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A Photo-Based Monitoring Technique for Willow Communities

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Abstract

*Willow (*Salix *spp.) and associated riparian shrub communities provide habitat to a wide variety of wildlife species. Because of high between-observer variability and a lack of standardized protocols, ground-based monitoring of willow abundance has proven difficult. The objective of this study was to evaluate variability associated with collection and analysis of field data for a photo-based monitoring technique for willow communities. We evaluated variation in data collection by photographing 5 willow clumps, 10 times each, and comparing profile-area estimates within clump. We assumed this to mimic variability associated with repeat monitoring of a given clump(s) over time. We set high-visibility markers at known distances apart to provide scale references in the photographs. We removed camera and markers and replaced them between successive photographs. Scanned images of the photographs were spatially rectified using digital image–processing software. We determined the profile area of willow clumps by digitizing clump boundaries within rectified images. We examined variability associated with image analysis by asking 6 individuals (analysts) to determine profile area for a series of 5 images. We then compared the results across analysts. We calculated sampling error for each photograph by dividing root mean square error by the mean value. Results indicate field data collection produced minimal variability; sampling error averaged 1.82% (±1.05). Between-analyst sampling error averaged 1.63% (±0.73) across clumps and was <3% for all clumps. Trained analysts took <10 minutes per image to obtain profile-area estimates. These results indicate our technique produces quick and repeatable estimates of willow abundance, would be useful in evaluating change in abundance over time, and minimizes person-to-person variability.* (WILDLIFE SOCIETY BULLETIN 34(4):1049–1054; 2006)

Key words

inventory, monitoring, photo-based monitoring, riparian, Salix *spp., shrub, willow.*

Woody plant species including willow (*Salix* spp.) play important functional roles in riparian ecosystems (Winward 2000) and provide critical habitat for a variety of wildlife species (Thomas et al. 1979, Bowyer and Van Ballenberghe 1999, Scott et al. 2003). In practice, field measurement of woody plants has proven difficult (Bryant and Kothmann 1979), results often vary between observers (Hall and Max 1999), and labor inputs can be high (Bobek and Bergstrom 1978). Additionally, field techniques used to measure woody plant abundance often lack a standardized protocol (Harniss and Murray 1976), which can result in incomparable data between monitoring efforts. Photographic monitoring techniques (e.g., Hall 2001) provide a permanent record of vegetation status and may decrease observer variation. Boyd and Svejcar (2005) proposed use of a visual obstruction–based photographic technique for assessing point-in-time biomass and changes in biomass (i.e., herbivory) associated with willow clumps. This technique proved effective for assessing small (<2 m tall), individual willow clumps. Here we explore the use of photographic monitoring and image analysis to determine changes in the profile area of willow communities that may include multiple clumps and a variety of clump sizes (e.g., >2 m tall). Specifically, our objectives were to evaluate a photo-based willow-monitoring technique with respect to 1) variability in willow profile-area estimates associated with data collection, 2) variability between image analysts, and 3) within-analyst variability for repeat analysis of the same image.

Study Area

The study site was located in the Big Creek drainage of Grant County, Oregon (11T0370683 UTM4890874), USA. Big Creek is a C-class stream (Rosgen 1994) flowing through a wet–mesic meadow system that has a patchy distribution of willow communities. The dominant willow species on the site were Booth's willow (*Salix boothii*) and Geyer's willow (*Salix geyeriana*).

Methods

Field Technique and Terminology

Our technique was based on photographic "scenes." A scene consisted of 4 elements: 1) a willow clump or clumps of interest, 2) a camera location, 3) endpoint markers, and 4) a meter board (Fig. 1). We defined "image" as a spatially rectified electronic representation of a photograph of a scene. For field use we identified all elements with permanent markers. We photographed each scene using a 35-mm single-lens-reflex camera (Canon EOS Elan II; Canon, Lake Success, New York) equipped with a 50-mm lens and loaded with color slide film (200ASA; Kodak, Rochester, New York). We took all photographs during July and August of 2003. We allowed the program function of the camera to automatically determine aperture size and shutter speed for each photograph. Camera distance from willow clumps varied between scenes but was sufficient to allow for an approximate doubling of clump size, in both height and width, without clumps becoming larger than the view through a 50-mm lens. We constructed scenes such that

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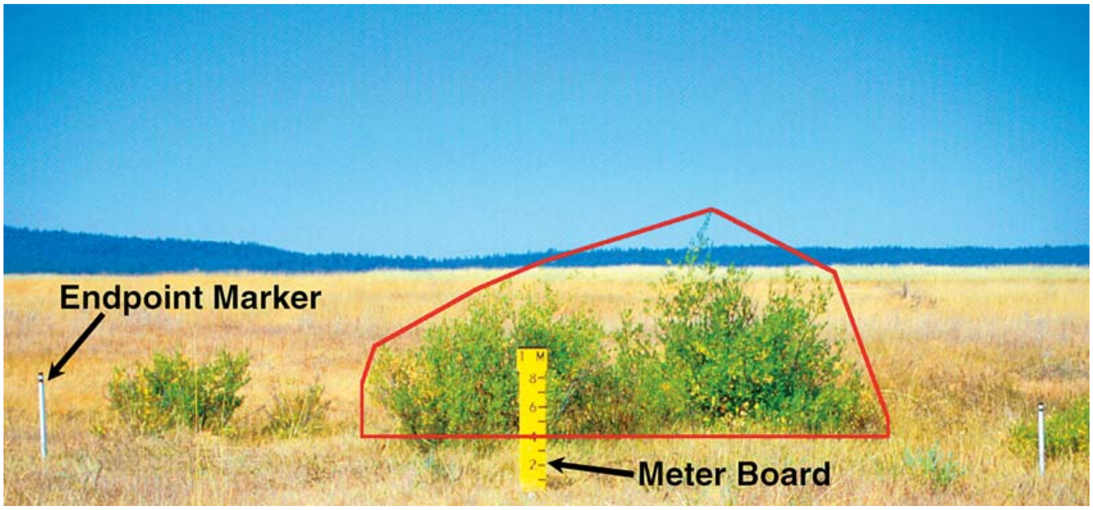

Figure 1. Our photo monitoring technique was based on "scenes." A scene consisted of a willow clump, endpoint markers, a meter board, and a camera location. Locations of the endpoint markers, meter board, and camera were permanently marked. In this image, a minimum convex polygon has been drawn around a willow clump for use in indexing profile area. The endpoint markers and meter board provide reference points for setting image scale and determining spatial location of the lowermost polygon boundary (e.g., at 40 cm on the meter board).

the camera angle was perpendicular to the long axis of the clump or clumps of interest. We took all photographs with "endpoint markers" consisting of 75-cm-long 1.9-cm-diameter white polyvinyl chloride (PVC) pipe with a sharpened metal rod glued in one end. We placed these markers at the outer edges of photographic view and measured the distance between markers for later use in spatial rectification of scanned photographs (Fig. 1). We placed a meter board (Hall 2001) in the center of the photographs immediately in front of the willow clump or clumps of interest (Fig. 1). In all photographs, we centered the midpoint of the viewfinder on the letter "m" on the meter board. We calculated camera height for each scene by using a handheld inclinometer to determine the camera height needed to have a "zero" slope from the center of the camera lens to the center of the "m" on the meter board. All photographs for a given scene were acquired from the same point and at the same height.

Analysis Technique

We scanned photographs to digital format using a Nikon (Melville, New York) LS 2000 slide scanner set at 472 pixels/cm. We conducted all image analyses with Sigma Scan 5.0 software (Jandel Scientific, San Rafael, California). This program allowed spatial rectification of scanned photographs using the known distance between endpoint markers. Following rectification, we digitized a minimum convex polygon around the outer boundaries of a clump. Outer boundaries were defined by green leaf material. We excluded dry limbs and leafless green limbs protruding above the leaf canopy. Because obstructing grass and dead woody materials often obscured or blurred the lowermost portion of the clump, the lowermost side of the minimum convex polygon was defined by the lowest visible willow leaf within the clump. We estimated this point and constructed a straight line at that height to define the lower clump boundary. This height was associated with a tick mark on the meter board to facilitate location within repeat photographs (Fig. 1). We then used the "measure objects" command in the software to determine the polygon(s) area (i.e., "profile area"). When this command was issued, the software used internal algorithms to determine area estimates for all polygons in an image.

Evaluation of Technique

Sources of variation relating to both field data collection and analysis of images were evaluated in 2 separate trials.

Trial 1: Data collection.—To evaluate variation in error estimates associated with field data collection, a scene was assembled, photographed, and then disassembled (including camera setup). We repeated this process 10 times for each of 5 different scenes. We took all photographs on the same day and conducted all analyses on the same computer. This exercise was assumed to mimic variability associated with repeat monitoring of a given scene over time. We selected the 5 scenes to be representative of the continuum of size classes of willow communities present within the study area. We used a single analyst familiar with the analysis technique to determine total clump profile area in each image from each scene. One scene had 1 clump and 4 scenes had 2 clumps. When multiple clumps were present, we summed values for all clumps to one profile-area value for the image.

Trial 2: Data analysis.—To evaluate variation in error estimates associated with data analysis, we selected 6 individuals to evaluate clump profile area in 5 different test images, each image representing a different scene. These persons (hereafter referred to as analysts) were previously unfamiliar with our analysis technique and the associated software. We chose the scenes to represent a variety of clump sizes present within the study area. Three of the 5 images had multiple clumps, but we analyzed only one clump in each image. Prior to analysis, we gave each analyst

Table 1. Mean values, range, and sampling errors for willow profile area present in 5 different scenes used in trial 1, southeastern Oregon, USA, 2003. Each scene was photographed 10 times and disassembled between photographs. Willow profile area was then determined in the resulting images. All area estimates were generated by a single analyst. Percent sampling error (SE) for repeat assembly was calculated by dividing root mean square error by the mean value.

	Profile area (cm^2)			
Scene	**Mean**	**High value**	**Low value**	**% SE**
1	34,205.4	35,599.2	31,534.9	3.11
2	52,271.4	53,118.9	51,675.5	1.03
3	99,116.5	104,239.0	94,920.4	2.92
4	150,308.4	152,779.0	147,934.0	0.98
5	199,228.6	203,102.0	196,103.0	1.06

a brief training presentation consisting of 1) an overview of the goals of our image-analysis technique and purpose of the trial in which they were participating, 2) an explanation of the purpose of each element in a scene, 3) a demonstration of how to spatially rectify the scanned photograph, 4) a demonstration of how to construct a minimum convex polygon around the profile of a willow clump, and 5) instruction on commands necessary to generate a computer-derived estimate of profile area. Following this presentation, we allowed each analyst to practice the technique on a sample image and ask questions. The images used for instruction and practice were not used in the subsequent trial. Analysts then indicated when they felt comfortable to proceed with analysis of test images. We recorded training time for each analyst. Analysts then constructed polygons and generated profile-area estimates for each of the 5 test images following a 2-day posttraining waiting period. This analysis was repeated 3 times (i.e., 3 replicates) with the same scene with 2 days between replication. The order in which we analyzed images was the same for all analysts and was randomized within replication. We provided the distance between endpoint markers and the meter board value for the lowermost portion of the clump for all images. We conducted all analyses on the same computer. This design allowed evaluations of between-analyst variability and adequacy of training, based on differences in profile-area estimates across replications for a given image.

Statistical Analysis

We performed all statistical analyses using SAS statistical software (SAS Institute, Inc. 1999). For trial 1 we determined the variability associated with repeat assembly of field scenes by calculating a sampling error for the 10 images of each scene. We calculated sampling error on a percentage basis by dividing the root mean square error for profile area by the mean profile-area value of the 10 repeat images.

In trial 2 regression of log standard deviations on log means (Box et al. 1978) indicated that data for profile-area estimates did not meet the assumption of homogeneity of variance among analysts and replications. We transformed profile-area data using a square-root transformation and the transformed data met the assumption of homogeneity of variance. We then used a single mixed-model repeated-measures analysis of variance procedure to evaluate the influence of image, analyst, and replication on profile-area estimates using replication as a repeated factor. When we detected significant main or interactive effects, we determined differences in treatment means by calculating a least significant difference (Montgomery 1991) based on the standard error for the effect as determined by the LS MEANS (SAS Institute, Inc. 1999) procedure. We considered differences significant at $\alpha = 0.05$. We used transformed data in the analysis and reported untransformed means. We calculated between-analyst sampling error for profile area in each image (averaged across replications) using the procedure discussed above for trial 1 with untransformed data. We reported all means with their associated standard errors.

Results

Time needed for scene construction in the field will vary depending on the visibility of permanent markers. Our experience suggests that scene construction, photography, and tear-down generally take less than 10 minutes (excluding travel time between sites). With 2 minutes allotted for slide scanning, the total monitoring time investment per scene should be $\leq$20 minutes. Clumps used in trial 1 ranged from 185 to 635 cm in width and 125 to 370 cm in height. Profile-area estimates ranged from approximately 35,000 to 200,000 cm^2 (Table 1). Percentage sampling error resulting from scene assembly averaged 1.82% (±1.05).

In trial 2, clumps ranged in width from 266 to 744 cm and varied in height from 210 to 247 cm. Time of analysis for test images ranged from 3 to 16 minutes (across analysts, replications, and images). Analysis times ranged from 8.03 minutes (±0.59) for replication 1 to 5.06 minutes (±0.24) for replication 3 (averaged across images and analysts) and varied from 4.1 minutes (±0.26) to 8.2 minutes (±0.60) for individual analysts (averaged across replications and images). Training time for the 6 analysts averaged 48.3 minutes (±4.0). Profile-area estimates differed by replication × image ($F_{8,40} = 3.78$, $P = 0.002$; Fig. 2) and analyst × image ($F_{5,40} = 4.68$, $P < 0.001$; Fig. 3). We found differences in between-replication area estimates in 4 of the 5 images (Fig. 2). These differences were associated with variation between replication 1 and the remaining 2 replications; in no case were replications 2 and 3 different. Between-analyst differences in profile-area estimates were evident in all images (Fig. 3). However, the relative ranking of profile-area estimates between analysts had similarities across images. For example, analyst 3 had the highest profile-area estimate for 3 of the 5 images, while analyst 2 had the lowest profile-area estimate for all images. Additionally, the only between-analyst difference in 3 of the 5 images was that analyst 2 had lower estimates than the other remaining 5 analysts. Average between-analyst sampling error was 1.63% (±0.73) and was <3% for all images (Table 2).

Discussion

Our technique has conceptual similarities to that of Hall (2001), who spatially rectified transparent grids (using the

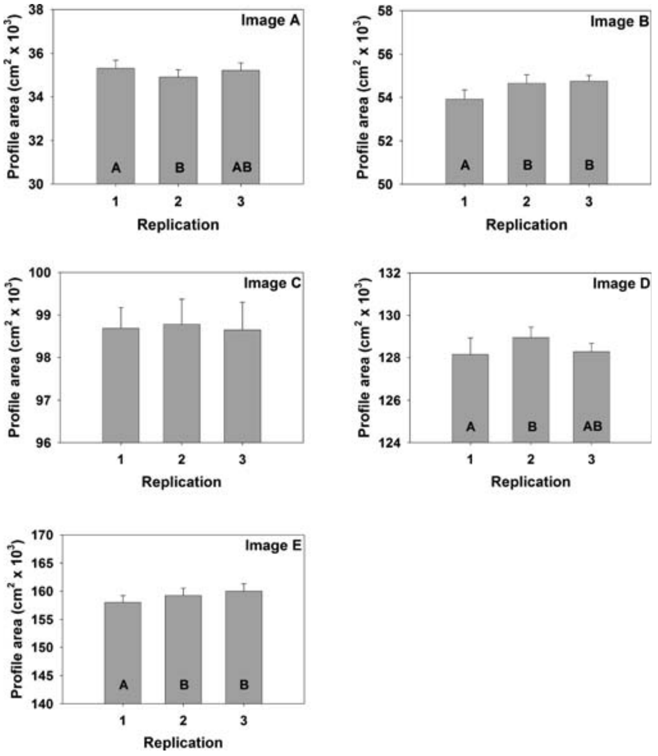

Figure 2. Relationship between replication and willow profile area for the 5 images used in trial 2, southeastern Oregon, USA, 2003. Within an image, bars without a common letter are different at α = 0.05. Between-replication differences are visually magnified on these graphs because the *y*-axis did not start at zero.

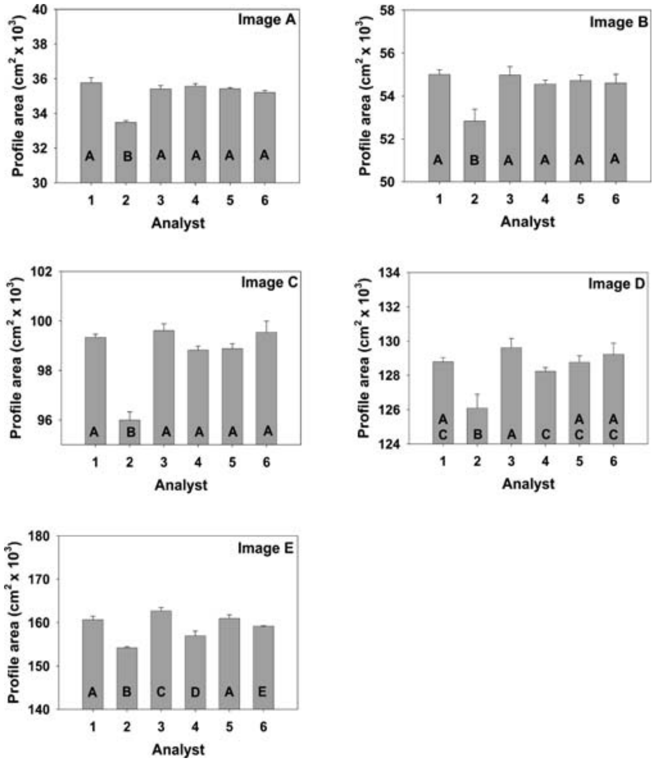

Figure 3. Relationship between analyst and willow profile-area estimates for the 5 images used in trial 2, southeastern Oregon, USA, 2003. Within an image, bars without a common letter are different at α = 0.05. Between-analyst differences are visually magnified on these graphs because the *y*-axis did not start at zero.

zoom feature on a photocopier) to match known distances between tick marks on a meter board. These grids were then placed over photographic prints and the number of cells associated with willow clumps counted as an index to plant area. Our technique differs in our reliance on digitizing of clump boundaries and digital processing of images. This digital processing is advantageous in that spatial rectification is easily accomplished, and other measures of clump geometry (e.g., clump height, diameter, and perimeter) can be calculated by the Sigma Scan software package (Jandel Scientific). While we utilized film cameras for technique development, digital cameras would work equally well provided that resolution was adequate to determine clump boundaries. In our experience resolution >400 pixels/cm usually is sufficient for distinguishing clump boundaries. Digital cameras have the advantage of eliminating film processing time.

We used minimum convex polygons to define the spatial extent of clumps to help minimize the number of possible interpretations of polygon boundaries. While it is possible to draw more complex polygons around clumps, the fractal geometry (Zeide 1991) of clumps presents an infinite number of possible polygons, which could increase between- and within-analyst variability for repeat images of the same clump over time. However, use of a convex polygon may limit the sensitivity of the technique to small changes in the spatial extent of a clump. Imposing a lower limit on clump boundaries is somewhat arbitrary but it likely would not affect the ability of the technique to describe increases in profile area over time because most clump growth would occur as increases in lateral or elevational extent (i.e., clumps generally grow by expanding to the side[s] or increasing in height). Assessing the accuracy of our technique in predicting profile area of willow clumps is difficult because we lack known area values to compare our estimates to (i.e., we are developing a method to determine willow clump profile area because that methodology is lacking). It also is difficult to ascertain how the levels of field and analyst-based

Table 2. Mean values, ranges, and sampling errors for willow profile area present in the 5 different images used in trial 2, southeastern Oregon, USA, 2003. Image profile-area values were generated based on analysis by 6 separate analysts who analyzed each image 3 times (replications). Mean values for an image were averaged across analyst and replications. Percent between-analyst sampling error (SE) was calculated by dividing root mean square error by the mean value.

	Profile area (cm^2)			
Image	Mean	High value	Low value	% SE
A	35,140.8	35,760.0	33,479.0	2.37
B	54,445.6	55,002.0	52,833.6	1.49
C	98,701.2	99,612.9	95,997.8	1.38
D	128,454.5	129,620.0	126,086.0	0.97
E	159,078.2	162,653.0	154,138.0	1.94

error reported here would compare to a known magnitude of annual change in profile area. Using the current technique, data from permanent monitoring stations within the study area suggest an average annual growth in profile area for individual willow clumps of 13.3% (±1.9, $n = 5$ clumps) over a 3-year period. These clumps were within the size range of willow clumps used in the current study, were not exposed to livestock use, and had only incidental browsing from wildlife species. The magnitude of between- and within-analyst sampling errors reported in the current study (approx. 1–3%) suggests our technique would be capable of detecting these annual growth increments.

Our technique would be of limited utility in dense, expansive willow thickets where lateral boundaries of clumps are not readily discernable. In such cases measurements of growth would be limited to elevational expansion. We did not assess the ability of this technique to describe changes in clump geometry associated with herbivory; however, the limited variability we found with repeat analysis suggests that our technique would be suitable for tracking interannual changes in profile area, regardless of the mechanism that induced such changes. The magnitude of within-season utilization of biomass by herbivores may be difficult to detect using a clump geometry approach and repeat images (within-season) given that browsing is not limited to the edges of a clump. Boyd and Svejcar (2005) presented a photographic monitoring technique that accurately predicted changes in biomass associated with simulated herbivory; their technique would be more suitable than the present effort when within-season utilization is of primary interest.

Comparable error estimates for other techniques used to estimate willow abundance were not found in the literature. However, Hall and Max (1999) used hierarchical analysis of variance to differentiate analyst-based variability associated with estimates of browse utilization using the twig disappearance method (United States Department of the Interior, Bureau of Land Management 1996). This work indicated that observer-to-observer variation accounted for 20% of the variance in utilization estimates, roughly twice that of shrub-to-shrub variation. In our study minimal differences in profile-area estimates between replications (Fig. 2) and low sampling error associated with field data collection (Table 1) suggest minimal variability of between-year analysis of repeat images. Additionally, low between-analyst sampling error (Table 2) suggests that differences noted in profile-area estimates across analysts may not be sufficiently large to reduce the utility of the technique for monitoring purposes.

For field use care must be taken to ensure that the meter board is perpendicular to the ground surface; the degree to which the board is not perpendicular decreases accurate relocation of meter board tick marks in repeat photographs and may bias repeat location of the lowermost portion of a polygon. Meter board setup can be improved by mounting or placing a bubble level along the top edge of the board. Consistency of camera lens focal length and camera distance are of less concern given that endpoint markers provide a consistent scale reference across repeat images. Additionally, although we have described a technique utilizing one camera location, multiple camera locations could be used to document additional dimensions of clump profile area and growth (Hall 2001). To decrease difficulty in relocating permanently marked locations within a scene, highly visible (white) markers constructed from 30-cm lengths of 2.5-cm-diameter PVC pipe with an end cap installed were driven to 2.5 cm above ground level. We placed a 5-cm length of metal rebar inside the pipe prior to installation. In most cases the PVC proved highly visible in the field, and when not readily locatable (e.g., areas of high grass biomass), the rebar insert allowed use of a metal detector to locate markers. Use of Global Positioning System coordinates will greatly facilitate location of both monitoring sites and elements within a scene.

In summary, the technique evaluated here generated repeatable estimates of willow profile area. Training time for image analysis was minimal and previous experience with the analysis software is not necessary. While statistical differences across analysts were apparent for all images, actual between-analyst sampling error was minimal (i.e., a maximum across images of 2.37%), suggesting that statistical differences in profile-area estimates do not indicate a lack of viability for field use. Similarly, the low variability associated with repeat photography of scenes (SE average of 1.82% across scenes) suggests minimal technique-based error with between-year sampling. This low variability combined with minimal training effort and analysis time indicates our technique should provide a valuable tool for habitat managers interested in monitoring the abundance of willow communities.

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