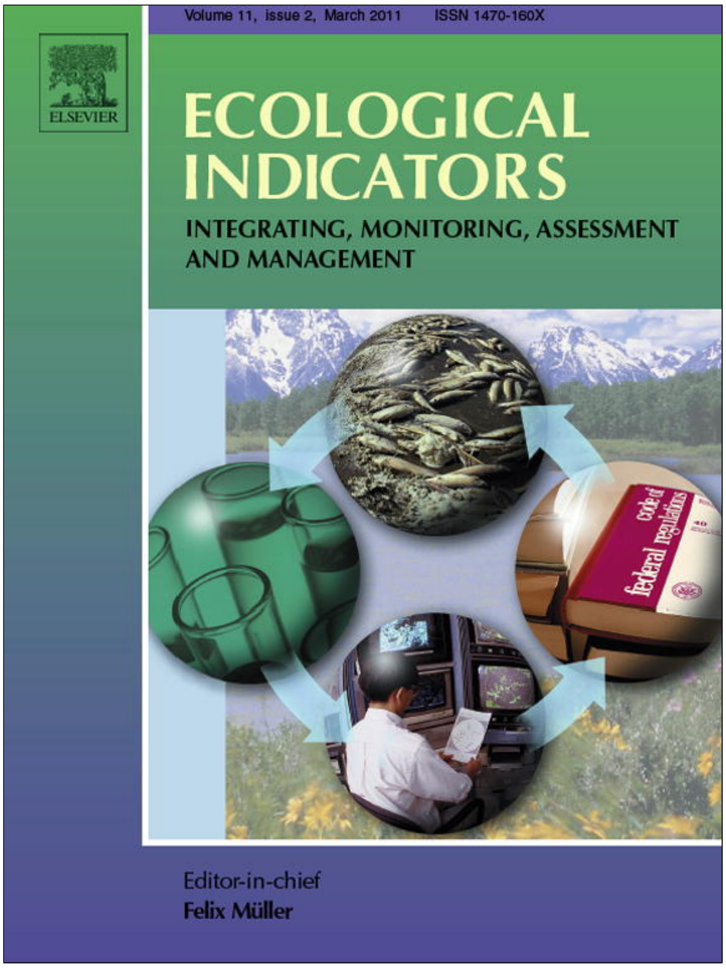
Volume 11, issue 2, March 2011 ISSN 1470-160X
ELSEVIER
ECOLOGICAL INDICATORS
INTEGRATING, MONITORING, ASSESSMENT AND MANAGEMENT
code of federal regulations
Editor-in-chief
Felix Müller

Ecological Indicators 18 (2012) 512–519

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Short communication

Willow cover as a stream-recovery indicator under a conservation grazing plan

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ARTICLE INFO

Article history:
Received 23 July 2010
Received in revised form
26 December 2011
Accepted 29 December 2011

Keywords:
Aerial imagery
Effectiveness monitoring
Ecological indicators
Riparian management
Objective measurements
Watershed-scale sampling

ABSTRACT

Many rangeland streams and associated fisheries have suffered from livestock grazing as a cost of upland-forage utilization. Due to damage from intensive usage, restoration of damaged streams is now a common land-management objective. The Squaw Valley Ranch of Elko County, Nevada, US, in cooperation with the US Bureau of Land Management (BLM) and Barrick Gold Corp., is attempting to improve those portions of the Rock Creek watershed negatively affected by past ranch operations. The watershed includes both historical and occupied habitat for the threatened Lahonton cutthroat trout (*Oncorhynchus clarki henshawi* [Richardson]). From 2003, and continuing to the present, hot-season livestock grazing on Squaw Valley Ranch private and permitted public-land riparian areas was greatly reduced. To assess the effectiveness of this conservation effort, we (1) evaluated BLM archived images of riparian photo points in the watershed, (2) tested for change over time using data from systematic, intermittent, aerial sampling that acquired 2-cm resolution images from low-altitude surveys conducted in 2003, 2004 and 2006, and (3) compared Landsat scenes of the area from before and after 2003. Willow (*Salix* spp.) cover was chosen as the primary ecological indictor of riparian condition and we introduce willow canopy (m^2) per m of stream length in the image field-of-view, as a practical measure of willow status. Archived images from photo points show mostly low-condition riparian plant communities, often with little or no willow canopy evident before 2003, but with conspicuous improvement thereafter. This subjective perception is supported by objective analyses finding, (1) the relative increase in willow cover nearly tripled on one stream, more than doubled on three others, and increased on all but one (fire affected) and (2) a highly significant post-2003 increase in willows in the Landsat record. Thus, the post-2003 increase in willow cover documented in three complementary lines of evidence from ground, air, and space support the predicted ecological benefits of reduced hot-season riparian grazing and the utility of 2-cm imagery as a tool for assessing watershed-wide conservation benefits from a federal cost-share-eligible conservation practice. This appears to be the first use of willow measurements from an aerial survey as a particular indicator of riparian condition and trend and the first demonstration of change detection based on objective measurements from a watershed-scale riparian monitoring effort that used systematic sampling (versus subjective selection) and high sample density to address the large Type II error (false negative) risk common to conventional land-management survey efforts.

"*Because of a lack of uniformity in grazing, certain areas may be sacrifice areas and be overused*"; "*Overuse of these sacrifice areas in valley bottoms and around water holes is justified if the manager is conservative as to the area involved.*" (Stoddart and Smith, 1955, pp. 144 and 279).

1. Introduction

Cattle preference for riparian areas during the hot season leads to riparian damage (Stoddart and Smith, 1955, pp. 144 and 279; McInnis and McIver, 2009) and management that does not specifically control this preference is linked with overuse – specially of willow (*Salix* spp.) (Kauffman et al., 1983; Kovalchik and Elmore, 1992; Schulz and Leininger, 1990; Scrimgeour and Kendall, 2003). Willow loss along desert streams has critical consequences, including increased stream temperatures (White and Rahel, 2008; Zoellick, 2004), loss of beaver and associated habitat and

Abbreviations: BLM, US Department of the Interior, Bureau of Land Management; COST, cosine theta; FOV, field of view; GSD, ground sample distance; NAIP, National Agriculture Imagery Program; NDVI, Normalized Difference Vegetation Index; PIF, pseudo invariant feature; PRA, potential riparian area; SVR, Squaw Valley Ranch; RGB, red, green, blue, the primary colors of a color digital image; TM, Thematic Mapper, the Landsat 5 sensor.

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1470-160X/$ – see front matter © 2012 Published by Elsevier Ltd.
doi:10.1016/j.ecolind.2011.12.017

water-storage capacity (Hebblewhite et al., 2005; White and Rahel, 2008), loss of the well-recognized bank-armor function against high flows (see Vincent et al. (2009), for a recent re-affirmation of the importance of willows for reducing bank erosion along desert streams), and adverse effects to native trout fisheries (Harig and Fausch, 2002; White and Rahel, 2008; Zoellick, 2004). The ecological consequences of willow deficiencies along desert streams are well established. The current issue is how to evaluate the effectiveness of large-area stream-recovery efforts. How can the biological benefit be measured to assess return on investment of watershed-scale stream conservation programs?

In 2003, the Squaw Valley Ranch (SVR) of Elko County, Nevada, US, in cooperation with the US Bureau of Land Management (BLM) and Barrick Gold Corporation, instituted a conservation grazing management program to improve riparian condition in portions of the Rock Creek watershed affected by SVR operations. The goal is restoration of aquatic habitat for the threatened Lahonton cutthroat trout (*Oncorhynchus clarki henshawi* [Richardson]) (U.S. Federal Register, 1975; USFWS, 1995; *unpublished memorandum*: Biological opinion for the 2004 through 2024 livestock grazing system for the Squaw Valley Allotment, Elko County, NV. United States Fish and Wildlife Service, 2004, File Number 1-5-04-F-05. Reno, NV, 68 pp; the opinion cites historic season-long grazing as a predominant factor in trout habitat degradation). Poor riparian condition at survey stations for key streams in the watershed from 1977 through 1997 is documented in *Squaw Valley Allotment Multiple Use Decision: Biological Assessment for Formal Consultation Request* (6 July 1998, on file, BLM Elko District Office). Further evidence of poor riparian condition is found in archived BLM and Landsat images of the watershed.

To evaluate the biological outcome of their conservation-grazing program, SVR cooperated with the US Department of Agriculture, Agricultural Research Service in sequential aerial surveys of the Rock Creek watershed. Aerial photography can be a cost-effective means for collecting riparian data (Clemmer, 2001; Manning et al., 2005; Marcus et al., 2003), but the value of such assessments depends largely on the spatial resolution of the data (Congalton et al., 2002; Davis et al., 2002; Johnson and Covich, 1997; Muller, 1997; Prichard et al., 1999). Low-altitude, 2-cm GSD (a measure of digital-image resolution), intermittent-capture aerial imagery allows superior riparian assessments at a cost less than half that of ground-based methods (Booth et al., 2006a).

Given the reports of poor riparian condition in the Rock Creek watershed cited above, we predicted (1) willow cover would be reliably measured from low-altitude, 2-cm GSD, intermittent-capture aerial imagery thereby allowing detection of willow-cover changes over time, (2) that BLM archived photographs, and (3) the Landsat image record, would be consistent with cited documents for pre-2003 conditions; therefore, that (4) the conservation effectiveness of SVR's reduced hot-season riparian grazing could be objectively determined, and (5) that analysis of these three lines of willow-abundance evidence would provide an objective test of the biological benefit of the SVR conservation-grazing program. This appears to be the first attempt to use willow measurements from an aerial survey as a particular indicator of recovery in a degraded stream system.

2. Methods

2.1. Study area

Aerial surveys were conducted in 2003, 2004, and 2006 over the 330,000-ha Rock Creek watershed (41°17′ N, 116°23′ W) in the Tuscarora Mountains of north-central Nevada, US (Fig. 1). The BLM manages 66% of the watershed but 90% of riparian areas are owned by the SVR. Watershed elevation is 1500–2400 m. Precipitation is 250–300 mm (SCAS, 2005). The riparian zones contain coyote and yellow willow (*Salix exigua* (Nutt.) and *Salix lutea* (Nutt.), syn. *rigida*) and are characterized by shallow, low-volume streams of which Rock Creek is the primary drainage (plant nomenclature follows NRCS, 2009). Rock Creek flow is highly variable with mean monthly flows March through May between 2.9 and 4.2 $m^3 s^{-1}$ falling to 0.05 $m^3 s^{-1}$ in August (stream gauge 10324500 near Battle Mountain, Nevada [USGS, 2006]). Sampled streams are 1500–2200 m in elevation, and fall into eight distinct geomorphological valley bottom types (*unpublished 1995 report*: Inventory and assessment of riverine/riparian habitats-Rock Creek Basin, Nevada. White Horse Associates, Logan, UT). We used White Horse Associates' inventory and definition of stream reaches and divided our aerial sampling by reach.

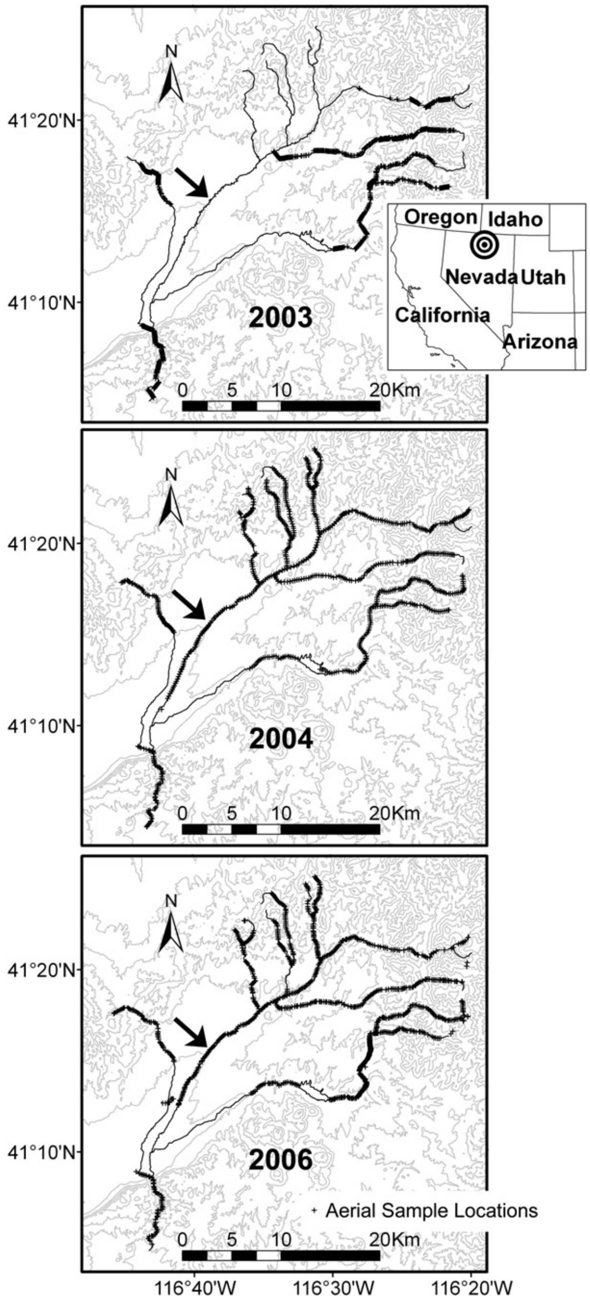

Fig. 1. Photo locations (·) by year for the major streams of the Rock Creek watershed in north-central Nevada, shown against 100-m contour intervals. The black arrow indicates the location of Fig. 3, Landsat TM series.

Table 1
Willow cover for nine streams by year. Cover data are $m^2\ m^{-1}$ of stream in image ± S.D. and the relative increase factor over 2 or 3 years is in multiples of 2003 or 2004 cover.

Creek	2003		2004		2006		Relative increase
	Willow cover	*n*	Willow cover	*n*	Willow cover	*n*	
Frazer[a]	2.9 ± 3.1	42	3.9 ± 4.5	30	7.3 ± 6.0	36	2.5×
Lewis	9.5 ± 4.8	30	9.9 ± 6.3	21	11.0 ± 6.8	46	1.2×
Middle Rock[a]	0.9 ± 1.1	28	0.2 ± 0.5	36	1.0 ± 2.0	51	1.1×
Nelson	7.2 ± 4.3	21	8.4 ± 6.7	12	16.8 ± 8.8	36	2.3×
Upper Rock[a]	18.2 ± 17.0	28	10.2 ± 10.1	25	10.2 ± 8.0	87	−0.6×
Soldier[a]	–	–	1.2 ± 1.7	21	1.7 ± 2.1	26	1.4×
Toejam	3.8 ± 4.0	71	6.4 ± 6.4	54	8.7 ± 8.8	81	2.3×
Trout	–	–	4.1 ± 3.9	40	4.2 ± 6.2	56	1.1×
Willow[a]	1.8 ± 3.2	64	3.6 ± 5.8	40	5.2 ± 6.9	146	2.9×
All	5.2 ± 7.9	284	4.9 ± 6.3	279	7.1 ± 7.9	565	1.4×

[a] Portions of this stream were within a 2005 burn perimeter.

The stream reaches averaged 3.4 ± 2.1% slope (mean ± std. dev.), meaning channel elevation dropped 34 m km^{-1}, on average, across the watershed. Isaak and Hubert (2000) reported this channel-slope range was associated with the highest cutthroat trout (*O. clarki*) density in southeastern Idaho. While 27% of Rock Creek watershed reaches fall in the high-slope category of >4.3%, over 66% fall into the medium slope category of 1.8–4.3%, indicating that the watershed provides prime (potential) trout habitat.

From 2003 to the present, there has been no intentional hot-season livestock grazing on riparian areas; however, instances of 100–200 head of non-permitted, late-season riparian use are known for the first 2 years. (The non-permitted use is 6–10% of permitted grazing and began in late July 2004 and in September 2005.) Three major wildfires in 2005 and 2006 burned upland areas surrounding 15 of the 27 stream reaches photographed, inflicting varying degrees of damage to riparian vegetation (Table 1).

2.2. Ground images

The BLM Elko Field Office provided us with 743 landscape-view photographs from 111 riparian photo points associated with 7 streams in the watershed. These included upstream, downstream, and across-stream views. Image acquisition dates ranged from 1977 to 2009. Because the conservation grazing management program was begun in 2003, we selected 92 image sets having at least one pre-2003 image, a 2003 image, and 2 images from 2004 to 2009. All image sets exceeded the 4-image minimum. We asked 5 people to rate the photo-point sequences for change in willow abundance between 2003 and earlier versus 2004 and later, using a rating where 0 = no rating due to apparent movement of the photo-point or other irregularity, 1 = large decrease, 2 = moderate decrease, 3 = no change, 4 = moderate increase, and 5 = large increase. We then counted the number of ratings in each category. Among the five observers were 3 college students between 20 and 30 years of age, and 2 rangeland professionals over 40 years of age. Four were females. None of the observers was a co-author on the paper or associated with either the SVR or the BLM.

2.3. Aerial images

Color digital, 2-cm GSD images were acquired from a light sport airplane (FAA, 2010) equipped with: (1) a navigation system; (2) 11- and 16-megapixel, single lens reflex digital cameras (RGB) fitted with 100 mm *f*/2.0 and 840 mm *f*/5.6, lenses respectively; (3) a laser altimeter; and (4) two laptop computers (Booth and Cox, 2006, 2008; Booth et al., 2006b,c). This is a sampling, not a mapping, method. Flight plans were created using ArcView 3.3 and ArcMap 9.0 (ESRI, Redlands, CA). All images were captured with associated time and location data (Booth et al., 2006c).

Segments of 11 streams (27 reaches), totaling 170 km, were surveyed July 17–18, 2003, September 9–10, 2004 and September 12–13, 2006 (Fig. 1). Each stream was sampled at approximately 100-m intervals along a continuous length starting at the source and ending at either the junction with a larger stream, or when the stream exited the survey boundary. Because images were triggered manually by the pilot and not pre-programmed, photographic overlap between years was coincidental. Target flight altitude AGL was 200 m in 2003 and 2004, and 250 m in 2006, a change made to increase image FOV.

2.3.1. Cover measurements

We used *SamplePoint* (Booth et al., 2006c) to measure cover from images of nine streams that represent the watershed's geomorphological variation. We used 100 points per image with the following cover-type categories: (1) non-riparian area, (2) water, (3) willow, (4) riparian vegetation and (5) other. Vegetation color, indicating higher moisture, defined the riparian area. Points outside the riparian area were classified as non-riparian. Only points falling inside the riparian area were classified into the other four categories. This method required subjective delineation of riparian boundaries, as do all methods that measure riparian indicators. Cover percentages were converted into actual area (m^2), and then normalized by dividing actual area by the stream length within the image (see below) to allow inter-year comparison. Thus, cover is reported in $m^2\ m^{-1}$ stream. Stream length was used for normalization because it shows higher annual consistency than riparian width or area.

2.3.2. Repeat measurements

Random airplane movement and manual triggering make it impossible to plan riparian aerial surveys at this resolution in a way that will reliably capture the same piece of ground in repeat flights; however, the acquisition of hundreds of images resulted in some chance overlap. These partially overlapping images were used to measure change directly for individual willow canopies using rocks for accuracy calibration. Using paired photos in *ImageMeasurement* (Booth et al., 2006b), we measured canopy diameter of individual willow plants. Repeat samples are also valuable in tracking changes in channel sinuosity and bank erosion.

2.3.3. Stream length

Stream length within each image used to measure willow cover was measured on a line with a minimum of 20 segments placed down the center of the bank full channel using *ImageMeasurement*. Additionally, the distance from each sample to the upstream end of the stream reach containing the sample was measured from topographical maps (1:100,000-scale) in ArcMap 9.0.

2.3.4. Statistics

A paired *t*-test was used to compare willow canopy on repeated measures of 24 willow plants. Comparisons of willow cover among years used unpaired samples because of the limited number of repeated samples.

Spatial autocorrelation was assessed with Moran's I z-scores generated by ArcMap 9.2 (ESRI, Redlands, CA). Because most data were spatially autocorrelated, we condensed the data into means for stream reaches (*personal communication:* P. Chapman, Colo. State Univ. Dept. Statistics, 2010). The condensed data had insufficient sample size to calculate Moran's I z-scores or fit an autogregressive model to check for spatial autocorrelation, so we used Proc Mixed in SAS (SAS v 9.1, SAS Institute, Nashville, TN, USA) to test for a random creek effect using stream reaches to determine if intra-stream values were more correlated than inter-stream values where creek was tested as a random effect (P. Chapman, op cit.). We omitted 2003 data in all cases from the random-effect test due to limited data. Willow-cover data were square root transformed to satisfy the equal variance assumption. The 2005 fire burned two reaches of Upper Rock Creek, reducing willow cover for both and resulting in loss of statistical independence between them. Therefore, these data were averaged together and treated as one reach. Other reaches burned, but they were not combined because we had no evidence that these riparian areas sustained significant damage. Annual change was tested using *t*-tests paired by years for individual streams.

2.4. Landsat TM record

The assessment of riparian habitat over time from Landsat imagery was accomplished by first delineating potential riparian areas (PRAs) for nine streams using Feature Analyst Software (Visual Learning Systems, Missoula, Montana, US) with NAIP images (1-m resolution, aerial, 2006, color infrared). The PRAs were defined laterally by topographic limits and we used plant community at the riparian-upland interface to deduce that topographic limit. Thus, the PRAs were low-lying lands supporting riparian, or remnant riparian, communities with associated upland vegetation and judged capable of supporting a larger riparian community given a higher water table and (or) greater soil-water storage. After the PRAs were defined on NAIP imagery, the image locations were used to ensure geographic precision of the area for temporal analysis in sequential Landsat images. The riparian vegetation within the PRA for each stream reach was measured from Landsat images by developing NDVI values and images for each reach (Lyon et al., 1998). These were then used to determine the percent of potential riparian area actually occupied by riparian vegetation. This allowed the Landsat archive to be used to assess the 1989–2003, and 2004–2009, trends in riparian condition (the years 1995 through 1998 were not used due to cloud-cover issues with scenes of interest). Differences in atmospheric conditions, sun angle, and sensor calibration make it necessary to calibrate multi-temporal imagery and we used COST and PIF normalization to correct for these effects (Schott et al., 1988; Chavez, 1996; Sant, 2005). The above two methods of radiometric correction were applied to our Landsat scenes using publicly available tools (Utah State University, 1999, 2011) to make the COST corrections, and PIF normalization.

Between sensor differences and changes in intra-sensor calibration was accounted for by applying the appropriate published calibration values for the different Landsat TM sensors. The 1994 TM image was acquired on a clear day and is temporally in the center of the dates represented by the TM image dataset. Therefore, we selected it to be the master image. The rest of the images were normalized to the master using PIF normalization. Because there are few manmade features on our images, we used salt flats for bright area-calibration and north facing slopes (shadow) and water for dark area-calibration. We restricted our scenes to early September to reduce the variation from inter-annual precipitation. In this summer-dry climate, upland herbaceous vegetation is senesced by September regardless of the amount of preceding winter and spring precipitation. The sharp contrast in herbaceous vegetation senesced on the upland and green in the riparian zones facilitated an accurate delineation of the riparian areas. Change over time of the percent of the PRA occupied by riparian vegetation of the nine streams was calculated from NDVI values and those values compared across streams for the years 1989–2003 versus 2004–2009 using a paired *t*-test.

2.5. Precipitation analysis

Precipitation data were downloaded for the five closest Snotel stations (29–46 km away; NRCS, 2007), and monthly precipitation was averaged across all stations for 2004, 2006 and for the 29-year period from 1982 to 2010 (extent of data) by using the first 28 days of each month to standardize the observations among months and years.

3. Results

3.1. Ground images

The 5 observers rating the 92 image sets produced 460 total ratings of which 4 were rated as showing moderate decrease, 103 as showing no change, and 353 as showing either a moderate or large increase in willow abundance for the period 2004–2009 relative to 2003 and earlier.

3.2. Aerial images

3.2.1. Data acquisition

The aerial surveys produced 723 useable images in 2003, 590 in 2004 and 959 in 2006. Mean image GSD was 1.8 cm in 2003, 2.0 cm in 2004 and 2.3 cm in 2006. Twenty image FOVs from 2006 partially overlapped 2004 image FOVs, and were used for direct repeat measurements of willow canopy. *ImageMeasurement* analysis accuracy was confirmed by comparing measurements of unchanging objects made from the 2004 to 2006 images. Absolute measurement error (average of under-measures and over-measures without regard to sign) was 7.2 cm, or 3.8% ($n = 12$), which agrees with the <10% measurement error previously reported (Booth et al., 2006b). Stream length captured by images averaged (mean ± std. dev.) 72.5 ± 23.1 m ($n = 161$) and 94 ± 24.3 m ($n = 436$) in 2004 and 2006 respectively.

3.2.2. Willows

Willow cover ($m^2\ m^{-1}$ stream) increased 3.1% between 2003 and 2006 ($p = 0.02$, $n = 12$ reaches) and 2.0% between 2004 and 2006 ($p = 0.004$, $n = 20$ reaches), but there was not a significant increase between 2003 and 2004 ($p = 0.18$, $n = 12$ reaches; Table 1). Measurement of 24 individual willow plants across 20 pairs of repeat sample images (2004–2006) revealed an average increase in canopy size of 55 ± 66.2% (Fig. 5A and B).

3.3. Landsat TM record

All nine streams for which change-over-time differences in NDVI values were calculated had riparian-vegetation increases within PRAs for 2004–2009 as compared to 1989–2003 ($p < 0.001$; Figs. 2 and 3).

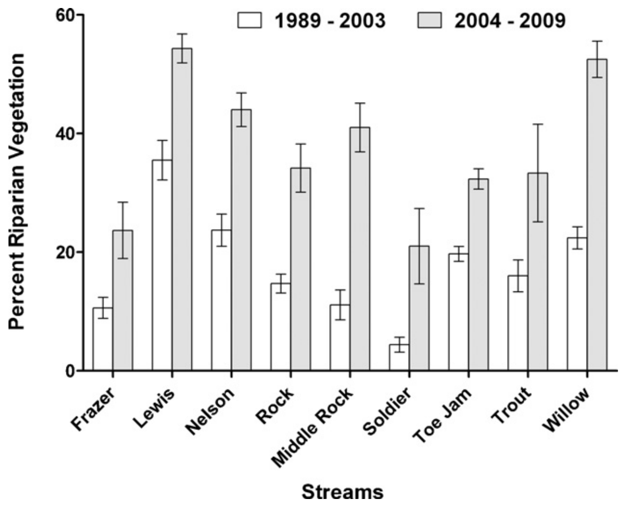

Fig. 2. Change over time in the percent of the potential riparian area occupied by riparian vegetation of nine streams and measured from Landsat images using Normalized Difference Vegetation Index values and images as illustrated in Fig. 4 ($p < 0.001$ across all streams). Error bars indicate standard error of the mean.

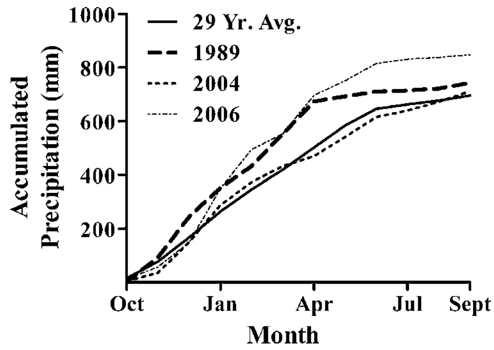

Fig. 4. Average cumulative precipitation for the five closest weather stations to the study site, all located within the same mountain range and within 50 km of the study site, for water years 1989, 2004, 2006 and the 29-year period 1982–2010 (full data extent for the 5 stations). We used 28 days per month to standardize the observations among months and years.

3.4. Precipitation analysis and stream flow

Cumulative precipitation in 2006 was above the 29-year average preceding, and throughout, the growing season (Fig. 4), and is reflected in measured stream flow. Annual runoff in 2006 was $118.0 \times 10^6\,m^3$ compared to 100.0×10^6, 20.9×10^6, and $5.5 \times 10^6\,m^3$ in 2005, 2004, and 2003 respectively, and to an average $36.9 \times 10^6\,m^3$ for 1918–2006 (Bonner et al., 2005; USGS, 2006). The September 2006 flow of $1.08\,m^3\,s^{-1}$ was the greatest recorded flow for any September up to that time (USGS, 2006). There are 6 periods prior to 2003 where cumulative water-year (October–September) precipitation exceeded the 29-year average of 697 mm: 1980, 1982–1984, 1986, 1989, 1993, and 1995–1998; cumulative annual precipitation for these years ranged from 729 to 1108 mm (NRCS, 2007).

4. Discussion

Ground and space images give supporting evidence for the poor pre-2003 condition of key streams as documented in *Squaw Valley Allotment Multiple Use Decision: Biological Assessment for Formal Consultation Request* (6 July 1998, on file, BLM Elko District Office). The pre-2003 condition contrasts sharply with post-2003 conditions where the relative increase in willow cover nearly tripled on Willow Creek during the first 3 years of the new grazing plan and more than doubled during the same period on three other streams (Table 1). The trend of increasing willow cover is consistent with reduced livestock grazing (Brookshire et al., 2002; Case and Kauffman, 1997; Holland et al., 2005; Schulz and Leininger, 1990) and is thought to result primarily from established-plant growth under a reduced-herbivory regime (Fig. 5).

Why should changes in willow cover be ascribed to reduced livestock grazing and not to above-average precipitation and greater stream flow? We propose four reasons: (1) we found no reports of a similar willow-growth response from a season of increased precipitation, (2) such a growth response would be phenomenal, and inconsistent with reported annual growth rates (see Brookshire et al., 2002), (3) there are reports (cited above) documenting

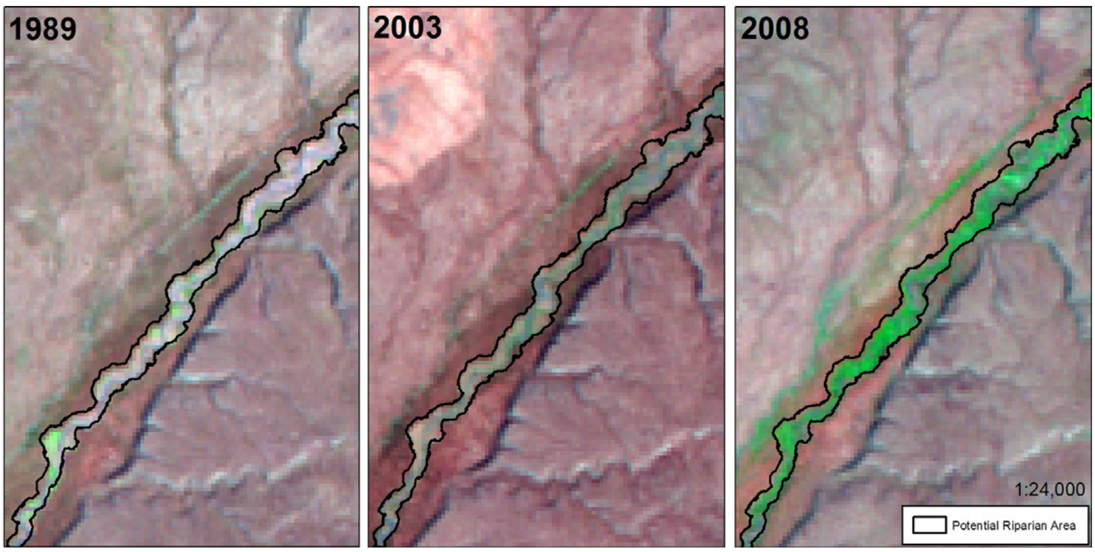

Fig. 3. A September sequence of Landsat TM scenes showing a nearly static riparian condition between 1989 and 2003, but a large improvement by 2008. The 2008 image is consistent with the improvements documented using BLM photo-point images and 2004 and 2006 aerial surveys after the 2003 change to reduced hot-season grazing on riparian areas. The images are true color composites using a band 7-4-3 combination. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 5. Images of a particular location on Middle Willow Creek photographed in 2004 (A) and 2006 (B) with white lines indicating measurements. The willow canopy diameter in the upper left was 1.7 m in 2004, and 2.3 m in 2006, and the willow canopy in the lower right increased from 1.7 m in 2004 to 3.0 m in 2006. The width of the open water increased from 1.3 m to 3.4 m.

a willow-growth response to multi-year protection from grazing that is consistent with our findings, and (4) willows along the streams are accessing the water table so that growth is supported in both dry and wet years unless (a) the water table drops beyond reach of the willow roots (Bilyeu et al., 2008) or (b) rises significantly, putting roots in an anaerobic situation (Bourret et al., 2005). Thus the water from a year–or even a multi-year sequence–of above-average precipitation is unlikely to stimulate above-average growth of established willows but it could *reduce* willow growth if it produced a significant sustained elevation of the water table.

There is evidence that above-average precipitation has the potential to bring more nitrogen into a riparian system, particularly in overland flow from rainfall events, and that the added nitrogen will contribute to willow growth (Schade et al., 2002; Schade and Welter, 2005; Welter et al., 2005). The time period covered by our ground and Landsat images includes several pre-2003 wet periods (1989 for example), and images for those periods do not show the same increases in willow growth that occurred after 2004 (e.g., Fig. 4). Given our data, we doubt that nitrogen added by wet years made a difference in pre-2003 willow cover due to the ongoing hot-season grazing. We suspect nitrogen added by wet years is a factor in the post-2003 willow-cover increases.

The increases in willow cover herald structural changes, including increased stream shading, bank armor, and channel obstructions–especially the development of beaver (*Castor canadensis* [Kuhl]) dams–that are consistent with long-term progress toward slowing runoff, increasing water retention, and promoting perennial stream flow.

This study appears to be the first use of willow measurements from an aerial survey as a particular indicator of recovery in a degraded stream system. Our results demonstrate that 2-cm imagery and associated image-analysis tools can detect, document, and facilitate measurement of temporal change in this, and other, key indicators – including changes due to weather, fire, and management. We demonstrate that the 2-cm imagery fills a critical gap between conventional field methods and the lower-resolution imaging methods cited by Clemmer (2001), Marcus et al. (2003), and Manning et al. (2005). We also demonstrate the benefit of using space, aerial, and ground images to address a question.

Riparian systems are important in all parts of the world. The aerial methods we used are applicable to any place that can be safely flown by a light sport airplane at 100–300 m altitude AGL, and that have one or more indicators that, like willow cover – can be measured from acquired imagery.

5. Conclusions

Willow cover and canopy-size increases suggest an upward ecological trend for surveyed streams of the Rock Creek watershed after 2003. Ground photographs and the Landsat record provide a historical context for the aerial-survey data and allow us to conclude that willow cover, measured from 2-cm GSD aerial imagery, increased significantly during the first 3 years of the current SVR grazing-management program. The findings imply that reduced hot-season grazing will increase remnant willow populations along desert streams in the western United States where stream incision has not substantially lowered the water table. The improvement we measured bodes well for the restoration of flow-regulating, water-storing components of the hydrologic system and the concurrent recovery of habitat for Lahonton cutthroat trout. We conclude that the low-altitude, 2-cm GSD aerial surveys, and related image analyses allowed us to detect and quantify these riparian-system changes better than could be done with any other currently available monitoring method or combination of methods. Aerial surveys like those used in this study make high sample density and systematic sampling (versus subjective selection) of watersheds and other landscape-scale units practical, thereby addressing the large Type II error (false negative) risk common to conventional land-management survey efforts.

Role of the funding entities

Barrick and BLM had no role in study design; or in the collection, analysis, or interpretation of data, or in writing the report except that S.E. Cox entered on duty in his current position in 2011, and has participated in post-submission revision. USDA-ARS approved submission of the manuscript upon successful pre-submission external peer review.

Disclosures

Open Range Consulting is retained by Barrick to manage the SVR.

Acknowledgments

The research was funded in part by Barrick Gold Corporation (Barrick), Elko, Nevada; the USDA-ARS; and the Wyoming State Office of the BLM. Carol Evans, Fisheries Biologist for BLM, Elko Field Office, provided valuable assistance. Barrick provided aviation facilities and crew lodging. Joe Nance, CloudStreet Flying Services, acquired aerial images. Carmen Kennedy, USDA-ARS, provided technical assistance. Dr. Phil Chapman, Colorado State University Department of Statistics, consulted with us on the statistical analyses, and Larry Griffith, USDA-ARS assisted in the analysis. We thank Drs. G. Perry and D. W. Bailey, also C. Evans and M. Bishop for reviewing an earlier version of the manuscript. Throughout this manuscript, mention of products and proprietary names is for information only and does not constitute an endorsement by the authors, Barrick, USDA, or BLM.

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