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Restoration of Riparian Areas Following the Removal of Cattle in the Northwestern Great Basin

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Abstract We assessed the effects of the elimination of livestock in riparian systems at Hart Mountain National Antelope Refuge in southeastern Oregon, 23 years after the removal of cattle grazing, using 64 photos taken before grazing was removed compared with later retake photos. Two methods were used for this assessment: (1) a qualitative visual method comparing seven cover types and processes and (2) a new quantitative method of inserting digital line transects into photos. Results indicated that channel widths and eroding banks decreased in 64 and 73 % of sites, respectively. We found a 90 % decrease in the amount of bare soil ($P < 0.001$) and a 63 % decrease in exposed channel ($P < 0.001$) as well as a significant increase in the cover of grasses/sedges/forbs (15 % increase, $P = 0.037$), rushes (389 % increase, $P = 0.014$), and willow (388 % increase, $P < 0.001$). We also assessed the accuracy of the new method of inserting digital line transects into photo pairs. An overall accuracy of 91 % (kappa 83 %) suggests that digital line transects can be a useful tool for quantifying vegetation cover from photos. Our results indicate that the removal of cattle can result in dramatic changes in riparian vegetation, even in semi-arid landscapes and without replanting or other active restoration efforts.

Keywords Riparian · Grazing · Cattle · Repeat photography · Passive restoration · Hart Mountain

Electronic supplementary material The online version of this article (doi:10.1007/s00267-014-0436-2) contains supplementary material showing the 64 photo pairs, which is available to authorized users.

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Introduction

Livestock grazing is permitted on nearly one million square kilometers of public land in the 11 western states of the US, including nearly 80 % of BLM land and 60 % of US Forest Service land (Beschta et al. 2013). Cattle tend to congregate in riparian areas due to easy access to water, lush forage, and favorable terrain (Kovalchik and Elmore 1992). This concentration of cattle in riparian areas makes these systems particularly susceptible to the effects of livestock (Fleischner 1994; Belsky et al. 1999; Donahue 1999). The effects of livestock grazing on ecosystems are numerous, and effects on riparian systems in particular have been the subject of much study. Hydrology, plant and animal species composition, and soil characteristics can all be dramatically altered with the presence of cattle (Kauffman et al. 1983; Read et al. 2011).

Cattle grazing can indirectly cause a significant decrease in bird species abundance and diversity, largely by removing shrubs that are important habitat for many bird species (Taylor 1986). Altered stream cover, water depth, and bank stability due to cattle grazing can all affect fish populations, and have been shown to lead to declines in salmonids (Knapp and Matthews 1996). Cattle grazing can accelerate stream bank erosion, causing streams to become shallower and wider, which can result in higher water

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temperatures (Kauffman et al. 1983). Other water quality issues that can result from the presence of cattle include pollution from excrement and increased sedimentation from trampled banks (Chaney et al. 1993). Decreases in both the density and height of woody plants have been documented with grazing activity (Kovalchik and Elmore 1992; Green and Kauffman 1995) along with increases in exotic species (Hayes and Holl 2003). Although grazing can sometimes lead to greater species richness and diversity, this often occurs due to the introduction of invasive species and the suppression of vegetation cover (Green and Kauffman 1995; Hayes and Holl 2003). Other documented effects of cattle include loss of native biodiversity, interruption of nutrient cycling, and destruction of biotic soil crusts (Kauffman and Krueger 1984; Skovlin 1984; Fleischner 1994; Trimble and Mendel 1995).

Cattle grazing can exacerbate effects of climate change. Ecosystems stressed by grazing activity may be less resistant to temperature and moisture changes, compared to ecosystems that have had time to recover from such anthropogenic stress factors (Beschta et al. 2013). Removing grazing pressure and allowing systems to undergo a process of passive restoration represent an important management option for enhancing ecosystem resilience and resistance to climate change effects.

With grazing ubiquitous across much of the western US, it is important to understand not only the effects of grazing, but also how ecosystems change with the removal of cattle both in the short and long term (Floyd et al. 2003). Two years after grazing was stopped along portions of Meadow Creek in northeastern Oregon, shrub cover increased by 50 %, and black cottonwood (*Populus trichocarpa*), alder (*Alnus* spp.), and willow (*Salix* spp.) greatly increased in crown-volume (Case 1995; Kauffman et al. 1995). Herbaceous vegetation density increased 4–6 times in riparian areas of the San Pedro River in Arizona, and 42 of 61 bird species increased in abundance when cattle were removed (Krueper et al. 2003). Ecologically important biological soil crusts also increased within a few decades after cattle removal (Read et al. 2011).

There can be dramatic results from passive restoration following the removal of cattle from a system. Plant communities may rapidly switch from disturbance-resistant ruderal grasses to hydrophytic plant communities in riparian areas after the removal of grazing (Hough-Snee et al. 2013). Twelve years after the removal of cattle from Hart Mountain National Antelope Refuge in southeastern Oregon, there was a 64 % increase in the number of medium-diameter aspen in sampled riparian areas (Earnst et al. 2012). Forb and mesic shrub cover increased by 68 and 29 %, respectively, in the riparian aspen stands of the refuge, and sagebrush cover decreased by 24 %. With the increase in riparian vegetation, bird abundance increased by 33 % (Earnst et al. 2012). These examples provide evidence of the potential of passive restoration to redress cattle impacts. Active restoration methods such as plantings or stream channel stabilization may sometimes be needed to restore riparian damage caused by cattle grazing (Booth et al. 2012); however, passive restoration processes alone may be sufficient to restore ecosystem functions in many cases (Kauffman et al. 1995).

Photographs have long been an important tool for detecting ecosystem change (Hart and Laycock 1996). Studies have used repeat photography to understand both the merits and deleterious effects of grazing (Elmore and Beschta 1987; Anderson et al. 1990; Reid et al. 1991; Chaney et al. 1993). While photos have been useful for illustrating ecological change qualitatively, less work has been done on extracting quantitative data from photos. Quantitative studies have included use of indices of visual obstruction to gage willow clump densities (Boyd and Svejcar 2005), detection of species change using geographic information systems (GIS) with pixel color and object recognition (Michel et al. 2010), and measurement of vegetation heights in historical photos based on known heights in retake photos (Ripple and Beschta 2006). Matching camera type and focal lengths with repeat photography is not critically important, as long as the retake photo was captured at the same location as the historical photo (Hall 2002). This allows for the opportunity for historical photos to be used for analysis via repeat photography even when the photos were not initially intended for this purpose. Here we investigate new methods to study ecosystem change using photos.

The objectives of this study were to (1) use repeat photography to illustrate riparian vegetation change over time following the cessation of cattle grazing at Hart Mountain National Antelope Refuge, Oregon; (2) use image analysis to quantitatively measure the amount of change in vegetation cover, as well as the change in cover type; (3) compare vegetation cover at sites with active management treatments versus those with only cattle removal; and (4) assess the accuracy of inserting digital lines into photos to measure vegetation change. We hypothesized that passive restoration (cattle removal without additional vegetation management) would result in changes in riparian vegetation cover, bare soil, eroding stream banks, and exposed stream channels. This study may provide insights that could guide similar restoration efforts in other areas of the western US.

Study Area

The study was conducted at Hart Mountain National Antelope Refuge (see Fig. 1 for location) which is administered by the U.S. Fish and Wildlife Service (USFWS) and

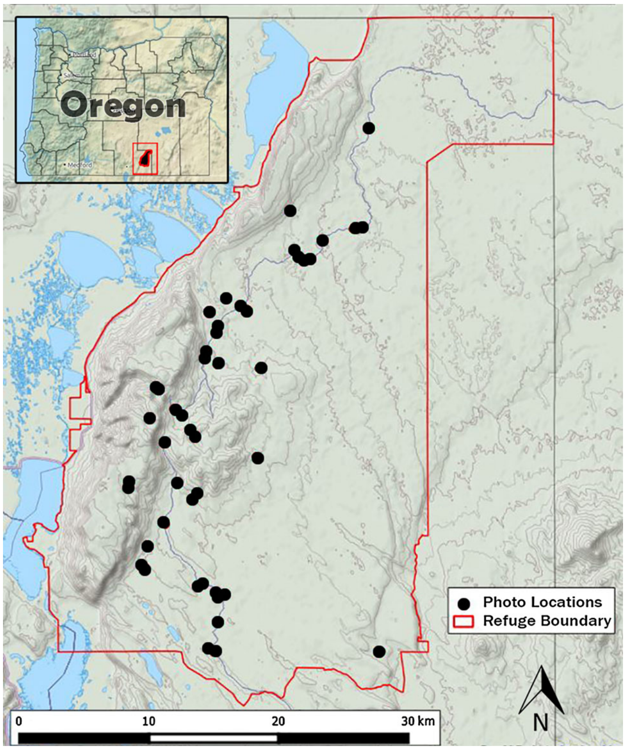

Fig. 1 Hart Mountain National Antelope Refuge is located in Oregon. The majority of riparian areas in the refuge are located in the western half of the refuge. The 64 photo plots were well distributed along a north–south axis but were limited to riparian areas that historical photos captured. Background map ©OpenStreetMap contributors http://www.openstreetmap.org/copyright

encompasses 1,095 km^2 of high desert in the Northern Basin and Range Ecoregion in southeastern Oregon (Omernik 1987). The refuge was established in 1936 for the protection of pronghorn (*Antilocapra americana*). Over time, the refuge has broadened its management goals to include conservation and restoration of wildlife and native ecosystems. Cattle grazing was long thought to be part of a strategy for meeting these goals. For example, the 1970 management plan for the refuge designated grazing as the "primary means by which vegetation would be managed" under the assumption that light to moderate grazing on 1–2-year intervals would improve the vigor and quality of forage, and improve pronghorn habitat. However, grazing along valley bottoms and riparian areas continued to be relatively heavy throughout the refuge, with many areas never given time to recover from grazing effects (USFWS 1994). By the 1990 s, cattle grazing was deemed incompatible with new management goals focused on restoring the refuge and all cattle were removed from the refuge as of 1991 (USFWS 1994). There was occasional trespass of cattle and feral horses on the refuge since cattle were officially removed, but their use of our study sites was extremely low compared to allotment cattle prior to 1991. Also, prescribed fire (sometimes with mowing) was used on some sites to remove litter, invigorate willows and remove sagebrush, and in some areas willow cuttings were planted (personal communication, Gail Collins).

Four wild ungulate species are found at Hart Mountain. Summer populations of pronghorn were estimated at < 500 animals during the 1970 s. This number increased to 1,000–2,000 animals after cattle removal, and numbers were recently estimated at 2,000–3,500 animals (Beschta et al. 2014). Other ungulates at Hart Mountain include mule deer (*Odocoileus hemionus*; < 1,000), small numbers of elk (*Cervus elaphus*; 15–20 individuals), and bighorn sheep (*Ovis canadensis*) (Beschta et al. 2014).

Climate at the refuge includes hot dry summers and cold winters with most precipitation as snow (USFWS 1994). Average precipitation ranges from 15 to 20 cm on the western foot of the mountain to 30–45 cm of precipitation at higher elevations. There are over 242 km of perennial and intermittent streams within the refuge but riparian areas comprise less than 1 % of the total land area. Approximately one half of the stream reaches on the refuge (113 km) are inhabited by fish except during periods of drought when adequate water is not available. In 1994, only 13 % of the streams were characterized as being in good condition with 73 % of riparian areas characterized as either poor or very poor condition. Cattle grazing was identified as the leading cause of stream and riparian degradation at Hart Mountain (USFWS 1994).

Common tree and shrub species in the refuge include quaking aspen (*Populus tremuloides*) and willows (*Salix* spp.) in riparian areas, with western juniper (*Juniper occidentalis*) and scattered pockets of mountain mahogany (*Cercocarpus ledifolius*) in upland areas. Rabbitbrush (*Chrysothamnus* sp.), low sagebrush (*Artemisia arbuscula*), Wyoming big sagebrush (*Artemisia tridentata*) and silver sagebrush (*Artemisia cana*) are ubiquitous across the refuge. Common riparian herbaceous vegetation includes several rushes (*Juncus* spp.), spikerushes (*Eleocharis* spp.), and bullrushes (*Scirpus* spp.). Common grasses in the refuge include saltgrass (*Distichlis spicata*), bluegrass (*Poa* sp.), and ryegrasses (*Lolium* spp.). California false hellebore (*Veratrum californicum*) is common in some riparian areas. Invasive grasses such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*) are present in scattered patches across the refuge.

Methods

Grazing reports were summarized to determine the amount of cattle grazing on the refuge between 1972 and 1990. Animal unit months (AUM) for each year were calculated by multiplying the number of animals by the number of months of grazing. Average monthly Palmer Drought Severity Index (PDSI) (Alley 1984) was calculated for each year from 1972 to 2013 to account for possible changes in climate fluctuations (annual moisture and temperature) during the study period. A two-sample *t* test (unequal variances) was used to compare mean PDSI between the 10-year period leading up to the removal of cattle (1981–1990) and the 10-year period preceding this study (2003–2012). Data for monthly PDSI were obtained from the Western Regional Climate Center for the Oregon-Closed Basin hydrologic unit, which includes all of the study area (WRCC 2014).

Photos of riparian areas within the refuge taken in the period 1984–1991 were collected from Hart Mountain National Antelope Refuge (hereafter, historical photos). Of this initial set, sites for 110 photos were relocated and photographed again in 2013 and 2014 (hereafter, retake photos). Photo locations included Rock Creek, Poker Jim Spring, Willow Creek, Paiute Creek, Bond Creek, Cold Creek, North Fork DeGarmo Creek, South Fork DeGarmo Creek, Stockade Creek, Guano Creek, Deer Creek, Warner Creek/Big Flat Wetlands, Goat Creek, and Warner Ponds. Retake photos were taken during the same season as historical photos. Sixty-four of the 110 photo sites were used for analysis (Fig. 1). Forty-six photo pairs were eliminated for one of three reasons: (1) multiple photos of the same geomorphic feature, (2) the photos did not have a clear foreground focus and were instead a broader landscape view, or (3) photo location could not be accurately determined using the original photo.

Stream measurements were taken of the active channel width and depth at 34 sites, where the stream channel was clearly visible in the photo. Heights of the five tallest willows within 50 m of the photo retake location were recorded if present. Percent height change was calculated for individual willow clumps when they could be identified in both the historical and retake photos.

Historical photos and retakes were registered together using photo-processing software (Adobe Photoshop CS6). Photos were matched by overlaying a semi-transparent copy of each retake photo on top of the historical photo and aligning features such as individual trees, rocks, and land contours. Retake photos were cropped as necessary to match the field of view of the cameras used to take historical photos.

Two methods were used to assess change between photo pairs. First, a qualitative visual site assessment was used to evaluate change between the historical and retake photos. Categories included willow cover, sagebrush cover, aspen recruitment, amount of bare soil, exposed channel, eroding banks, and channel width. We determined if each category had increased, decreased, had no visible change, could not be assessed, or was not applicable (Fig. 2). Second, a digital line intercept method was developed to measure change between photo pairs. Line transects were digitally inserted into each photo pair, parallel to the base of the photo. The transect was first placed in the historical photo at the location where there was the best view of the riparian vegetation and stream channel (Fig. 3). The transect was then placed in the same location in the retake photo. Each pixel on the transect was assigned one of seven categories: bare soil, exposed channel, willow, grasses/sedges/forbs (G/S/F), rushes, sagebrush, or "other". The "other" class was comprised of rare elements that appeared in less than five digital transects (e.g., aspen, mosses, juniper) or had little potential to change (e.g., rocks). If a section of the line had more than one class present (e.g., bare soil and G/S/F), the section was identified by the predominant class.

Accuracy of the digital line intercept method was assessed with field data. A tape transect was placed and photographed in the field at approximately the same position as the digital line transect in the photo. Categories of ground cover were recorded along these transects in the field. Four points were placed at equal intervals on each transect, and using the field data, the cover type was determined at each of the points. These points served as "ground truth" and were compared to the categories assigned to the points using only the photographs. Estimates of accuracy for each category were obtained. In the rare occurrence that a foreground shrub obscured the tape transect at a sample point, the site was not used for this assessment. A classification error matrix was generated and the overall accuracy level and Cohen's kappa statistic were determined (Lillesand et al. 2004). The kappa statistic accounts for probability of agreement through random chance.

Distances were measured along the tape transects in the retake photos and used to measure the length of digital transects. Images were then standardized by resizing so 1 pixel equaled 5 cm on the ground in each photo. Percent transect occupied by each cover type was calculated for each photo. A paired two-sample *t* test (two-tailed, 95 % confidence level) was used to compare percentage of digital transect occupied by each cover type in the historical and retake photos. Sample size varied depending on the number of paired transects in which the cover type occurred in either the historical or retake photo.

A raster calculator (QGIS Development Team 2014) was used to assess change in cover types between historical and retake photos. Each pixel was assigned a value of 1–11 (depending on cover category) in the retake images and the same number multiplied by 100 for the corresponding category in the historical photo. The matched pixels of the two transects were then added together and the sum indicated the beginning and ending cover category for that pixel. These values were then expressed as percentages of

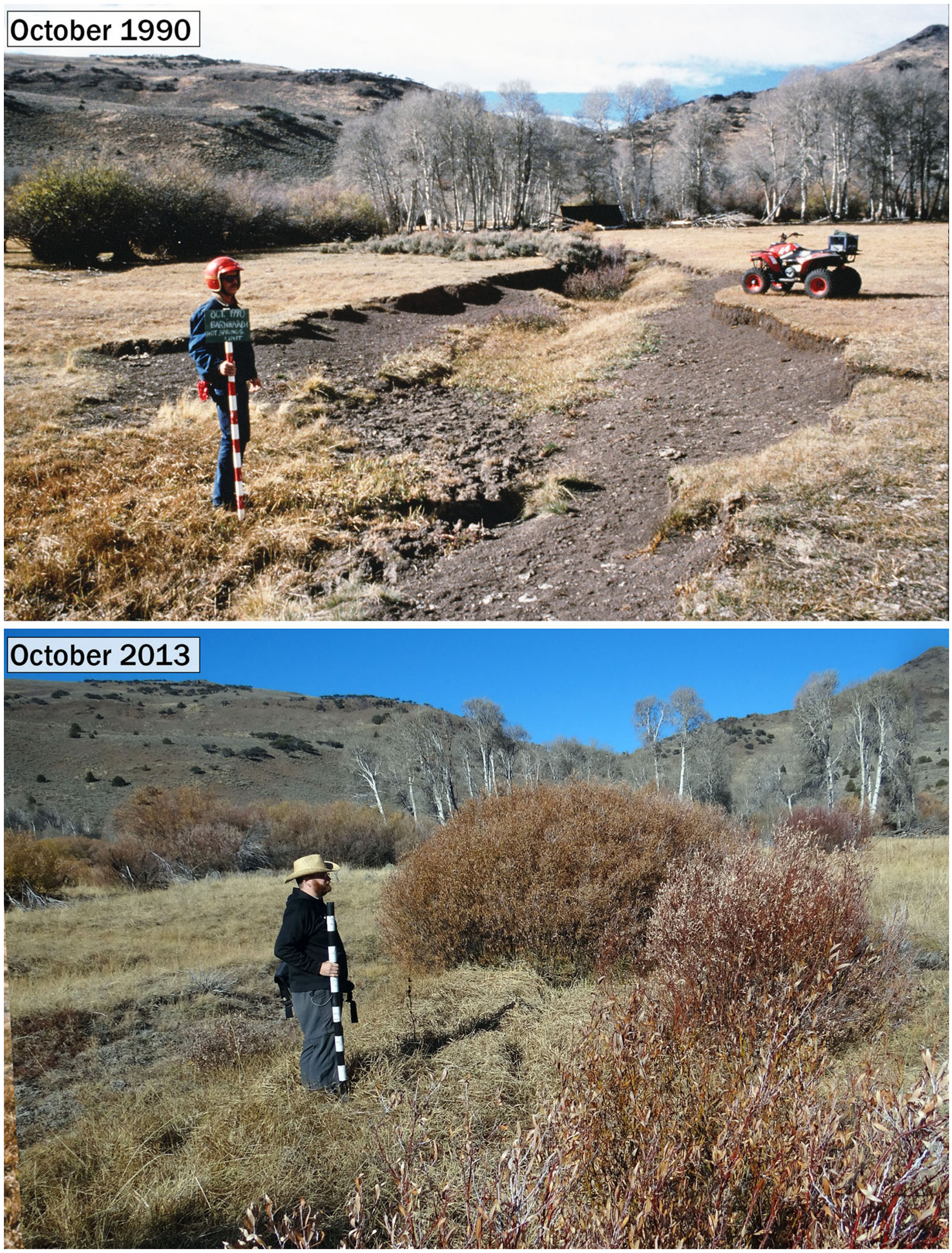

Fig. 2 An example of comparing two photos using the visual site assessment method in Barnhardy Meadow. Willows have increased. Aspen are present in the photo, but due to the willow obstruction, it is unclear if the level of recruitment has changed. Bare soil has decreased, eroding banks have decreased, channel width has decreased, and amount of exposed channel decreased. Photo credits: 1990-Hart Mountain National Antelope Refuge, 2013-Jonathan Batchelor

transect length. For example, bare soil was given a value of 1 in the retake and 100 in the historical photo; G/S/F was given a value of 6 in the retake and 600 in the historical. A value of 101 indicated bare soil stayed bare soil, 106 indicated bare soil became G/S/F, 601 indicated G/S/F became bare soil, and 606 indicated G/S/F stayed G/S/F.

We compared sites that were likely treated with prescribed fire or willow plantings to those sites that did not have any active management. With visual assessment data, we compared change over time for willow and sagebrush. With line intercept data, we used a two-sample t test (unequal variances) to check for significant differences in percent cover in the retake photos of willow, sagebrush, and herbaceous vegetation (G/S/F). We were unable to assess the effects of mowing because of low sample size ($n = 5$).

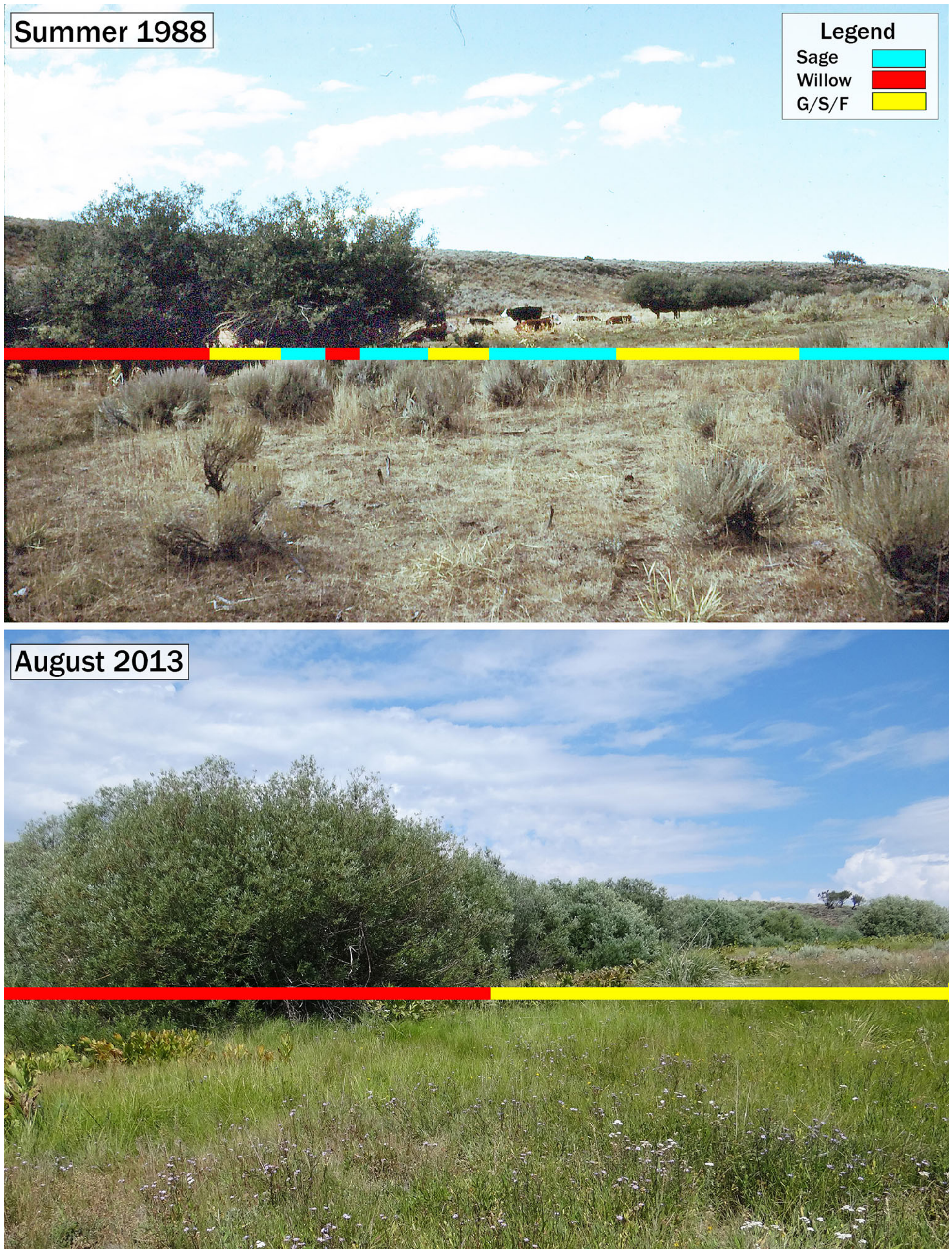

Fig. 3 Photo pair demonstrating the digital line intercept method on Stockade Creek, with a color key showing the categories identified on the transect. Transects were placed in both photos in the same location and classified by cover category. The location of the transect on the ground is affected by the oblique view from the camera, but the method is still valid as we compared two photos of the same site, taken at the same oblique angle. Photo credits: 1988-Steve Herman, 2013-Jonathan Batchelor

Results

Annual AUMs averaged 13,400 on Hart Mountain Refuge between 1972 and 1989 and dropped to 3,049 in 1990, the final year in which cattle were allowed to graze (Fig. 4). The refuge was subdivided into grazing allotments with differing grazing levels, and grazing was relatively high at all historical photo sites except two. Mean PDSI was 1.87 for the 10-year period 1981–1990, and 0.18 for 2003–2012, with no significant difference between these time periods ($P = 0.25$).

Field Measurements

Mean width/depth ratio for the 34 stream reaches measured in 2013 and 2014 was 5.0 (SD 3.9, range 0.7–20.0). One or

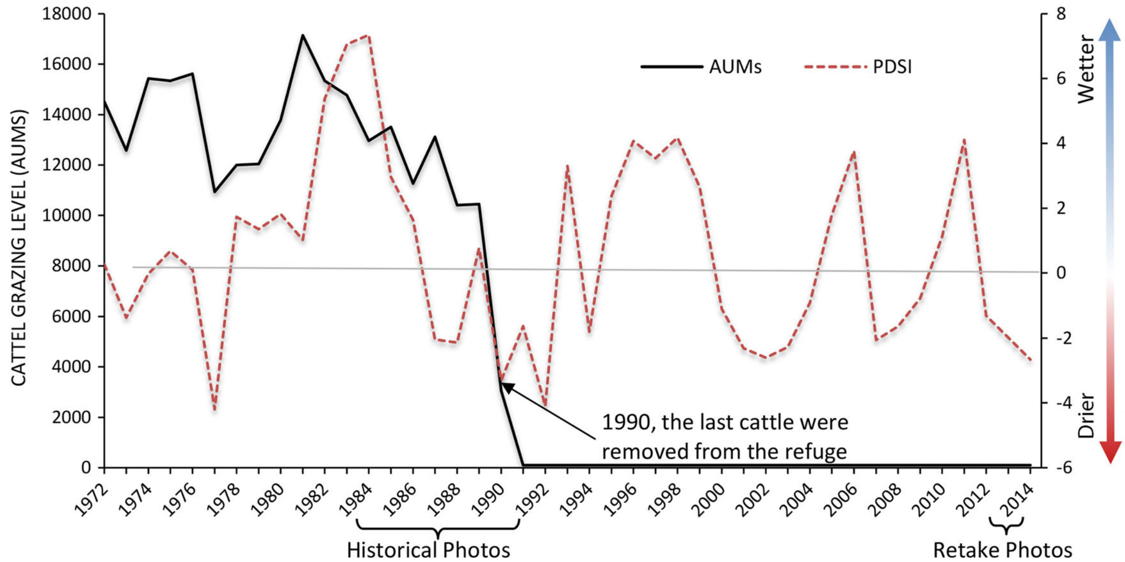

Fig. 4 Animal unit months (AUMs) permitted on the refuge since 1972 on the left axis with the Palmer Drought Severity Index for the Oregon-closed basin hydrologic unit on the *right axis*. The PDSI value for the years when the historical photos were taken range from 7.35 in 1984 to −3.31 in 1990

more individual willow clumps were identified at 12 sites in both the historical and retake photos. Of these 12 sites, seven had an increase in willow heights, averaging ~ 200 % with increases up to 300 % in some sites. Willow heights measured at retake sites averaged 3.3 m (range 0.8–6.0, $n = 30$). Five sites showed little change in willow height. However, these willows had a mushroom shape in the historic photos (Fig. 2, top photo) indicating heavy browsing pressure at the base of the plants, with growth occurring at heights above the reach of cattle (Painter and Ripple 2012). In the retake photos, these willows had full shapes with no evidence of constriction by browsing.

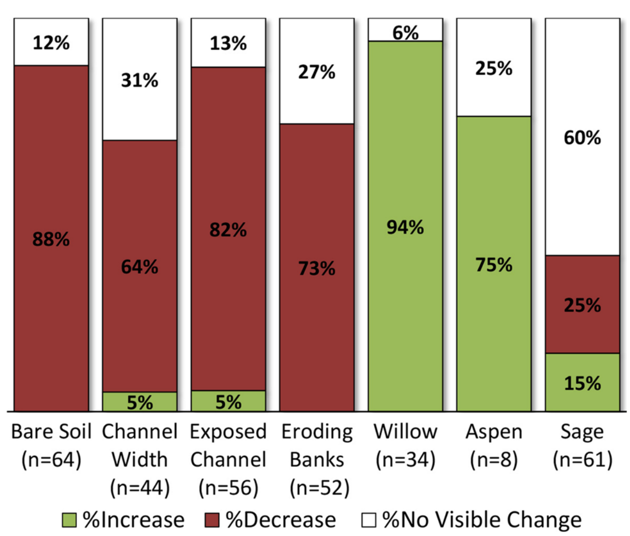

Fig. 5 *Bar graph* illustrating the visual site assessment results. Percentages are of the number of sites where a change was assessed, and not a measure of the amount of change. Sample size (n) differed because the visual site assessment was limited to photo pairs in which the category was visible in at least one of the photos

Visual Site Assessment

Overall, the amount of bare soil, exposed channels, channel widths, and eroding banks decreased since cattle removal. In 52 historical photos that showed stream banks, 73 % of the banks were eroding, while in the retake photos, 13 % were eroding (Fig. 5). Of these 52 pairs, stream banks appeared to have less erosion in 38 (73 %) of the retake photos. The remaining 14 (27 %) appeared to have no change. No site had an increase in bare soil or eroding banks. Two sites showed an increase in channel width and three sites showed an increase in exposed channel. Both willow and aspen had increased dramatically in the retake photos. Only eight sites had an unobstructed view of aspen regeneration that allowed for assessment of understory aspen change. Of these eight sites, the two that did not have an increase in aspen recruitment had a decadent aspen stand in the historical photo and the trees had died by the time of the retake photo without new recruitment. Sagebrush was the most variable in response with 25 % of sites increasing and 15 % decreasing in amount. Two sites were in areas that historically had very low grazing activity, and these had little visible change in the retake photos.

Digital Line Intercept

In both historical and retake photos, G/S/F had the highest percentage of transect length (Fig. 6). In the historical

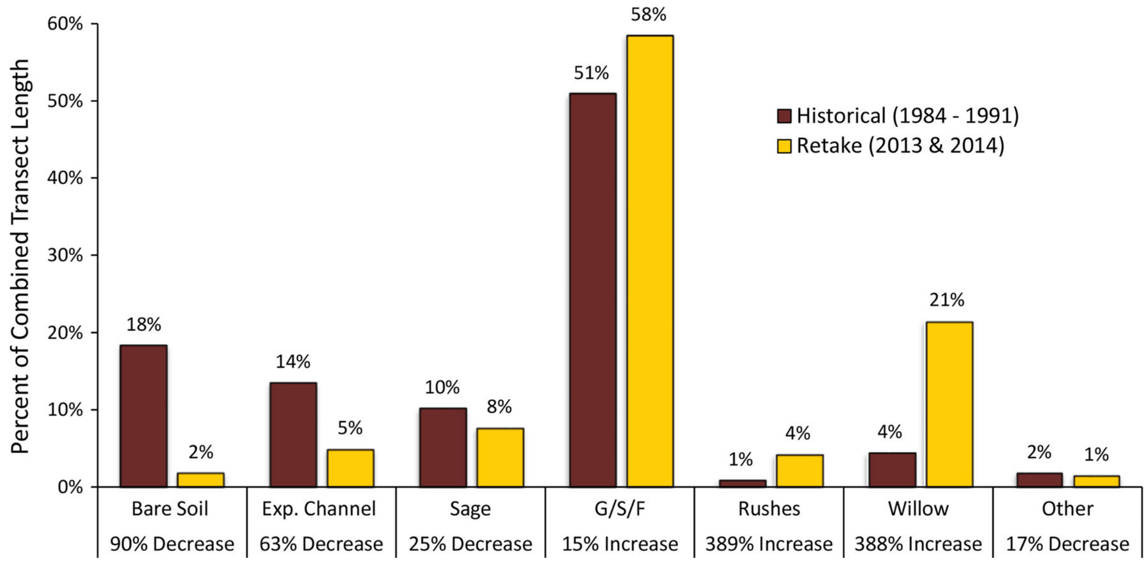

Fig. 6 Percentage of combined digital transect length occupied by each category. The total length of all transects combined was 465.4 m

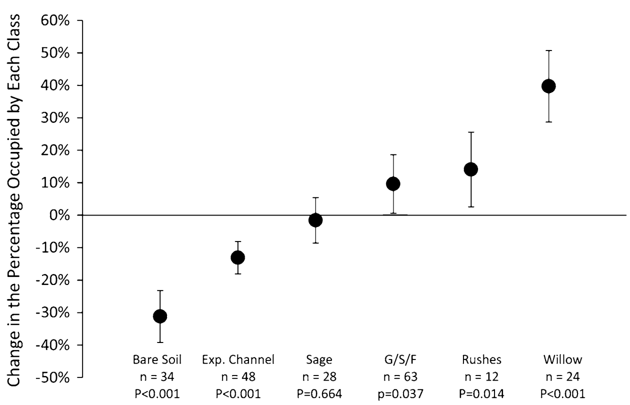

Fig. 7 The mean difference between the percentages of each class in the historical photo compared to the retake, using a paired *t* test with the digital transect percentage for each category calculated for each site individually. Ecosystem recovery is indicated by negative values for bare soil, exposed channel, and sagebrush, and by positive values for G/S/F, rushes, and willow. For example, the percentage of bare soil present in the historical photos decreased on average by about 30 % compared to the retakes. *Error bars* show 95 % confidence intervals. Sample size (*n*) is the number of transect pairs where the category was present. Values were not calculated for the "other" classification as this class is comprised of multiple biotic and abiotic elements

photos, bare soil was the second highest percentage, while in the retake photos willow was the second most dominant cover type. There was a significant decrease over time in amount of bare soil and exposed channel and a significant increase in willow ($P < 0.001$; Fig. 7). The amount of G/S/F ($P = 0.037$) and rushes ($P = 0.014$) also increased significantly. There was no significant difference in sagebrush cover ($P = 0.67$).

Through summing the category lengths from all historical photo transects, we found that the most common categories were G/S/F, willow, exposed channel, and sagebrush. G/S/F accounted for 51 % of the historical combined transect (Table 1). Within this category, 66 % remained G/S/F in the retake photos, and 24 % became willow. Only 6 % of what was bare soil remained as bare soil, while 65 % changed to G/S/F and 13 % became willow. Of the 13 % historical digital transects identified as exposed channel, 18 % remained exposed channel, while 49 % became G/S/F, 15 % became rushes, and 12 % became willow in the retake photos. Almost half (47 %) of what was sagebrush became G/S/F.

A total of 240 points were selected to assess the accuracy of the digital line intercept method for 60 photographed tape transects. Sixteen points were eliminated due to visual obstruction leaving 224 points for the assessment. The overall accuracy level was 91 % with a kappa statistic of 83 % (Table 2). Highest level of accuracy was for the willow category with (100 %). Bare soil and rushes had the lowest level of accuracy with 60 and 64 %, respectively.

Comparing Active Versus Passive Management

Using visual assessment, willow cover increased in 94 % ($n = 16$) of the sites that had burned and 94 % ($n = 18$) of the sites without fire, while sagebrush decreased at 28 % of the sites that burned ($n = 29$) and decreased at 22 % of the sites that did not burn ($n = 32$). Also, willow cover increased in 100 % of the sites that were planted ($n = 13$) and 90 % of sites not planted ($n = 21$). Two additional sites that were planted had no willows visible in either the historical or retake photos.

Table 1 Results of change from historical photos to retake photos

Historical category	Total length	What historical categories changed to in retakes: G/S/F	Bare soil	Exp. channel	Sage	Willow	Rushes	Other
Grasses/sedges/forbes	51 % (237 m)	66 % (157.8 m)	1 % (1.8 m)	2 % (4.2 m)	3 % (6.3 m)	24 % (58.2 m)	3 % (6.7 m)	1 % (2 m)
Bare soil	18 % (85.35 m)	65 % (55.9 m)	6 % (4.8 m)	7 % (5.7 m)	5 % (4.1 m)	13 % (11.5 m)	3 % (2.6 m)	1 % (0.85 m)
Exposed channel	13 % (62.85 m)	49 % (30.9 m)	1 % (0.55 m)	18 % (11.4 m)	4 % (2.3 m)	12 % (7.45 m)	15 % (9.8 m)	1 % (0.45 m)
Sage	10 % (47.4 m)	47 % (22.36 m)	0 %	0 %	43 % (20.25 m)	5 % (2.45 m)	1 % (0.5 m)	4 % (2.1 m)
Willow	4 % (20.5 m)	12 % (2.4 m)	0 %	0 %	5 % (1.05 m)	83 % (17.05 m)	0 %	0 %
Rushes	1 % (4 m)	26 % (1 m)	0 %	30 % (1.2 m)	11 % (0.45 m)	11 % (0.45 m)	22 % (0.9 m)	0 %
Other	2 % (8.3 m)	31 % (2.6 m)	0 %	6 % (0.5 m)	11 % (0.9 m)	39 % (3.2 m)	0 %	13 % (1.1 m)

The total length column is the length of each category in the historical photos, which was calculated by adding up the category lengths from all photos transects

Table 2 Classification error matrix for classification data of photos compared to field observations

Predicted class (on image)	Observed class (in field): Bare soil	Exp. channel	Sage	G/S/F	Rushes	Willow	Other	Total
Bare soil	**3**	–	–	2	–	–	–	5
Exp. channel	–	**17**	–	1	–	–	–	18
Sage	1	1	**6**	3	–	–	–	11
G/S/F	–	2	1	**153**	5	–	1	162
Rushes	1	1	–	2	**9**	–	–	13
Willow	–	–	–	–	–	**12**	–	12
Other	–	–	–	–	–	–	**3**	3
Total	5	21	7	161	14	12	4	224
Accuracy 91 %								
Kappa 83 %								

Bold values in the diagonal represent correctly classified categories

Based on line transect data, there was no significant difference ($P = 0.67$) in willow cover between sites that were burned ($n = 10$) versus not burned ($n = 14$). There was a significant reduction ($P = 0.03$) in sagebrush cover at sites that had burned ($n = 7$) versus those without fire ($n = 15$). We also found no significant difference ($P = 0.28$) in the percent cover of herbaceous vegetation (G/S/F) between sites that were burned ($n = 30$) and not burned ($n = 30$). There was no significant difference ($P = 0.42$) in willow cover between sites with willow plantings ($n = 9$) compared to those that were not planted ($n = 15$).

Discussion

Consistent with our hypothesis and evident in the chronosequence of paired photos, marked changes were observed in riparian areas 23 years after cattle grazing ceased at Hart Mountain (see all 64 photo pairs in online supplementary material). These changes included a decrease in stream channel width, an increase in woody riparian vegetation, and a reduction in eroding stream banks. Almost all sites had a decrease in the amount of bare soil present (Fig. 5), and bare soil decreased by 90 % overall, changing primarily to grasses, sedges, and forbs, or to willow (Table 1). The width/depth ratio of streams varied widely but the visual assessment indicated an overall decrease in stream width, and the current average width/depth ratio of 5.0 appears to be much less than the historical value. Our results further suggest that the resurgence of riparian vegetation was not the result of any change in climate given that the years preceding when the historical photos were taken (1984–1991) were generally less drought-stressed than the years preceding photo retakes

(Fig. 4). Our comparisons of active versus passive management activities suggest that, at least in some circumstances, active restoration practices such as burning or the planting of willow are not necessary for the recovery of riparian willows after the removal of cattle.

The extent to which passive restoration has facilitated vegetation recovery at Hart Mountain speaks to the capacity for riparian systems to recover without further intervention (e.g., riparian plantings) (Fig. 8). Our results are similar to the pattern of passive restoration observed elsewhere when cattle were removed (Elmore and Beschta 1987; Kovalchik and Elmore 1992; Booth et al. 2012). With willows still absent along many of our study stream reaches 23 years after the removal of cattle, we speculate that the riparian recovery is still in the early stages. This situation may be similar to what was found in Yellowstone National Park 15 years after wolf reintroduction which was also in the early stages of recovery after reduced herbivory by wild ungulates (Ripple and Beschta 2012). It may take significantly longer for more extensive woody plant establishment (Floyd et al. 2003), but as the recovery proceeds, we expect additional cascading effects with increases in the diversity and populations of birds, mammals, other taxa, and overall riparian biodiversity (Earnst et al. 2012; Ripple and Beschta 2012).

The most dramatic changes between the historical and retake images were the widespread reestablishment of willow and the increased presence of rushes. Overall, rushes and willow both increased almost fourfold (Fig. 6). In many historical photos, rushes were nearly or entirely absent at sites where rushes were present in the retakes. Willow may be an important indicator of overall riparian health for some systems (Booth et al. 2012). Willows help reduce stream temperatures (Zoellick 2004; White and Rahel 2008) and protect stream banks against erosion (Vincent et al. 2009). The strong increase in willow cover observed in this study suggests that riparian systems at Hart Mountain are more stable, provide better habitat for many species, and are more resistant to erosion than when cattle were present.

Many willows observed in retake photos were not evident in historic photos. In addition to a limited amount of planting, willow establishment appears to be the result of two different mechanisms. The first is colonization of willow via seeds or woody segments from upstream sources. The second was through resprouting of existing willows that had found partial refugia inside incised stream banks. Incised stream banks can protect willows from grazing by creating refuges where short willows can persist. Once the grazing pressure has been removed, protected plants may rapidly grow taller. Both short and tall willows in historical photos exhibited a hedged or constricted shape resulting from repeated browsing (Painter and Ripple 2012), but in retake photos willows generally showed vigorous growth with no evidence of suppression by browsing.

A succession from bare soil to herbaceous vegetation to woody plants was observed following the removal of cattle. While there was only a modest increase in the amount of grasses, sedges, and forbs, 24 % (55.9 m of total transect length) of what was grasses, sedges, and forbs became willow and 65 % (58.2 m of total transect length) of what was bare soil became grasses, sedges, and forbs. This shows that as grasses, sedges, and forbs were establishing in the bare soil, willows were establishing in the grasses, sedges, and forbs at an almost equal amount (Table 1). Dobkin et al. (1998) found an exception to the succession that we describe for the majority of our sites. In a Guano Creek exclosure, they found a lack of willows after more than 30 years without cattle grazing, likely due to the establishment of a dense sedge community. We also found a reduction in the amount of sagebrush in riparian areas. This decrease in sagebrush could be indicative of an increase in the saturation zone providing more water for streamside vegetation. This could be due to bank stabilization and a resulting rise in the local water table possibly because of gains in flood-water detention storage and increases in baseflow (Beschta et al. 2013).

We observed a noticeable increase in aspen recruitment at the majority of sites where the understory of an aspen grove was visible. Other studies of aspen recruitment at Hart Mountain have also shown an increase in young aspen since the removal of cattle (Earnst et al. 2012; Beschta et al. 2014). The current state of most aspen groves observed at Hart Mountain is a decadent overstory dying out, with a new mid-story coming up, having been released from browsing pressure (Beschta et al. 2014). However, some aspen stands in historical photos have disappeared with only dead aspen littering the ground marking where there once was an aspen stand. Aspen are able to persist in a suppressed state without recruitment for a limited time until there is total stand mortality (Fitzgerald and Bailey 1984; Bartos and Campbell 1998).

The combination of the visual site assessment and the digital line intercept methods used for this study provided information that was synergistic, in that the combination of qualitative assessment and quantitative data allowed for site categorizations that would not have been possible if using only one type of data. The visual site assessment allowed for broad categorization of general riparian recovery trends. This method was fast, simple, and especially useful for showing general changes in the channel, bare soil, and willow cover. The digital line intercepts allowed for the detection of change in category type. This method detected what each category type changed into and would be useful if trying to quantify succession or disturbance patterns.

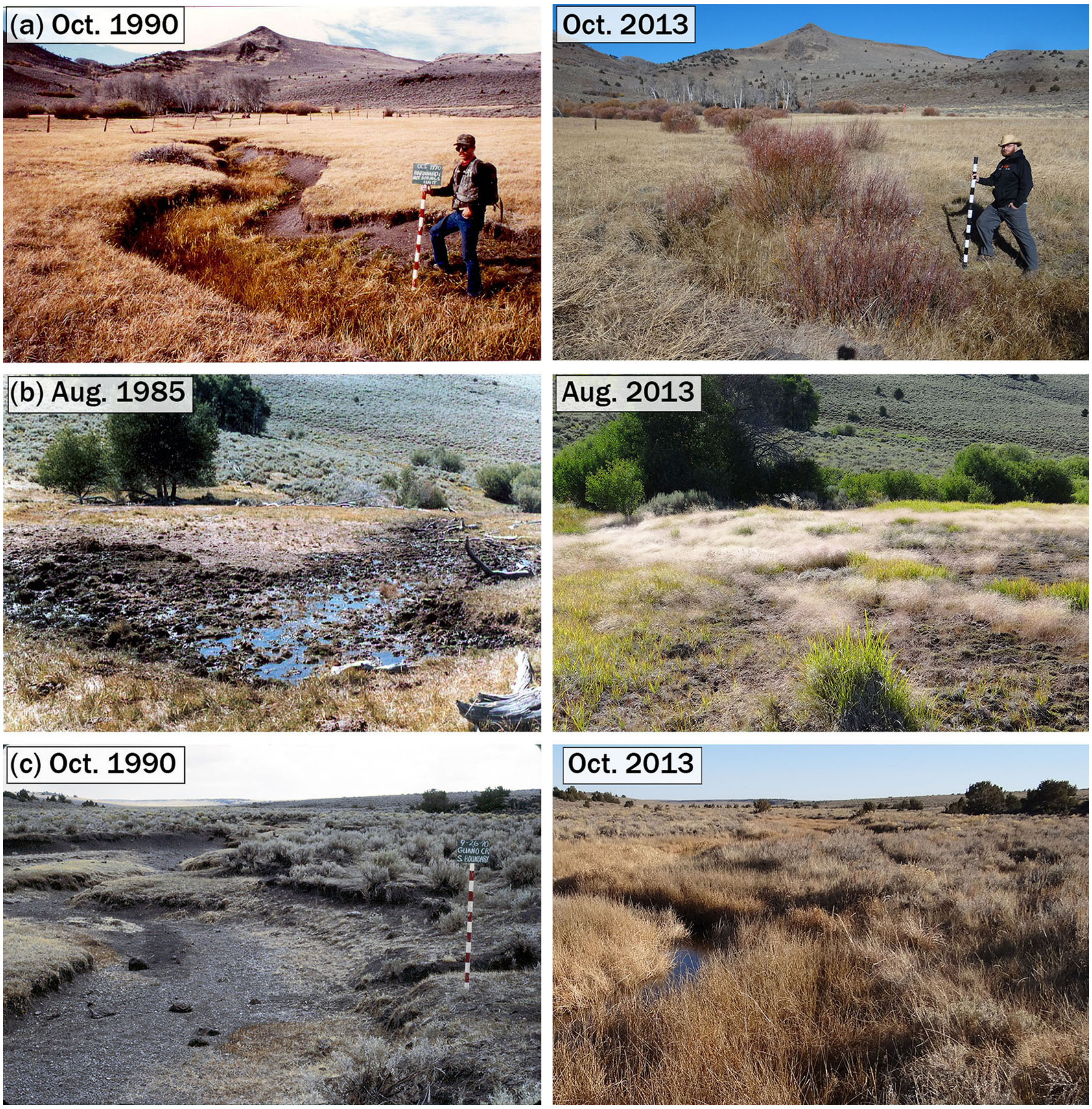

Fig. 8 Historical (*left*) and retake (*right*) photo pairs demonstrating the dramatic change that has happened at Hart Mountain and some of the mechanics of how cattle degraded the system and how the system is recovering. **a** Barnhardy meadow where the stream bed was eroding and willow nearly absent. The retake shows the stabilizing of the stream banks, narrowing of the active channel, and resurgence of willow. **b** Headwaters of Cold Creek where a seep had been trampled into a mud pit. In the retake, mosses and grasses have established in the seep, and aspen and willow have increased in the background. **c** Guano Creek at the southern border of the refuge. A dramatic increase in rushes and riparian vegetation is evident, as well as the stabilization of the stream banks and narrowing of the stream channel. Photo credits: images on *left*-Hart Mountain National Antelope Refuge, images on *right*-Jonathan Bachelor

There are inherent difficulties in trying to replicate photo locations of historical photos that were not intended for use as repeat photography stations. Given the nearly impossible task of trying to find the exact location of a historical photo, it should be assumed that there is some error in the alignment of photo pairs. However, the digital line intercept method showed the succession from bare soil to herbaceous species to willow, and had a high level of accuracy (91 %) in categorization of ground cover types. Accuracy was the lowest for categories similar in appearance (grasses, sedges, and forbs compared to rushes) and categories easily obscured (bare soil), but there is great potential to refine this process by using marked photo-points with marked transects on the ground. With new technologies such as ground-based LiDAR providing spatially explicit data, coupling this ability with photo retakes and other remote sensing applications could provide a level of change detection previously not possible.

In conclusion, this study at Hart Mountain National Antelope Refuge provides insight into how riparian systems in sagebrush/bunchgrass ecosystems of the Great Basin can respond to the cessation of livestock grazing. Fourfold increases in willow and rushes, with bare soil decreasing to a tenth of what it was during the period of cattle grazing, show just how much a system can change within only two decades of cattle removal. Hart Mountain presents a unique opportunity to assess passive restoration as a means to rehabilitate a landscape after decades of cattle grazing. The results are promising, and similar on sites with passive versus active restoration treatments such as burning or planting. Simply removing cattle from areas may be all that is required to restore many degraded riparian areas in the American West.

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