trees on the landscape. Two indicators, percent aspen canopy cover and regeneration per acre, show a strong positive relationship to both axis 1 and 2 of the ordination.

Additional indicators with lesser, but telling, relationships in the NMS results are instructive (Table 2). Pearson's coefficients are a measure of relationship between two variables; in this case the named variable and the specified axis in our final NMS ordination. Values of zero have no relationship, while positive values relate positively to the primary axes and negative values correlate negatively to the primary axes. Aspen stand aspect (as a moisture index) relates positively to recruitment (and other measures of aspen fecundity) and negatively to elk presence (axis 1; Fig. 7C). It may be that elk favor drier aspects, their browse impacts are more evident in these locations, or that their scat was simply easier to detect with less plant cover found in such locations. Overall stand canopy height corresponds closely to mature aspen trees per acre, but negatively to standing dead trees (mortality) per acre (axis 2). Interestingly, we did not see a strong relationship between elk presence and slope, a phenomenon that has been documented elsewhere (Rogers and Mittanck, 2013).

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 \( < -0.5 \). TPA = trees per acres.

<table>
<thead>
<tr>
<th>Environmental Variable</th>
<th>Axis 1</th>
<th>Axis 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Aspen Cover</td>
<td>0.584</td>
<td>0.553</td>
</tr>
<tr>
<td>Canopy Height</td>
<td>0.051</td>
<td>0.474</td>
</tr>
<tr>
<td>Aspect</td>
<td>0.392</td>
<td>0.167</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.01</td>
<td>-0.241</td>
</tr>
<tr>
<td>Regeneration /acre</td>
<td>0.632</td>
<td>0.508</td>
</tr>
<tr>
<td>Percent Browse</td>
<td>-0.118</td>
<td>0.034</td>
</tr>
<tr>
<td>Recruitment (Ht.) /acre</td>
<td>0.835</td>
<td>-0.041</td>
</tr>
<tr>
<td>Aspen TPA</td>
<td>-0.113</td>
<td>0.706</td>
</tr>
<tr>
<td>Recruit. % of Aspen TPA</td>
<td>0.643</td>
<td>-0.128</td>
</tr>
<tr>
<td>Mortality % of Aspen TPA</td>
<td>-0.026</td>
<td>-0.432</td>
</tr>
<tr>
<td>Recruit. (DBH) /acre</td>
<td>0.78</td>
<td>0.149</td>
</tr>
<tr>
<td>Basal Area</td>
<td>0.019</td>
<td>0.229</td>
</tr>
<tr>
<td>Elk Pellets /acre</td>
<td>-0.617</td>
<td>0.099</td>
</tr>
<tr>
<td>Deer Pellets /acre</td>
<td>0.112</td>
<td>0.118</td>
</tr>
<tr>
<td>Total Pellets /acre</td>
<td>-0.574</td>
<td>0.113</td>
</tr>
</tbody>
</table>

Spatial Distributions

A geographic look at key aspen indicators at WCR is informative in terms of where problem spots are and how we might begin to take actions to address them (Fig. 9). Linking spatial and ecological patterns between regeneration, recruitment, elk presence, and overall stand conditions gives us a unique perspective on previously discussed statistical results. In general, regeneration is adequate near the perimeter of WCR, with the exception of the east side and portions of the southwest border (9A).
Recruitment follows a similar pattern, with a concentration of poor recruitment near the center and east side of the landscape (9B). Elk presence, as measured by pellet counts per acre, is highest along a string of plots trending NW-SE through the center of WCR (9C); peaking in areas where regeneration, and particularly recruitment, is low. (High elk pellet counts associated with lower regeneration and recruitment were also reflected in these index-based maps [Fig. 9C]. Where elk presence was high, as evidenced in pellet counts and browse levels, regeneration and recruitment were low and vice versa.) There is broad agreement with recruitment and elk presence in the stand condition rating (9D), though there are discrepancies at some locations.

DISCUSSION

What is the condition of the WCR aspen landscape?

Overall there is clear cause for concern regarding the sustainability of the aspen forests at WCR. The degraded condition of these ecosystems, however, is not as bad as locations further south and east in Utah where climates appear to be dryer, browsing heavier, and recovery times are slower (e.g., Rogers and Mittanck, 2013). Still, nearly half of our sample locations showed low recruitment and poor regeneration (Figs. 2, 4, 5). Following the guidelines of previously published work (Jones et al., 2005), nearly three quarters of the WCR survey locations contained browse levels deemed unsustainable over time. Overall, aspen canopy cover, regeneration, and recruitment clearly declined, and mortality increased, as stand condition decreased (Fig. 7). Among several minor trends, we found a direct and inverse relationship between elk presence and aspen recruitment: where there is less recruitment, there was a higher amount of elk pellets per acre (Fig. 8). About a quarter of the locations, concentrated in the central and eastern portions of WCR were estimated to be in poor condition (Fig. 9).

What is the role that elk play?

As with other localities, concentrated and unperturbed use by either wild or domestic ungulates strains aspen system resilience to various disturbance and climatic factors (Fortin et al. 2005, Jones et al. 2005, Beshta and Ripple 2010, Rogers and Mittanck 2013). At WCR we detected little sheep dung, and only a few more deer pellets—these factors were insignificant. Elk are clearly the dominant browser in this system, with no natural predators to limit either their numbers or time at particular aspen locales. Consequently, elk appear to be exerting a strong negative influence on current aspen regeneration and recruitment. Thus, we expect to see some stands collapse at WCR as mature trees die from a combination of common diseases, insect infestations, and complexes of disease and insects brought on by old age. The good news is that elk are not impacting the landscape uniformly (Fig. 9). This pattern of vegetation use and presence should provide us with clues regarding effective restoration.
Figure 9: Maps of Wolf Creek Ranch survey plot locations by key indicators: A) Regeneration per acre, B) Recruitment as percent of live mature trees per acre, C) Elk pellets per acre, D) Stand Condition rating (see Table 1).
Aspen Ecosystems and Biodiversity

As a keystone species, quaking aspen support a large diversity of plants and animals (Griffis-Kyle and Beier 2003, Bartos 2008, Rogers and Ryel 2008, Anderegg et al. 2012). Degradation in compositional and structural components of aspen ecosystems has consequences for dependent species. For example, domestic livestock grazing may cause reductions in aspen reproduction and cover, resulting in losses to plant community diversity (Kuhn et al. 2011). Similarly, large herbivore browsing attributed to wild elk has been shown to have indirect deleterious impacts to insect, bird, and small mammal populations and diversity (Bailey and Whitham 2002, Martin and Maron 2012, Parsons et al. 2013). These impacts may be of particular concern in the face of warming climates, which bring shorter winters and less snowpack retention (Brodie et al. 2012, Martin and Maron 2012). In brief, less snow means that large herbivores may extend their browsing season, thereby increasing annual impacts to forest structure, function, and diversity. In Yellowstone National Park, for example, researchers have documented greater upland consumption of aspen leading to decreased recruitment with a lessening snowpack. This type of access, in some cases, has allowed year-round consumption of both shrubs and aspen recruitment, resulting in decreased avian diversity (Martin and Maron 2012). In sum, there are many cascading sustainability and biodiversity concerns that may result from "bottom up" aspen forest degradation.

RECOMMENDATIONS

A look in the toolbox: Options for aspen restoration

Fortunately, there are a number of options for addressing aspen communities suffering from excessive herbivory. Options for restoration may address symptoms, causes, or both simultaneously. Aspen researchers have long known how to stimulate abundant sprouting (symptoms) via a number of silvicultural practices. Any severing of auxin flow between apical meristems and roots stimulates cytokinin reproduction in lateral root buds, thus beginning aggressive asexual sprouting (Schier 1973). A driving paradigm in modern forest management is to emulate natural disturbance and succession processes to the degree possible (Franklin et al. 2002). Moreover, selection of appropriate actions should be influenced by local conditions, parameters, and preferences of landowners. With this in mind, our "toolbox" for addressing the symptom of limited recruitment includes partial cutting, tree girdling, root ripping, burning, or a combination of these prescriptions. Previous work provides detailed descriptions of the pros and cons of active management prescriptions (Shepperd et al. 2006), though for our purposes it is sufficient to note that there are multiple options—along a continuum of intrusiveness—available. We caution, however, that in an effort to emulate natural processes, clearfell-coppicing (erroneously called "clearcutting" by some) is inappropriate for stable aspen types where stand-replacing disturbance is rare (Rogers et al. 2013b). Similarly, burning is mostly inappropriate for the same reason, but also may be very difficult to implement since pure aspen stands often do not burn well (Shinneman et al. 2013). Limited silvicultural practices, barring extreme drought, will no doubt result in abundant (at minimum stand replacement) regeneration. However, the real difficulty lies in addressing the underlying problem of herbivory, which remains a threat to the success of any regenerative practices.

Clearly, addressing the underlying cause of recruitment failure is the more difficult of the two approaches. Contemporary hunting and recreational "publics" demand high numbers of big game species, including elk. Parallel to this, it is currently politically unpopular to recruit apex predators into the state
which might limit elk numbers and increase their movement. However, a recent review of aspen-ungulate issues in the West recommends that no active management be undertaken until ungulate browsing is evaluated and addressed (Seager et al. 2013). Failure to take this step may result in complete aspen collapse on some sites as mature trees are harvested and regenerating trees are browsed. In the absence of predators, hunting 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 work, as well as present outcomes, reinforce the critical nature of monitoring for recruitment and animal presence (at minimum) in aspen ecosystems where ungulate browsing is affecting resilience (Rogers and Mittanck 2013, Seager et al. 2013).

Fencing to exclude elk as the cause of limited recruitment holds promise for small acreages and in stands targeted for additional treatments. Fencing helps guarantee a protected, strong, regenerative response, though only on a temporary basis. Fencing alone protects young trees so that where acceptable levels of natural regeneration exist it translates into recruitment to the overstory. It should be noted, however, that fenced exclosures are as unnatural as overabundant game species: exclosures allow no browsing at all, whereas areas outside the fence facilitate increased herbivory. Erection and maintenance of fences on a landscape level is cost prohibitive. A fencing only approach is likely to equate to a "zero sum game" where herbivores displaced by fences will likely increase browsing of aspen elsewhere (unless browser numbers are simultaneously reduced). The zero-sum nature of protecting aspen regeneration contributes to a self-perpetuating problem in which there will always be stands in need of fencing or other treatments, as long as the numbers of browsing ungulates stays high. In addition, dependence on fencing may provide short-term "victories" in limited areas, but will not allow us to better understand the consequences of reduced elk browse—as opposed to complete cessation inside or elevated herbivory outside fences—at the landscape-scale (Rogers et al., 2013a).

In the end, we recommend solutions using a combination of approaches focusing on symptoms and causes: ecologically appropriate protection sometimes in conjunction with necessary stimulation of new aspen stem production, while also curtailing of browser numbers and sedentary time in WCR aspen stands. Aspen treatments should initially be limited and carefully monitored for financial, ecological, and conservation reasons. We advise the highest priority be on reducing the numbers of elk or changing their behavior to reduce their impact on the ranch, because most 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. 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.
Stewards of private forest lands have many choices regarding sustenance of ecological, economic, and aesthetic values of their properties. The aspen forests at WCR provide a biodiverse legacy for future generations; ubiquitous aspen cover amounts to nearly half (43%) of the total WCR land. Though other landscape elements—sagebrush, riparian, conifers, and landscaped properties—deserve equal consideration, our task here was to assess immediate threats to aspen forests. As outlined above, the condition of a large proportion of our targeted aspen monitoring is currently on a non-sustainable trajectory given the level of elk browsing. In the prior section we mapped out various management options for correcting, or at least improving, this situation. Ultimately, however, vested decision-makers at WCR will need to prioritize the importance of healthy aspen landscapes (versus other expenditures) and allocate time and resources to enact their decisions. One approach to taking on these decisions may be to engage stakeholders in "envisioning" a variety of forest futures from deteriorating aspen to improving forest resilience. Choices along the deterioration-to-resilience continuum should be cognizant of the many plants and animals that are dependent on aspen trees and forests. Though we may assume that all WCR residents wish to preserve the landscapes, dynamic as they may be, in the forest cover for which they originally were attracted, an explicit process of stakeholder involvement is probably warranted. Full benefits of an aspen legacy should be spelled out, alongside other concerns and priorities at WCR, to illicit informed decision-making for these lands.

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