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Riparian monitoring using 2-cm GSD aerial photography

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Abstract

Riparian monitoring is a key aspect of sustainable resource management and is mandated by US federal law for federal land management agencies. However, it is an endeavor hampered by rising manpower costs and time-consuming travel and methods. These limitations tend to reduce sampling intensity per reach of stream and limit monitoring to the larger waterways of management units—limitations that reduce the accuracy of inferences derived from resulting data with consequential reductions in the effectiveness of landscape-level resource management. We tested the utility of low-altitude, high-resolution, intermittent aerial digital imagery for relatively inexpensive, high-intensity sampling in a watershed inhabited by the Lahonton Cutthroat trout, a species listed as threatened under provisions of the US Endangered Species Act. Measurements gleaned from the aerial imagery included late-summer open water width, number and location of late-summer dry channels, widths of riparian areas and willow coverage. All measurements were georeferenced to allow spatial data display. Riparian proper functioning condition (PFC) was assessed from the imagery by a USDI, Bureau of Land Management team. These assessments were compared to similar on-the-ground assessments made during the preceding year. PFC assessments from aerial photography were made using an average 4 staff hours per stream compared to an estimated 36 staff hours per stream for ground PFC assessments. The two assessment methods yielded roughly comparable results. We conclude that riparian-condition assessments from 2-cm GSD digital aerial imagery allowed increased sample intensity (and thus increased inference accuracy) and that it did so in our study at a cost less than half that of conventional ground-based methods. We recommend the acquisition and analysis of 2-cm GSD digital aerial imagery be further trialed for its utility and cost efficiency in ecological monitoring of riparian systems.

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Keywords: Aerial imagery; Measurement; Measurement software; Resolution; Riparian measurements; Stream width; ImageMeasurement; Merge; LaserLOG

1. Introduction

Freshwater streams and associated flora of the western United States make up less than 9% of public land and are widely scattered (Prichard et al., 1994), but are resources for which the US Federal Land

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Policy and Management Act of 1976 mandates 5-year ecological assessments. Riparian proper functioning condition (PFC) is the standard method for assessing how well the physical processes of riparian systems are working. The PFC assessment uses multiple indicators as judged by a team of resource professionals (Prichard et al., 1998). Because riparian areas are scattered, travel is a significant portion of assessment costs. Aerial photography and other remote sensing methods are recognized as cost-effective means for collecting riparian data (Clemmer, 2001; Marcus et al., 2003; Manning et al., 2005) and with some limitations, for assessing PFC (Prichard et al., 1999). Satellite imagery is too coarse to characterize western US riparian systems on anything but a gross level (Lillesand and Kiefer, 2000; Congalton et al., 2002). The accuracy of land or vegetation characterization from remote sensing data is a function of spatial resolution (Johnson and Covich, 1997; Muller, 1997; Harvey and Hill, 2001; Congalton et al., 2002; Davis et al., 2002). Yet, both Prichard et al. (1999) and Clemmer (2001) recommend the use of the lowest-resolution photographs that allow observation of features like flood plains, beaver dams, channels, deposition, and bank vegetation (typically scales between 1:40,000 and 1:60,000). Their recommendation appears based on the number of photographs to be examined and the perceived need for total photographic coverage. Total coverage at high resolution (small field-of-view) multiplies the number of images needed compared to low resolution (large field-of-view). Yet, accurate feature measurement requires higher resolution than feature observation. There is a move toward greater objectivity in riparian assessment (BLM, 2002) and lower-resolution photography (1:40,000–1:6000) is inadequate for extracting measurements accurate to decimeters, or to provide the detail required for a trained team to make PFC assessments. Nagler et al. (2005) reported that willows could not be distinguished from cottonwoods at 50-cm GSD (1:6000). Davis et al. (2002) recommended ≤ 20 -cm GSD imagery (1:2400) for riparian vegetation monitoring. Maiersperger et al. (2004) recommended ≤ 15 cm GSD (1:1800) for shrub determination and Lonard et al. (2000) recommended a scale of 1:600 (5-cm GSD) to discern woody vegetation types. Until recently, aerial photography with a resolution greater than 1:600 was not practical, but recent advances now

allow the acquisition of aerial images with resolutions as fine as 1-mm GSD (3 m \times 4 m field-of-view, $\sim 1:12$) (Booth and Cox, in press; Booth et al., 2006). We found a 3 m \times 4 m field-of-view impractical for stream-width measurements, but 2-cm GSD imagery ($\sim 1:200$) gave a good balance between the resolution needed for accurate measurements and a larger field-of-view. Continuous coverage at 2-cm GSD is usually not needed, since lower-resolution (1:6000 to 1:40,000), continuous-coverage imagery is often better suited for observational purposes. New image analysis tools allow measurements to be made from images at a rate and precision not possible using the older photogrammetry techniques (Booth et al., 2006). In 2003 we conducted, as described hereafter, a first test of our aerial methods for monitoring riparian systems. As a consequence of lessons learned we developed and tested new tools (Booth et al., 2006), then in 2004, retested our capability for aerial assessments of riparian systems. Here we describe the collection and utilization of very large scale aerial (VLSA) imagery, illustrate the utility of the data for ecological assessment—including a comparison of PFC assessments made from imagery and on the ground, and provide a cost comparison of ground and aerial methods.

2. Methods

2.1. Study area

The study area was the 330,000-ha Rock Creek watershed (41°17'N, 116°23'W) in the Tuscarora Mountains in north-central Nevada. The USDI, Bureau of Land Management (BLM) manages 66% of the watershed, but 90% of the riparian areas are owned by Squaw Valley Ranch. Watershed elevation ranges from 1500 to 2400 m and is in a 250–300 mm precipitation zone (SCAS, 2005). Greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.) and saltgrass (*Distichlis stricta* (Torr.) Rydb., listed as *Distichlis spicata* (L.) Greene, by USDA NRCS (2005)) form the majority native-plant community at the lower elevations and sagebrush (*Artemisia* sp.) bitterbrush (*Purshia tridentata* (Pursh) DC), mountain mahogany (*Cercocarpus* sp.) and aspen (*Populus tremuloides* Michx.) with grass understory occupy the higher-elevation sites (BLM, 1998). Infestations of cheatgrass (*Bromus tectorum* L.) threaten the

native shrub communities. Riparian zones are characterized by shallow, low-volume streams of which Rock Creek is the primary drainage. Rock Creek has highly variable annual flows that average $3.94 \text{ m}^3 \text{ s}^{-1}$ in spring to $0.04 \text{ m}^3 \text{ s}^{-1}$ in late summer. Sampled streams ranged from 1500 to 2200 m in elevation, and fall into eight distinct geomorphological valley bottom types (Whitehorse Associates, 1995). The watershed is home to the threatened Lahonton Cutthroat trout (LCT) (*Oncorhynchus clarki henshawi*) (U.S. Federal Register, 1975). An agency Biological Opinion (US F&WS, 2004) cited historic year-long grazing (including spring lambing and growing-season use of riparian areas) by the previous ranch owner as a predominate factor in LCT habitat degradation.

2.2. Field data collection

Proper functioning condition (PFC) assessments of stream reaches were conducted by a 4-person BLM crew at 60 permanent monitoring stations along 6 streams in 2003 (Table 2) using standard BLM protocol (Prichard et al., 1995, 1998). The “Standard Lotic Checklist” used in the field to determine PFC includes YES/NO/NOT APPLICABLE blocks for 17 key indicators of riparian health encompassing hydrologic (i.e. riparian zone has achieved potential extent), vegetative (i.e. diverse age class and composition; high vigor) and soils-erosion/deposition attributes (i.e. point bars revegetating, deposition balances erosion).

2.3. Acquisition of 2-cm GSD, very-large scale aerial (VLSA) images

VLSA surveys are designed to systematically sample an area of interest by acquiring numerous images at intermittent intervals over the survey area and its subdivisions (stream reaches). VLSA is *not* intended to accomplish riparian mapping. To acquire VLSA images we used a light airplane (225-kg empty weight, fixed wing, 3-axis), a navigation and camera-triggering system, a digital camera, and a laser rangefinder (Booth and Cox, in press; Booth et al., 2006). The navigation system was powered by Tracker¹ software (Track'Air

B.V., Oldenzaal, The Netherlands) on a laptop computer interfaced with (1) a central navigation box, (2) a WAAS-enabled geographic positioning system (GPS) unit, and (3) a 15-cm in-cockpit pilot display. The navigation system can either be programmed to automatically trigger the camera when the pilot reaches a pre-defined target located along a linear flight line, or it can simply display airplane position relative to a georeferenced line drawing of target areas (riparian zones) on the cockpit display screen and record time and GPS location of manually triggered shots. The latter method requires greater pilot responsibility in positioning the airplane over the riparian zone while manually triggering the camera with an electronic cable release attached to the aileron control stick. In this study we tested both methods of acquisition on-site in 2003 and found the latter method resulted in a larger ratio of photographs capturing the creek in the imagery. Thus, in 2004 we used manual triggering exclusively. In both cases, ArcView 3.3 (ESRI, Redlands, CA) was used to create flight plans for pilot reference in-flight.

We used a Canon EOS 1Ds 11.1-megapixel single lens reflex, color (RGB) digital camera with a Canon 100 mm f/2.8 EF USM lens. The camera interfaced with a laptop PC running Canon Remote Capture software and images were stored directly on the 40-GB laptop hard drive (Canon USA, Lake Success, NY, USA). Images were first saved as 10 MB RAW files (non-lossy) and later converted to 12 MB, 4064×2704 -pixel minimum-compression JPEG files for analysis. Both laptops involved in data collection and storage were time-synchronized via a network command at the start of each mission so that all data collected would match up precisely by time.

A Riegl LD90-3100VHS-FLP laser distance meter (Riegl, Orlando, FL) was used as an altimeter in conjunction with LaserLOG software (Booth et al., 2006) to continuously read and record the airplane's altitude above-ground-level (AGL) below 300 m. Altitude was displayed for the pilot on the laptop screen, while stored data were saved for later correlation with images. Flight altitudes at image-capture ranged from 150 to 300 m AGL, resulting in image resolutions of 1.3–2.6-cm GSD.

Segments of seven streams within the Rock Creek Watershed were surveyed over the course of 3 days in July 2003. Each stream was sampled at approximately 100-m intervals along a continuous length starting at the

¹ Throughout this paper mention of products and proprietary names is for information only and does not constitute an endorsement by the authors, USDA, or USDI.

source and ending either at the junction with a larger stream, or when the stream passed beyond established BLM riparian monitoring sites. In September 2004 this sampling was repeated with the addition of four nearby streams. Aerial samples collected in 2003 were not used for measurement analysis (see below) because our methods for making accurate measurements (Booth et al., 2006) were not yet developed. The 2003 samples do serve as an indication of the improvement in sampling efficiency with manual triggering. In rare instances where 2004 image fields-of-view chanced to overlap 2003 fields-of-views, an assessment of willow canopy change was possible (Fig. 1).

2.4. Image analysis

Dimensional analysis of imagery follows Booth et al. (2006). The first step towards making a linear measurement from digital imagery is to determine the resolution, measured as the ground sample distance (GSD) and calculated as (derived from Comer et al., 1998; for a detailed discussion of image distortion, see Booth et al., 2006):

$$\text{GSD} = \frac{\text{SW} \times \text{OD}}{\text{FL} \times \text{IW}}$$

where GSD is the resolution in mm/pixel; SW the sensor width in mm; OD the object distance (distance between the ground and the camera lens in mm); FL the lens focal length in mm; IW is the image width in pixels.

Once the GSD is known, image measurements can be converted into object measurements. Merge software (Booth et al., 2006) was used to pair image files with altitude AGL readings (from the LaserLOG report) using precise image trigger times (± 10 ms from Tracker report), and generate an Excel spreadsheet with GSD for every image. This information was formatted into a database for use with ImageMeasurement. ImageMeasurement provides a dimensional analysis framework based on a database containing image filenames and associated image GSD (Booth et al., 2006). Images appear in a window in ImageMeasurement where a user can measure up to 50 objects/image by clicking on a start and stop point of a measurement line. Because the database is referenced during this process, the exact GSD for each image is used to calculate object dimensions, even as the user zooms in or out. All measurements are saved to the database. Three grid patterns (4-crosshair lines, 20 vertical or 20 horizontal equidistant lines) can be superimposed upon an image for selection of random or systematic measurement points.

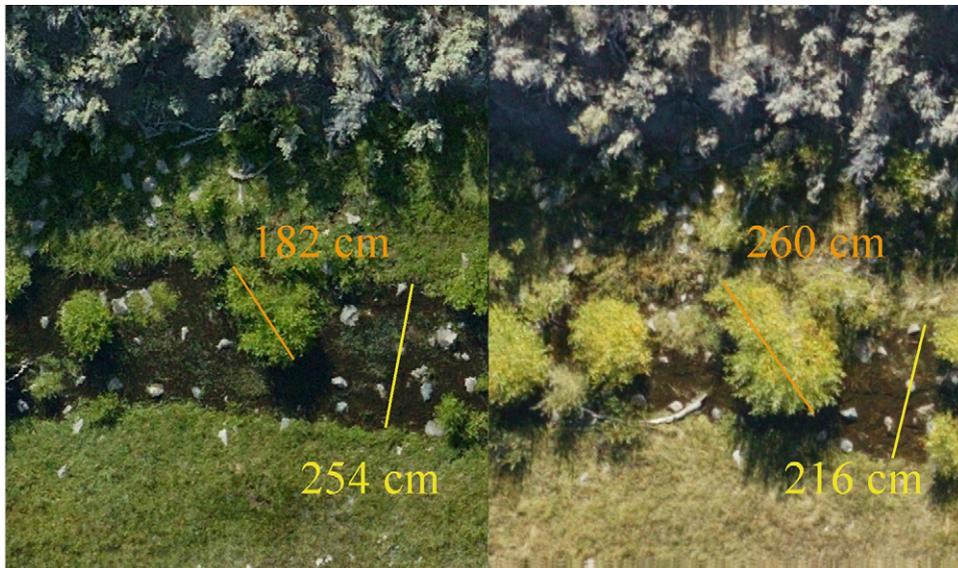


Fig. 1. A chance repeat sampling of a portion of Nelson Creek, with July 2003 in the left pane and September 2004 in the right pane, allowed measurements of willow canopy and stream width. Differences in image GSD were normalized by calibrating the images based on two measurements of channel rock distances, which were assumed, and appear, to have been unchanged between sampling dates.

Aerial images were systematically sampled and measured perpendicular to stream flow (Booth et al., 2006) for several quantitative parameters: (1) open water width, (2) riparian width, (3) riparian vegetation and (4) willow canopy. BLM Aquatic Habitat Monitoring Procedures (BLM, 2002) were consulted to determine key indicators of riparian trend that could be successfully measured from aerial photographs. Obviously, width/depth ratio or bank undercut cannot be measured from two-dimensional aerial images. However, several linear measurements outlined in the procedural handbook can, with some modification of protocol, be measured from the aerial images (C. Evans, personal communication, 2005). Open water width was measured as the width of the water column in the riparian channel (single measurement). This measurement is essentially made in the same way from the images as described in the BLM procedural handbook. As vegetation stabilizes stream banks, water channels generally grow deeper and narrower with improving riparian condition (BLM, 2002). A count of the number of dry channels was a defacto subset of these measurements.

The BLM (2002) procedures call for measuring the width of riparian vegetation surrounding the water channel. The measurement is made from the beginning of the riparian zone, defined as where the riparian vegetation is within half of its average un-grazed height to the water's edge, and extends outward until the average distance between riparian plant species is greater than the average un-grazed height of those plants. From non-stereo aerial imagery it is not feasible to accurately judge the ungrazed height of riparian vegetation. Therefore, we introduced three measurements that can be easily recognized from the aerial imagery and that convey the same information. The measurement we term "riparian width" is simply the width of the area that is visibly influenced by the water channel, including the channel itself. Indicators of the boundary are a change in color from bright green to yellow, and in the species composition from reeds and forbs to upland grasses and sagebrush. This is a single measurement extending from 1 riparian-upland boundary, perpendicular to stream flow and across the riparian area, to the opposite riparian-upland boundary. While the width of the riparian zone is often constrained by geomorphology and hydrology – preventing this measurement from being proportional to riparian health (Gregory et al., 1991) – this measurement is useful to

detect a downward trend in the width of the riparian zone, and could potentially document an upward trend up to the constraints mentioned. Fluctuations in the water table could be detected with this measurement. We also measured the widths of distinct "riparian vegetation" patches (multiple measurements) falling within the already measured "riparian width". Patches of bare ground and any area in the stream channel were not counted in this measurement; therefore, "riparian vegetation" was almost always a lower value than "riparian width" (except when the riparian area was completely covered by mature willows). The justification for this measurement is that even though the riparian width may not change due to geological and hydrological constraints, riparian vegetation will fill in as riparian function is enhanced, and become patchier if riparian function diminishes (Kauffman et al., 1997; Rood et al., 2003). As an additional descriptor of the riparian vegetation, the combined widths of willow canopy within the riparian area (sum of multiple measurements) were also measured, the justification being that mature willows are an indication of a functional western US riparian system. In addition to the linear willow canopy measurement, we measured willow frequency by classifying each image as "willows present" or "willows not present". Improved riparian condition can be evident by an increase in the percentage of image frames that contain willows, while at the same time the measure of willow canopy should increase. These measurements do not replace the standard set of nearly 30 measurements outlined by the BLM (2002), but they do provide a relatively quick and easy indication of riparian condition, and are especially useful for low-priority streams.

All BLM monitoring stations within a single stream reach were lumped together to characterize the stream reach. Similarly, all aerial photographs that fell within a single stream reach were lumped together, with subsequent measurements used to characterize the stream reach, resulting in comparable measurements from the ground and from the air. Average stream reach widths from ground assessments were compared to aerial image measurements.

2.5. Aerial PFC assessment

Aerial photographs corresponding to 18 defined stream reaches were used to assess PFC by a four-person

BLM team using a digital-image projector. PFC ratings may fall into six defined categories: (1) Proper functioning condition, (2) Functional-at risk with upward trend, (3) Functional-at risk with downward trend, (4) Functional-at risk with no apparent trend, (5) Non-functional and (6) Not apparent. The BLM team consisted of a soil scientist, a botanist, a wildlife biologist, and a fisheries biologist—the same composition as the PFC field crew. Results from the ground and image PFC assessments were compared for agreement, though the time lapse between 2003 ground assessments and 2004 image assessments is a variable that must be considered.

3. Results and discussion

3.1. Sampling technique

Eighty-six more photographs were taken in 2004 (804) than in 2003 (718) and the percentage of photographs capturing a riparian scene increased from 44% in 2003 to 80% in 2004, resulting in 300 more riparian photographs to work with. From post-flight debriefing with the pilot, we attribute this increase primarily to manual triggering in 2004, and, to a lesser extent, pilot familiarity with the topography. The percentage of creek hits showing flowing water in the riparian area decreased from 73% in July 2003 to 39% in September 2004, reflecting the importance of critical-season (late summer) sampling. Considered by stream reach, each of the 60 BLM survey stations had an average 9.5 ± 7.1 S.D. ($n = 29$ reaches) corresponding aerial photographs (751). Simply photographing a creek does not necessarily allow measurements: images from 2004 were disqualified from some or all measurements due to image darkness (3%), incompleteness of the riparian zone (13%), water channel hidden under shrubs or otherwise indistinct (11%), or a dry channel (35%). Failing to measure open water width because willow cover obscured the channel introduces a bias since these areas would normally show a more narrow open water width. However, this does not negate the value of monitoring open water width in areas without willows since a narrowing of the channel is an indicator of improvement that precedes and coincides with willow proliferation.

3.2. Measurements from aerial imagery

The accuracy of measurements from aerial photography using our protocol has been previously established (Booth et al., 2006). That the accuracy of measurements from VLSA images allows detection of ecologically important change is illustrated by the change in willow canopy detected in consecutive images from 2003 and 2004 (Fig. 1).

Differences in ground and aerial sampling protocol and dates, and low sample numbers, make the two methods for measuring water width of questionable comparability (Table 1). Although many aerial samples were acquired, the number of dry stream channels (Fig. 2) means that aerial sample size for water width is often similar to the sample size for ground measurements. Except for Middle Rock, and perhaps upper Trout and middle Upper Willow, sample numbers are too low for confident inference. Measurements from the three reaches named are not inconsistent with the idea that aerial and ground methods are comparable within the realm of our ability to manage the resource.

It is apparent from the stream-width measurements and dry-channel occurrence (Figs. 2 and 3) that late-summer dry channels are an impediment to LCT recovery. Dry channels are partly a result of five successive years of drought (National Climatic Data Center, 2003). However, improper grazing significantly widens water channels, resulting in shallower, warmer water less

Table 1
Comparison of linear measurements of water width (mean \pm S.D.) from 11 stream reaches made using aerial images and ground methods

Stream	Reach	2003, ground measurement		2004, image measurement	
		water width (m)		water width (m)	
		Mean	<i>n</i>	Mean	<i>n</i>
Frazer	Lower	1.29 \pm 0.45	4	0.57 \pm 0.30	4
Frazer	Upper	1.34 \pm 0.15	3	0.45 \pm 0.14	3
Upper rock	Middle	1.05 \pm 1.44	5	1.68 \pm 0.24	2
Upper rock	Upper	0.69 \pm 0.79	1	3.14	1
Trout	Upper	0.39 \pm 0.40	7	0.43 \pm 0.13	5
Trout	Lower	0.73 \pm 1.04	2	4.73 \pm 3.26	3
Toejam	Lower	2.25 \pm 1.32	4	1.44 \pm 0.75	4
Toejam	Middle	0.25 \pm 0.44	3	3.32	1
Toejam	Upper	1.45 \pm 0.34	7	1.85 \pm 0.32	3
Upper Willow	Middle	2.21 \pm 1.62	4	1.87 \pm 0.83	20
Middle rock	Single	7.1 \pm 1.34	6	6.32 \pm 2.14	25

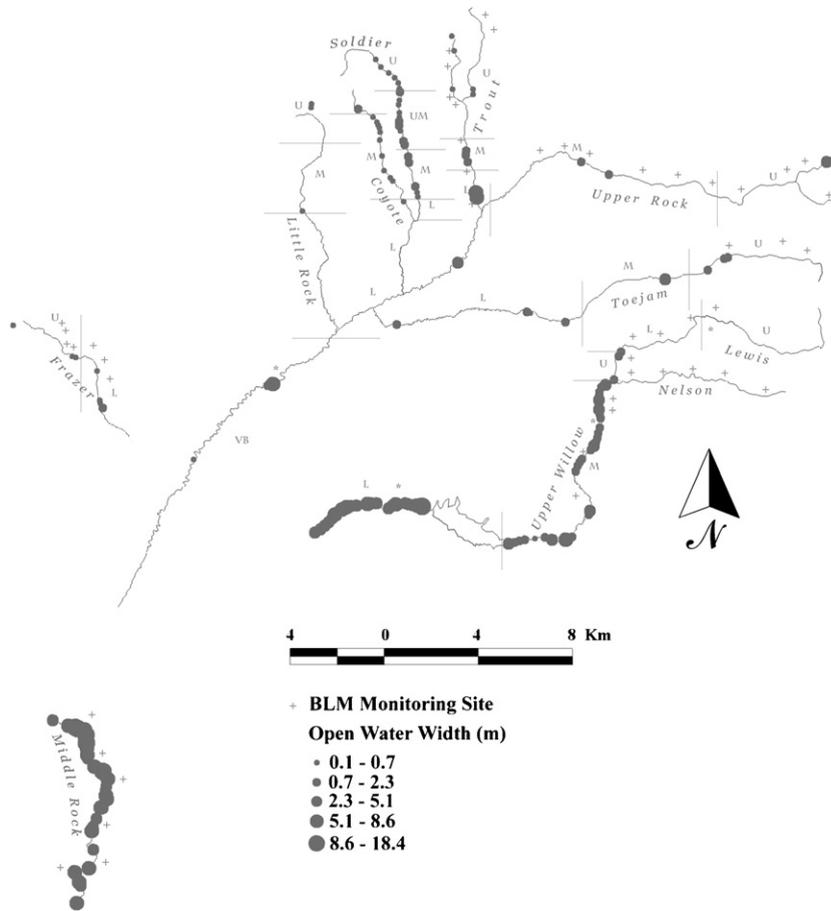


Fig. 2. Distribution and width of open water in the stream channel. Width is measured perpendicular to stream flow.

suitable for cold water fish populations (Kauffman et al., 1983). If grazing has widened the dry channels and contributed to no above-ground flow, then there is potential for re-development of narrow, flowing channels by riparian vegetation recovery—including an expansion of the measured riparian area (data not presented). Such a recovery could extend late-season stream flow, particularly with a return to normal precipitation (Kauffman et al., 1997). Repeat aerial sampling and measurement of changes in open water and riparian-area widths (both indicators of habitat quality), will allow trend analysis of the smaller streams and an assessment of grazing management effects on LCT habitat recovery. BLM ground monitoring methods cannot give as complete an assessment of the riparian resource nor can satellite imagery accurately detect the very thin ribbons of water flowing

in late summer—owing to the satellite imagery GSD being larger than the stream.

The quantitative measurements of willow canopy width, measured perpendicular to the stream flow at random points, are not presented, but will be useful in determining trend after repeat sampling. The result of the frequency (present or absent) assessment of willow coverage is shown in Fig. 4. Since willows are critical to bank stabilization and water temperature regulation, and both are important to trout habitat (Swift and Messer, 1971; Kauffman and Kreuger, 1984; Schulz and Leininger, 1990; Beschta, 1997), increased willow cover indicates LCT habitat improvement and is an indicator quickly monitored using 2-cm GSD aerial data. Woody species cannot typically be identified from satellite imagery unless they comprise large, pure stands (Nagler et al., 2005) and even 1:600 aerial

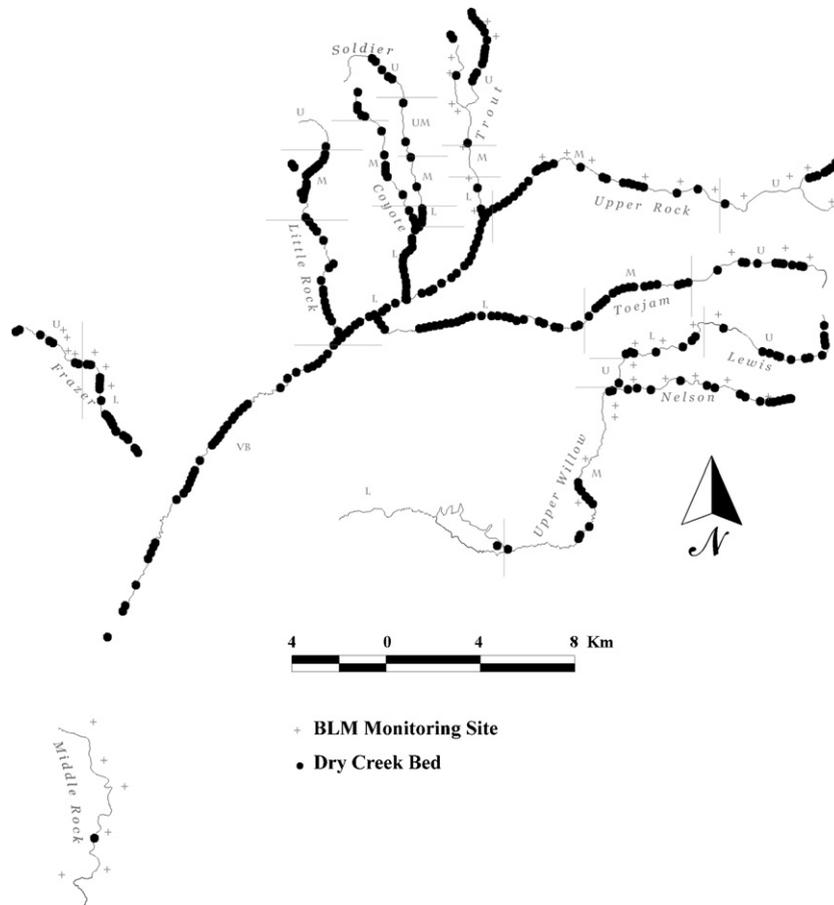


Fig. 3. Distribution of dry stream channels.

imagery may contribute to inaccurate riparian condition assessments if young willows are overlooked (see Lonard et al., 2000).

The maps (Figs. 2–4) illustrate the utility of systematic 2-cm GSD aerial surveys for landscape-scale LCT habitat assessment and trend analysis. Detecting ecologically important change across landscapes requires statistical power (of which sample size is a fundamental budgetary consideration) and uniform sample distribution representing the heterogeneity of the resource on a landscape scale (Brady et al., 1995; Sundt, 2002). In cases where it is not practical to obtain large sample sizes, repeat sampling on fixed plots measures trend, but does not adequately characterize resource area (Sundt, 2002). Coles-Ritchie et al. (2004) reported that the Greenline method for riparian condition assessment required between 56 and 224 sample transects to detect

a 10% change in key indicators, a number usually not met with conventional ground sampling (Table 1). In this study the mean number of samples per reach was 3.5 and 26 for ground and aerial sampling, respectively.

3.3. PFC assessment

Ground and image PFC assessments were separated by 1 year, a temporal separation that must be considered. Growing-season grazing by livestock adversely affects riparian systems (Kauffman and Kreuger, 1984; Clary and Kinney, 2002); therefore, the grazing rest that occurred during the 2004 growing season, between the ground and aerial assessments, can be expected to have improved riparian condition.

Along all streams monitored, there was an average 0.6 BLM monitoring stations/km and 3.2 useable

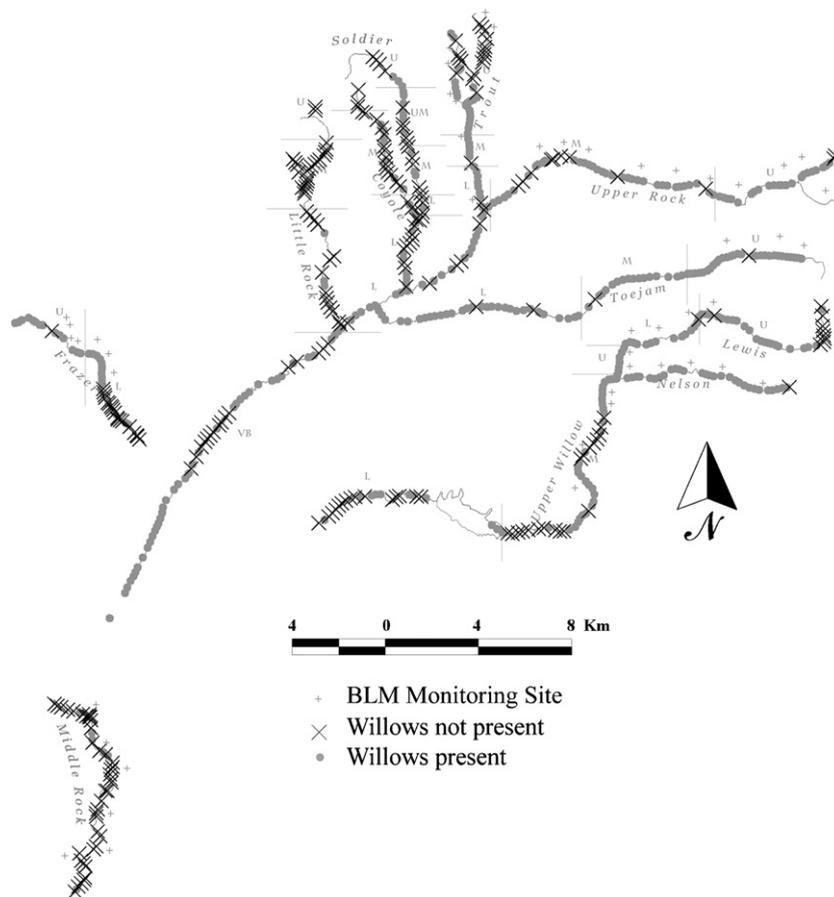


Fig. 4. Distribution of willows. Note that this figure does not reflect variance in willow density or canopy size, only the presence or absence of willows in the image scene.

aerial images/km. Two reaches (lower Frazer) were judged to have insufficient aerial data to allow a PFC rating, not because they had significantly fewer images/km than average, but because the variability along these reaches was higher, necessitating greater image coverage. For example, 2.1 images/km for middle Upper Rock was judged to be sufficient while the same density for lower Lewis was not (Table 2). Whenever the number of useable aerial images was less than four times the number of established BLM monitoring stations in the reach, aerial coverage was consistently judged insufficient for PFC assessment. Therefore, we recommend that the number of aerial samples be at least $4\times$ the established ground sample number and/or contain at least 3 images/km (320-m sampling interval).

Of the remaining 12 reaches, 4 showed exact agreement between the 2 methods, 1 showed close agreement (the ground rating was “PFC to Functional at risk, trend upward”, while the aerial rating was “Functional-at risk, trend upward”), and an additional 4 were in agreement that the condition was “Functional-at risk”, but differed on the trend rating. Ratings were distinctly different for Upper Toejam (“Functional-at risk” to “PFC”), and Lower Willow (“Non-functional” to “Functional-at risk, upward trend”). In the first case, it is the opinion of the multidisciplinary team that conducted the assessment that the difference is due to an actual change resulting from a year of grazing rest. In the second case, it was the opinion of the team that the initial rating was not correct, that the non-functional rating (provided by a contractor) was

Table 2

Proper Functioning Condition assessments performed on the ground in 2003 and from 2-cm GSD images taken in 2004

Creek	Reach	BLM monitoring stations	Aerial images	Ground PFC	VLSA PFC
Nelson	Single	5	22	Functional-at-risk, trend upward	Functional-at-risk, trend upward
Middle rock	Single	6	32	Functional-at-risk, trend upward	Functional-at-risk, trend upward
Lewis	Upper	1	21	No data	PFC
	Lower	3	11	Functional-at-risk, trend upward	Inadequate coverage for determination ^a
Trout	Upper	7	34	Variable	Nonfunctional to Functional-at-risk, trend downward
	Middle	1	4	No data	Functional-at-risk, trend not apparent to downward
	Lower	2	10	No Data	Functional-at-risk, trend not apparent
Frazer	Upper	4	9	Functional-at risk, trend upward, to PFC	Inadequate coverage for determination
	Lower	3	27	PFC to functional-at-risk, trend upward	Functional-at-risk, trend upward
Toejam	Upper	4	17	Functional-at-risk, trend not apparent	PFC
	Middle	3	18	Functional-at-risk, trend downward to not apparent	Functional-at-risk, trend upward
	Lower	7	28	Functional-at-risk, trend not apparent	Functional-at-risk, trend upward
Upper rock	Upper	3	14	PFC	PFC
	Middle	5	22	Functional-at-risk, trend not apparent to nonfunctional	Functional-at-risk, trend upward
	Lower	1	14	No Data	Nonfunctional
Upper willow	Upper	1	8	Functional-at-risk, upward trend	Functional-at-risk, upward trend
	Middle	4	30	Functional-at-risk, trend not apparent	Functional-at-risk, upward trend
	Lower	0	39	Nonfunctional to functional-at-risk, upward trend ^b	Functional-at-risk, upward trend

Ground assessments were based on the data from the BLM monitoring stations, while 2-cm GSD assessments were based on the number of aerial images.

^a The density of aerial imagery was not high enough to capture the variability within the stream reach, so no PFC rating could be assigned.

^b Cedar Creek Associates (2004) and C. Evans, Fisheries Biologist, BLM Elko, Nevada Field Office, personal communication, November 2005.

not warranted (Table 2). Similarly, slight differences in trend, notably the change from “Functional-at risk, no trend” to “Functional-at risk, upward trend” for reaches in Upper Willow, Upper Rock and Toejam creeks were attributed to the year of grazing rest.

The context of aerial and ground PFC assessment comparisons needs to be recognized as inexact. There is no standard by which the accuracy of the separate PFC assessment methods can be compared beyond the judgments of those experienced persons who participated in both PFC assessments. However, it was the opinion of the members of the interdisciplinary team which performed the PFC assessments that, relative to ground-observation, aerial images provided just as

good, if not a better, perspective from which to assess PFC. Our 2-cm GSD images allowed completion of a stream reach PFC assessment in 30 min compared to about 4 h for ground PFC assessments. The aerial image method was agreed to be particularly valuable for low-priority streams which typically lack data, and for which funding and time for ground-monitoring are not available. It was helpful if at least 1 member of the assessment team had visited the site in question in order to provide on-the-ground perspective to the sometimes disorienting view from above. As is indicated by the cost analysis in Table 3, the 2004 aerial assessment sampled 770 locations (Table 2) for US\$ 9000, whereas the 2003 ground assessment sampled

Table 3
Time and costs for 2004 aerial riparian survey of the Rock Creek Watershed and comparative ground survey costs

Item	Rate (\$/h)	Time (h)	Cost (\$)
Flight costs ^a			
Air time	125	6.5	813
Ground time (pilot)	40	13	520
Ground time (flight plan/support)	25	65	1625
Travel costs (two salaries) ^b	25/40	47	3055
Total			6013
Image analysis			
Measurements (ImageMeasurement)	25	30	750
Data entry/organization in GIS	25	40	1000
PFC from aerial photos (8 streams, four people)	170	8	1364
Total aerial assessment			9127
Ground PFC assessment (eight streams)			
Salary estimate (four people) ^c	170	72	12000
Actual salary costs for all ground stream assessments and measurements ^d	–	–	22586

The aerial survey produced 804 photographic samples of which 751 fell within 29 defined valley bottom types or reaches. There were 60 BLM monitoring stations on 17 reaches (Table 1).

^a Does not include an annual start up fee of US\$ 5000.

^b Aerial contractor based out of Fort Collins, Colorado. Common fuel and vehicle expenses related to travel to the watershed from Fort Collins, Colorado, are not included.

^c The 72-h figure for accomplishing PFC for eight streams is an estimate for only PFC assessments, hence, costs are rounded off. The ground-based PFC and other assessments were done together and required an estimated 66 staff hours per stream. It is a 6-h round from Elko to the watershed; therefore, crews stayed on site and did a number of reaches or whole streams before returning to Elko.

^d Common fuel and vehicle expenses related to travel to the watershed from Elko, Nevada, are not included. Salary cost information is courtesy of C. Evans, Fisheries Biologist, BLM Elko, Nevada Field Office, personal communication, November 2005.

60 locations at a cost of US\$ 23,000. The result implies that the aerial images are an efficient and effective way to collect and evaluate short- and long-term monitoring data on riparian areas.

4. Conclusions

Although earlier authors have recommended using lower-resolution (1:40,000), continuous-coverage aerial photography for riparian-area management, we conclude that the high-resolution digital imagery described here allows a more accurate assessment of resource conditions. Computer tools and software applications used in our image analysis make large numbers of photographs an easily managed situation. This is an important contrast to the significant hassle of using numerous medium-to-large-scale prints for watershed-scale evaluations.

The aerial methods we used for the Rock Creek Watershed allowed over 12 times the sampling intensity at 40% of the cost of ground methods. It allowed for a more complete sampling of streams – including minor streams that would otherwise be ignored – than is usually accomplished from ground surveys, and it provided greater sample numbers per reach. Both the aerial and ground PFC assessments included judgments on trend and we believe that future trend judgments can be compared with average physical measurements to determine whether open water width at the critical season is wider or narrower, whether percentage of samples for a given reach have more or less dry channels, whether the percentage of samples with willows is increasing or decreasing, and whether the width of the riparian area has changed. Thus, ecological trend can be evaluated in the future by change-over-time measurements as opposed to the impressions of a group.

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