Prepared in cooperation with the Northern and Southern Colorado Plateau Park Networks

Field-Based Evaluations of Sampling Techniques to Support Long-Term Monitoring of Riparian Ecosystems along Wadeable Streams on the Colorado Plateau

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Project Summary

To better plan for and implement long-term ecological monitoring, we measured riparian vegetation and fluvial geomorphic features at pilot study sites on four wadeable perennial stream reaches, representative of drainages across the Colorado Plateau. Our primary objectives were to (1) collect field data, (2) evaluate the efficiency and effectiveness of various ecological measures and measurement techniques for riparian ecosystems, and (3) use field-based sampling to inform and refine the development of standard operating procedures for use in implementing integrated, long-term monitoring of riparian ecosystems. Ultimately, this work was aimed at providing NPS staff with some of the information and methods needed to design and implement long-term monitoring of NPS riparian resources, which is both relevant to management, and fully operational within institutional resource constraints.

Our results suggest that selecting sampling reaches and establishing a sampling frame of 11 transects, across a range of stream types, is feasible given a limited set of decision rules. A distinctive feature of richness across all sites was the high percentage of rare species, defined here as species having a single occurrence at a site. Rare species represented from 33 percent to 47 percent of the species total across the four pilot sites. Our data show that the two smallest quadrat sizes, 0.01 m^2 and 0.1 m^2, rarely had any species that occurred in the desired frequency range and can be omitted from the monitoring protocol. Few species fell within the 30–70 percent range in the 1-m^2 quadrats, but this quadrat size appears to be useful at the Tsaile Creek (CACH) site. We recommend continuing to collect information at the 1-m^2 scale and re-evaluating its usefulness after more data are available from different types of sites. The 10-m^2 quadrat is adequate for monitoring changes in frequencies of very common species at all sites. Based on pilot study results, we conclude that at sites with low total species numbers (< 60 species), 40–60, 10-m^2 quadrats, would be sufficient to characterize overall species diversity for relatively common species. At sites with higher total numbers of species (> 100), 60–80, 10-m^2 quadrats would be required to characterize overall species diversity. Rare species of interest should be monitored using alternative approaches, such as a site inventory and/or mapping (see Elzinga and others, 1998). A large number of the systematically placed 10-m^2 quadrats span two or more geomorphic surfaces, especially adjacent to the channel. This makes resolution of species affinities with distinct geomorphic landforms difficult. Thus, we provide an amendment to improve characterization of herbaceous and shrub species on narrow, near-channel surfaces by sampling additional 0.5-m by 1-m quadrats on those surfaces. It appears that for sites in narrow valley settings where riparian zones average less than approximately 40 m, the number of 10-m^2 quadrats systematically placed on 11 transects will not provide shrub cover estimates at 20

percent precision. In such cases, additional sample reaches should be added in order to attain a minimum of 130 to 140 10-m^2 shrub quadrats.

The line-intercept technique can provide a relatively rapid, reach-scale quantification of proportional cover for woody vegetation and geomorphic surface types and that variance in these measures stabilizes by the eighth or ninth transect sampled. An overlay of the distribution of geomorphic surface data derived from line-intercept sampling on topographic survey information indicates that delineation of geomorphic surfaces could be done in conjunction with the topographic survey of each transect, obviating the need to record surface breaks using the line intercept. To include geomorphic surface identifications with the topographic survey, surface breaks and transitional surfaces should be included and identified in the survey, in addition to systematically placed survey points.

Compared to 5-m by 20-m tree quadrats, belt transects were shown to provide similar estimates of stand structure (stem density and stand basal area) in less than 30 percent of the time. Further, for the streams sampled, there were no statistically significant differences in stem density and basal area estimates between 10-m and 20-m belt transects and the smaller belts took approximately half the time to sample. There was, however, high variance associated with estimates of stand structure for infrequently occurring stems, such as large, relict or legacy riparian trees. Legacy riparian trees occurred in limited numbers at all sites sampled. A reach-scale population census of these trees indicated that the 10-m belt transects tended to underestimate both stem density and basal area for these riparian forest elements and that a complete reach-scale census of legacy trees averaged less than one hour per site.

Acknowledgments

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Introduction, Background, and Objectives

This project summarizes the results of a field-based pilot study designed to evaluate a set of measures (metrics) and measurement techniques to be used in the long-term monitoring of riparian ecosystems typical of the Colorado Plateau Physiographic Province (Scott and others, 2005). The National Park Service's Inventory and Monitoring Program (NPS-IM Program), in collaboration with 32 monitoring networks, are charged with developing a vital-signs monitoring program. Vital signs represent a select set of physical, chemical, and biological elements and processes of park ecosystems that are chosen to represent the overall health and condition of a park's resources. Together, the Northern and Southern Colorado Plateau Networks (NCPN and SCPN) have developed conceptual models of key ecosystems and identified an integrated set of vital signs for tracking resource conditions at 35 NPS units within or near the Colorado Plateau (Thomas and others, 2005; O'Dell and others, 2005). In order to select a monitoring approach that best matches management objectives and the attributes of NCPN and SCPN ecosystems to be monitored, there is a need to evaluate the effectiveness of various possible measures and measurement techniques related to chosen vital signs. Such evaluations are often done as field-based pilot studies in which problems with certain field methods are revealed and refinements in sampling design are identified (Elzinga and others, 1998). Thus, our overall objectives are to implement monitoring of riparian ecosystems as a pilot study, designed to do the following:

1. Collect field data and evaluate the utility and efficiency of a set of possible ecological measures and measurement techniques, used to meet NPS monitoring needs, across a range of riparian ecosystems characteristic of the Colorado Plateau;

2. Quantify within-site variability and sampling effort for selected measures to assist NPS in the design and implementation of efficient and effective long-term monitoring protocols;

3. Based on this field-based pilot study, refine standard operating procedures (SOPs) that are likely to be used in implementing long-term riparian monitoring.

This report summarizes field data collected during the 2006 field season. Statistical analyses are used to evaluate the efficiency of various sampling methods, based on the time required to characterize within-site variability in measures of species diversity, tree-basal area and tree-stem density. Species area or accumulation curves are used to evaluate the effectiveness of quadrat size and number in characterizing within-site species richness and frequency for the herbaceous community, relative to minutes of sampling effort. Finally, variance in estimates of cover for herbaceous vegetation will be evaluated for different quadrat sizes.

Methods

Study Areas

Streams for pilot sampling were identified in consultations between the NPS and USGS, to represent a range of Colorado Plateau stream types likely to be included in future NCPN and SCPN vital signs monitoring efforts (table 1). On the Colorado Plateau, riparian vegetation structure and diversity are typically best developed along alluvial reaches of perennial streams. Thus, the initial set of streams considered had perennial or intermittent flow that contained alluvial valley segments.

Range of Natural Variation

Riparian ecosystems in arid regions are inherently dynamic and highly variable in both spatial and temporal dimensions. It is worth noting that the 2006 field season included unusual precipitation events across the region, which had direct influence on riparian vegetation in some of the sampled reaches. For example, precipitation recorded at Bandelier, N. Mex., headquarters in 2006 was below average from January through June, followed by strong monsoonal precipitation in July and August, producing the fifth and first wettest months, respectively, over the last 30 years. This likely contributed to the high cover and diversity of herbaceous

Table 1. Description of riparian stream reaches sampled during 2006 field season. Stream type classification follows Graf (1987).

Park unit	Code	Stream name	Flow/stream type	Valley setting
Northern Colorado Plateau Network				
Arches NP	ARCH	Courthouse Wash	Intermittent/local stream	Confined alluvial
Southern Colorado Plateau Network				
Bandelier, N. Mex.	BAND	Capulin Creek	Perennial/local stream	Confined alluvial to colluvial
Canyon de Chelly, N. Mex.	CACH	Tsiale Creek	Perennial/local stream	Confined alluvial
Glen Canyon NRA	GLCA	Coyote Gulch	Perennial/local stream	Confined alluvial

vegetation observed in pilot sampling at Capulin Creek (C. Allen, USGS, Bandelier, N.Mex., *oral personal commun.*). In contrast, heavy rains in southern Utah from the storm event of October 6th and 7th, caused widespread flash flooding across the region. Provisional data from the USGS suggests that the recurrence interval for flood peaks resulting from this storm on regional streams ranged from a >5-yr event on Pine Creek near Escalante, Utah to a 100-yr event on the Dirty Devil River above Poison Spring Wash near Hanksville, Utah (Terry Kenny, hydrologist, USGS, Salt Lake City, Utah). Sampling on Courthouse Wash and Coyote Gulch followed significant flooding, which caused channel erosion and flood-plain deposition within both study reaches. This disturbance was an important factor correlated with the low cover and low diversity of herbaceous vegetation within these study reaches. Riparian vegetation patterns observed across these sites illustrates the potential range of short-term natural variation in these systems.

Defining Geomorphic Surfaces

There is tight linkage between fluvial geomorphic surfaces and cross-valley patterns in riparian vegetation along Colorado Plateau streams. Accordingly, sampling of riparian vegetation in this pilot study was carried out in relation to defined geomorphic surfaces, which have been previously described for a range of plateau streams (fig. 1). For example, the riparian zone, as defined in this study for a typical perennial stream, included the following elements: (1) the channel bed, including depositional bars; (2) the active channel shelf (a frequently inundated surface between the channel bed (or depositional bar) and the bank slope of the flood plain; (3) the flood plain, which is inundated by recurring high flows and may contain topographic irregularities including flood-plain bars and swales; and (4) riparian terraces. Riparian terraces typically support stands of relict cottonwoods (*Populus fremontii*) but no longer or rarely flood; thus, they are characteristically dominated by upland species in the understory. Riparian terraces have been described by previous researchers on the plateau and represent former flood-plain surfaces that were abandoned during widespread arroyo cutting, which began on the plateau in the mid to late 1800s (Hereford, 1984; Graff, 1987). Riparian terraces were observed along all of the streams sampled. Upland terraces are older alluvial surfaces that support only upland vegetation. These, along with colluvial deposits or outcrops of bedrock (fig. 1) were considered upland and therefore not included in the pilot sampling. Transitional surfaces also were identified and typically represented relatively steep, narrow transitions between geomorphic surfaces of different elevations. Transitional surfaces most commonly included flood-plain banks and terrace risers. Table 2 provides additional descriptions of geomorphic surfaces encountered and defined during the course of this study.

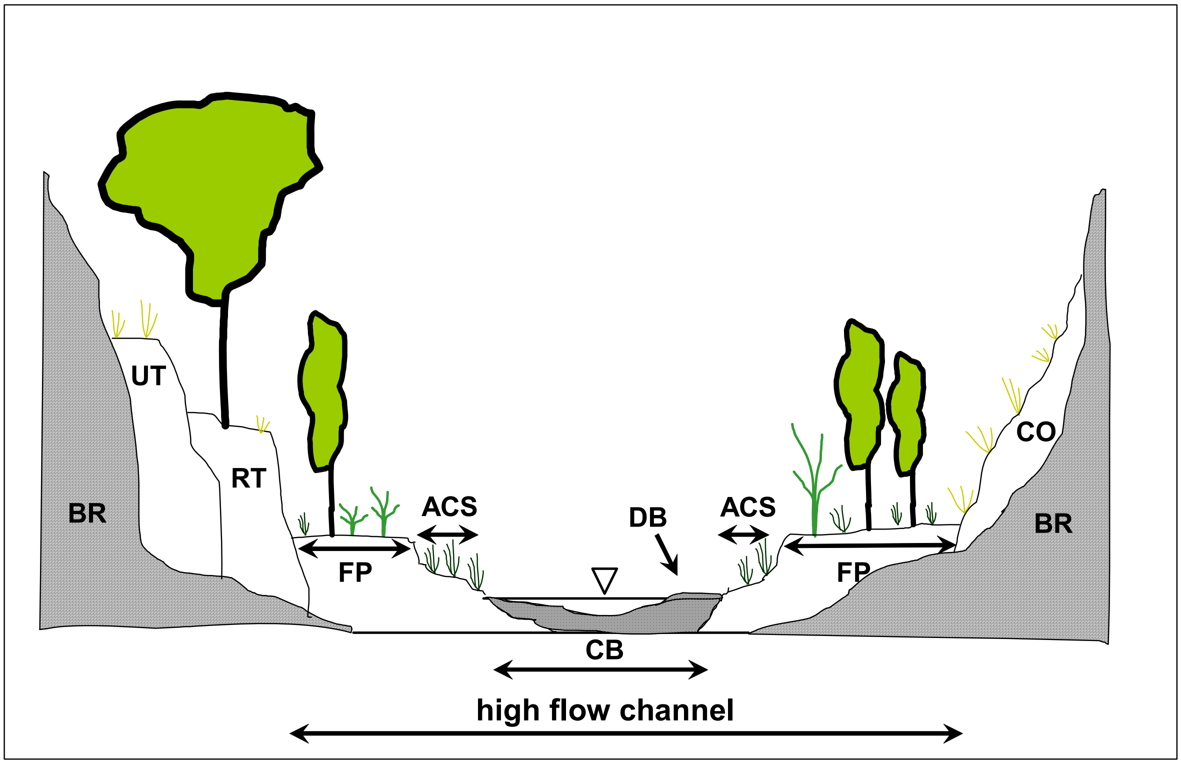

Figure 1. Illustration of geomorphic surfaces defined in 2006 riparian pilot studies . Symbols represent the following geomorphic features: BR=bedrock, CO=colluvium, UT=upland terrace, RT=riparian terrace, FP=flood plain, CB=channel bed, DB=depositional bar, and ACS=active channel shelf. Physiographic descriptions of surfaces based on Hupp and Osterkamp (1985), Graff (1987), Hupp (1988), Everett (1995), and Birkeland (1996). It should be noted that at any particular channel cross section, not all features would be expected to occur.

Table 2. Descriptions used for geomorphic and transitional surfaces along the perennial streams sampled in this pilot study (see table 1). These surfaces also are illustrated in figure 1.

Geomorphic surface	Description	Citations
Dominant geomorphic surfaces		
Channel bed and depositional bars	On a perennial stream, the *channel bed* is that portion of the channel that is inundated by flows below the mean discharge. At least a portion of the channel bed along a perennial stream remains wet at all times. Depositional bars are part of the active channel bed but slightly higher in elevation than the low-flow or base-flow water stage. They are typically devoid of woody vegetation.	Hupp and Osterkamp (1985)
Active channel shelf	The *active channel shelf* is a horizontal to sloping surface between the bank slope of the flood plain and the lower limit of persistent vegetation that marks the edge of the channel bed or a depositional bar. Along streams in more humid regions, these surfaces are frequently inundated and support a mix of flood-tolerant woody species.	Hupp and Osterkamp (1985), Hupp (1988)
Flood plain	That portion of the riparian zone that is typically inundated by recurrent high flows and dominated by woody riparian vegetation. Flood plains of many Colorado Plateau streams are topographically complex, including flood-plain swails and flood-plain bars.	Everett (1995)
Transitional/ infrequent geomorphic surfaces		
Flood-plain bank	A relatively steep transitional surface between the channel bed, depositional bar, or active channel shelf and the flood plain	Hupp and Osterkamp (1985)
Riparian terrace	Terraces are relict flood plains whose surfaces are rarely if ever inundated by flows of the modern river. Many Colorado Plateau streams have terraces that were formed by channel incision in the late 1800s to early 1900s. These terraces are typically 3 to 10 m above the current channel and often support large, remnant cottonwoods (legacy trees); although the understory vegetation is typically dominated by upland vegetation. Such terraces are here defined as *riparian terraces* because of the presence of legacy cottonwoods or other relict woody riparian species.	Hupp (1988), Graff (1987), Hereford (1984)
Upland terrace	Upland terraces are higher, older terraces that formed from channel incision of valley fills dating back a minimum of 800 years. Because of their age, these terraces, where they occur, are dominated by upland vegetation and are thus not considered part of the riparian zone.	Hereford and others (1996)
Terrace riser	A relatively steep transitional slope rising from lower elevation surfaces such as the active channel shelf or flood plain to a terrace surface.	
Colluvium	Material transported and deposited by the action of gravity. Streams of the Colorado Plateau confined within bedrock valleys often have colluvial deposits of rock and soil material that bound the edges of flood plains or terraces. These surfaces are dominated by upland vegetation.	Scott and others (2005)
Bedrock	Extensive bedrock exposures of largely sandstones, limestones, and shales characterize the Colorado Plateau and confine the valleys of many of the region's rivers and streams. In extreme cases, stream flow is completely confined within bedrock. In less constrained valley settings, flood plains may be bounded by side-valley exposures of bedrock.	Scott and others (2005)

Field Sampling

Sampling Reach Selection and Transect Layout

In consultation with NPS, it was agreed prior to field sampling that establishment of a sampling frame for each stream reach would be modified from existing EMAP and NAQWA protocols and would be based on width of the riparian zone rather than wetted channel width. Specific sampling reaches for the SCPN streams were selected by NPS personnel using a Generalized Random Tessellation Stratified (GRTS) selection design (http://www.epa.gov/nheerl/arm/designpages/monitdesign/survey_design.htm).

The sampling location for the NCPN stream (Courthouse Wash) was chosen subjectively, based on alluvial valley setting that was considered representative of stream reaches throughout the region. Sampling reaches for the SCPN streams were selected using GRTS as follows. The middle of the sampling reach (centroid) was located by navigating to the predetermined GRTS point using a GPS unit and a printout of the 1-m DOQQ or digital air photo imagery of the point and surrounding landscape features. GPS reception typically was not available or reliable in deep, narrow canyons; thus, the imagery was used to assist in pin-pointing the location of the centroid. Once located, the reach was evaluated for its suitability. In the process of selecting sample reaches, two important decision rules were established. First, no more than 25 percent of the sampling reach should include a distinctly different valley setting or stream type. Second, no more than 25 percent of the sampling reach should be located above or below a major tributary junction (see SOP 4). If a reach met the above criteria, sample reach length was determined by measuring the width of the riparian zone at five points—one at the centroid, two upstream, and two downstream of the centroid—at a spacing equal to the riparian zone as measured at the centroid. The sample reach length was obtained by averaging the five width measurements and multiplying that value by 10. In the event that this method produced excessively short or long sample reaches, minimum and maximum reach lengths of 300 and 800 m were defined.

Transect layout design was based on existing protocols (Peck and others 2003). Eleven systematically spaced transects represented the sampling frame (fig. 2). This frame was centered on transect 6 (the centroid) in a reach that was relatively uniform with respect to valley setting and channel slope. Transects were numbered in ascending order, starting with the downstream-most transect. Spacing between transects was determined by dividing reach length by 10 and measuring distance between transects with a tape along the thalweg or lowest point along the channel. Transect layout began at the centroid and proceeded upstream and downstream from this point. Each transect was positioned orthogonal to the channel and were therefore generally orthogonal to the riparian zone and the valley. Transects endpoints were defined by the width of the riparian zone, identified by the transition from surfaces supporting riparian vegetation to bedrock valley walls or surfaces dominated by upland vegetation; for example, colluvial deposits (fig. 1, table 2).

In one instance (Coyote Gulch), transect placement immediately upstream of a sharp, 90º bend in the channel and valley axis, resulted in the transect running parallel to the channel and valley in the downstream direction. For this and similar situations arising from channel sinuosity, we developed the decision rule that in laying out transects, if a transect situated orthogonal to the channel does not intersect the riparian-upland transition or valley wall before coming within 20 m of an adjacent transect, the spacing of that transect along the centerline of the stream should be increased until it is separated by at least 20 m from the adjacent transect. Transects located subsequent to the repositioned transect resume the original along-stream spacing (fig. 2).

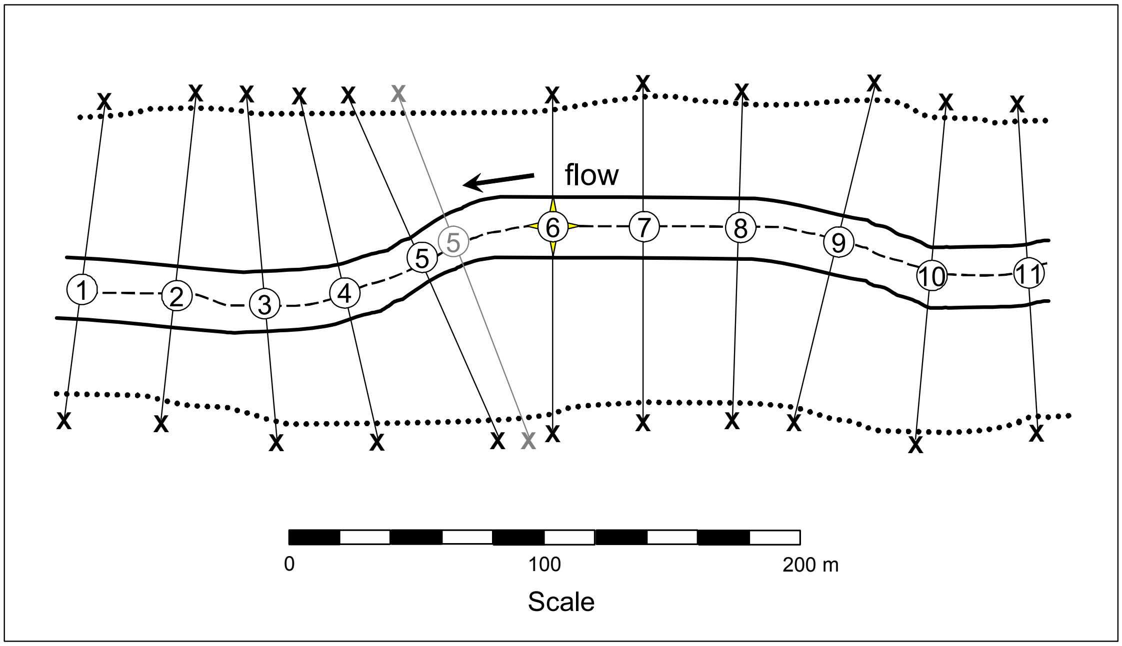

Figure 2. Illustration of reach-scale layout of transects for sampling geomorphic surfaces and riparian vegetation. Thick solid lines represent the stream channel. Dashed line is the channel centerline, and the dotted line represents the riparian-upland transition. Transect spacing is measured along the centerline, extending upstream and downstream from the centroid (transect 6). Transects (thin solid lines) are numbered in ascending order starting with the downstream-most transect and positioned orthogonal to the channel. Transect endpoints (X) are located at the valley wall or the transition from riparian to upland vegetation. Minimum distance between transects is 20 m. Initial layout of transect 5 (gray) violates this systematic spacing and is increased to maintain separation (transect 5, black). Systematic spacing resumes following transect repositioning.

Once transect location and orientation were determined, transects were delineated by stretching a Kevlar tagline and meter tape taut between two, 60-cm-long pieces of 1.2-cm-diameter rebar. Where possible, the transect endpoints or head pins were positioned one to two meters upslope of the upland-riparian transition (fig. 3). The left bank endpoints (stream bank on the left while facing downstream) were defined as the zero point for each transect. To minimize the effects of trampling on vegetation, care was taken to walk on the upstream side of each transect. Following transect layout, sampling proceeded as follows: nested quadrats, line intercept, belt transects, and census of legacy trees.

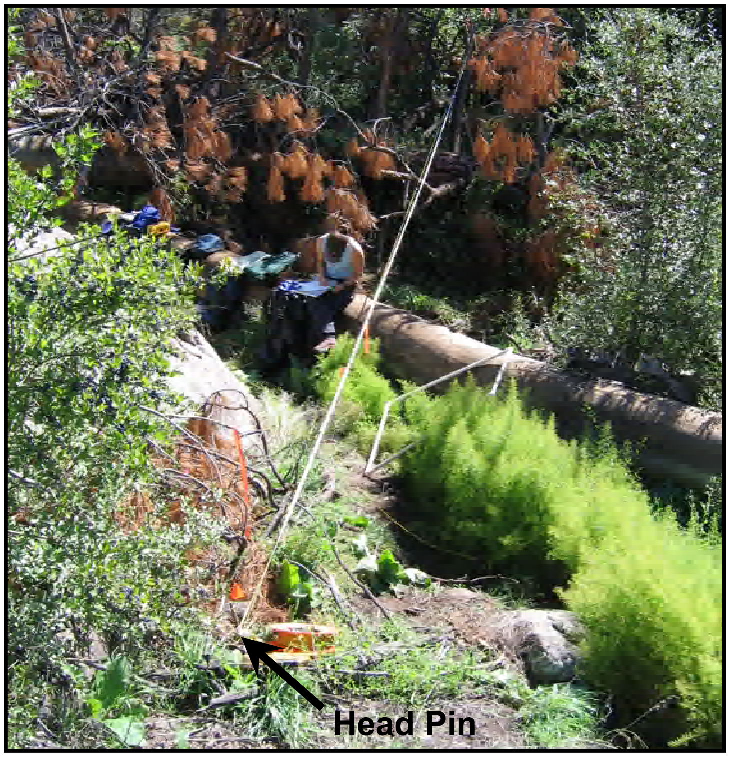

Figure 3. Right bank endpoint or head pin for a riparian transect at Capulin Creek, BAND. The head pin is positioned approximately 2 m above the riparian-upland transition. In this photograph, the stream channel is hidden below the fallen ponderosa pine in the middle of the photo.

Nested Quadrats

Nested quadrat sampling was used to estimate frequency of understory herbaceous vegetation, cover of soil-surface features, and cover of woody shrubs and tree seedlings. This sampling occurred at all sites and quadrats consisted of nested sampling areas measuring 0.01 m^2, 0.1 m^2, 1 m^2 and 10 m^2. The 1-m^2 quadrat was constructed of 2.5-cm PVC pipe and colored marks were placed on the frame with permanent markers to delineate corners of the 0.01-m^2 and 0.1-m^2 quadrats (fig. 4). Steel pins and a 25-m tape initially were used to lay out the 10-m^2 quadrats; however, we suggest that lightweight, breakdown tent poles, held together with shock cord, would be a more efficient way to lay out these quadrats (see SOP 7). To minimize trampling effects, the 0.01-m^2, 0.1-m^2, and 1-m^2 quadrats were placed on the downstream side of the transect. The 10-m^2 quadrat was centered on the transect; however, we suggest that all quadrats be placed on the downstream side of transects to avoid trampling in all cases. The nested quadrats were spaced regularly or systematically along each transect, beginning at the zero point, defined as the left head pin (fig. 5). To track the distribution of quadrats by geomorphic surface, we recorded the dominant surface for each 1-m^2 quadrat and the meter on the transect at which the quadrats were placed.

Minimum spacing between quadrats was 1 m. However, to ensure all geomorphic surfaces were sampled, maximum spacing between nested quadrats was 4 m. Wherever possible, spacing was adjusted to obtain a minimum of eight to ten sets of nested quadrats per transect.

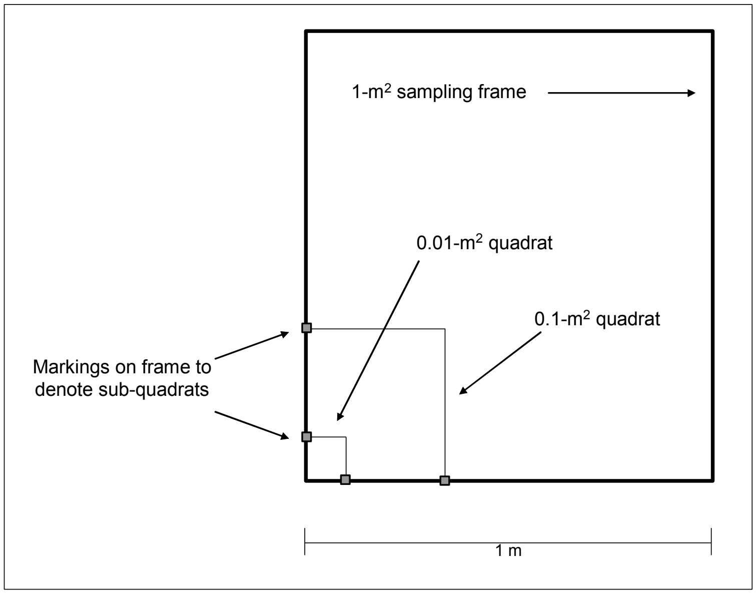

Figure 4. Arrangement of the 0.01-m^2, 0.1-m^2 and 1-m^2 nested frequency quadrats. Marks on the corner of the 1-m^2 quadrat were used to define the smaller quadrats.

Following frequency sampling, cover of all vascular herbaceous plants was recorded in the 1-m^2 and 10-m^2 quadrats, based on seven cover classes (table 3). Finally, cover of woody shrubs, in two size classes, and tree seedlings (table 4) were recorded in the 10-m^2 quadrat, based on the same cover classes. Table 5 lists those woody species treated as shrubs for this study.

Line Intercept

The line-intercept method, as described by Bonham (1989) and Elzinga and others (1998), was used to measure canopy cover of woody trees and shrubs by height and size class (tables 3 and 5) and the proportion of geomorphic surfaces across the riparian zone. Transects were the sampling unit, and along each transect the cover of each tree species, by size class, was recorded as start and stop points where overlying or underlying canopies intersected a tape stretched along the transect. Canopy intersections had to be greater than 1 cm and canopy gaps less than 20 cm were not recorded (see SOP 8). A telescoping survey rod with a level was used to improve the vertical projection of tall canopies down to the transect. The proportion of the riparian zone occupied by a geomorphic surface type (table 2) was similarly evaluated by recording start and stop points for each surface type beneath the transect.

Belt Transects

Belt transects were used to measure density and stand basal area of tree stems above the seedling size class (table 3). Both of these stand-structure metrics are expressed on a unit area basis and originally were to be measured in 5×20 m quadrats placed systematically along each transect. However, after evaluating the time involved in laying out and measuring tree quadrats on two transects at BAND, the decision was made to measure stand structure for the remaining pilot sites using belt transects centered on the transects and extended across the entire riparian zone from head pin to head pin (fig. 6). Where riparian tree stems were small and dense

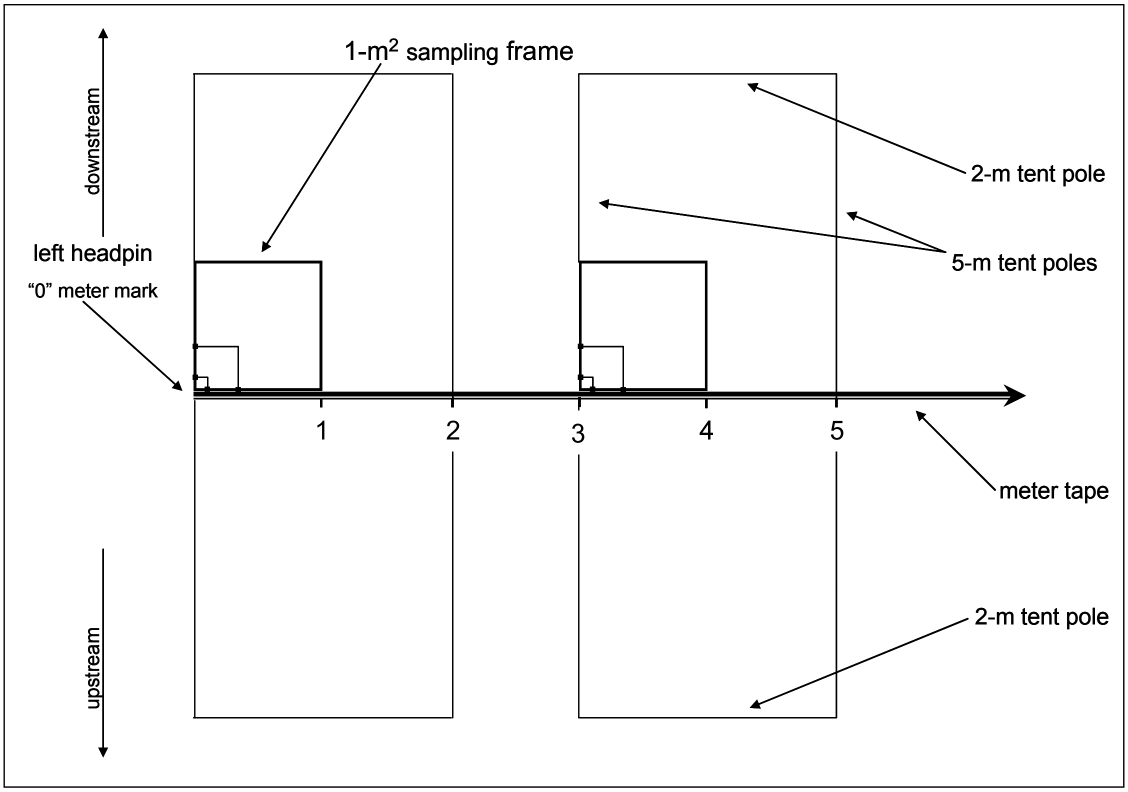

Figure 5. Location and spacing of nested quadrats relative to the zero point of the transect, defined as the left head pin. Transects are oriented orthogonal to the stream channel. The 0.01-m^2, 0.1-m^2, and 1-m^2 quadrats are arrayed on the downstream side of the transect to minimize trampling. The 10-m^2 quadrat is centered on the transect. Quadrats are systematically spaced along transects, with spacing based on transect length. Minimum spacing between quadrats is 1 m, as depicted, and maximum spacing is 4 m.

Table 3. Cover classes used to estimate cover in 1-m^2 and 10-m^2 quadrats.

Cover class	Range of cover (%)	Class midpoints (%)
1	<1	0.5
2	1–5	3.0
3	5–10	7.5
4	10–25	17.5
5	25–50	37.5
6	50–75	62.5
7	75–100	87.5

Table 4. Size (diameter at breast height [dbh]) and height classes for trees and shrubs used in pilot sampling.

Shrub height classes	Trees	
	Size class	Criteria
<2 m	Seedling	<1.37 m tall or ≥ 2.5 cm dbh
≥2 m	Pole	≥ 1.37 m and 2.5–15 cm dbh
	Overstory tree	≥ 15 cm and <50 cm dbh
	Legacy tree	≥ 50 cm dbh

Table 5. The list of woody species, by scientific and common name, that were considered shrubs during the pilot study. Three species, *Quercus gambelii, Q. grisea,* and *Salix exigua,* may occasionally achieve tree-like stature, as noted. Growth habit information from Welsh and others (2003).

Scientific name	Common name	Growth habit	Site
Artemisia tridentata	big sagebrush	Shrub to 3 m tall	ARCH, BAND, CACH
Baccharis salicina	Great Plains false willow	Shrub 1–3 m tall	ARCH, GLCA
Chrysothamnus depressus	longflower rabbitbrush	Low, spreading shrub	CACH
Chrysothamnus nauseosus	rubber rabbitbrush	Low to tall shrub (up to 3 m tall)	ARCH, GLCA
Chrysothamnus sp.	rabbitbrush species	Low to moderate shrub (up to 1 m tall)	ARCH, CACH, GLCA
Chrysothamnus viscidiflorus	yellow rabbitbrush	Low to moderate shrub (up to 1 m tall)	ARCH
Cornus sericea	redosier dogwood	Clump-forming shrub	CACH
Forestiera pubescens	stretchberry	Shrub up to 2 m tall	BAND
Gutierrezia sarothrae	broom snakeweed	Profusely branched shrub up to 0.9 m tall	BAND
Ptelea trifoliata	common hoptree	Large shrub up to 3 m tall	BAND
Quercus gambelii	Gamble oak	Clonal shrub to small tree (2–4 m), rarely up to 10 m tall	BAND, CACH, GLCA
Quercus grisea	gray oak	Small to large tree, up to 25 m tall in protected sites	BAND
Rhus aromatica	fragrant sumac	Clump-forming shrub up to 2.5 m tall	BAND, CACH, GLCA
Ribes sp.	currant	Low to moderate shrub	BAND
Rosa woodsii	Wood's rose	Shrub up to 2.5 m tall	BAND, CACH, GLCA
Salix exigua	narrowleaf/coyote willow	Clonal shrub up to 3 m tall; rarely treelike to 8 m tall	ARCH, CACH, GLCA
Salix lasiandra	green leaf willow	Shrub or small tree from 2–15 m tall	CACH
Sherpherdia argentia	silver buffaloberry	Shrub with spreading, opposite branches up to 4 m tall	ARCH
Symphoricarpos oreophilus	mountain snowberry	Shrub up to 1.5 m tall	CACH

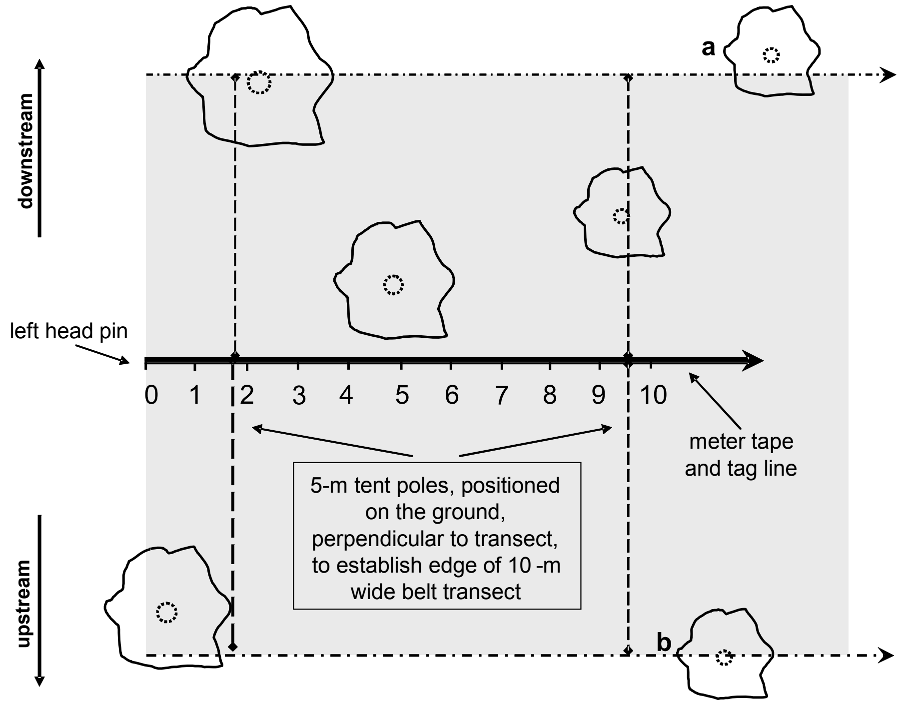

Figure 6. Layout of a 10-m-wide belt along a transect, starting at the left head pin. Five-m collapsible tent poles are used to establish the edge of the belt at points along the transect. Belt transects were established at the left head pin and extended across the entire riparian zone to the right head pin (not shown). All trees (irregular polygons) within the belt (gray shading) are sampled. If more than 50 percent of a tree stem (dashed circle) was outside of the belt it was not included; for example, trees a and b would not be sampled.

(BAND) or where transects were closely spaced (CACH), 10-m-wide belts were measured. At ARCH and GLCA, 10-m- and 20-m-wide belts were measured along each transect and compared for sampling efficiency. Outside edges of the belts were established by measuring out 5 m or 10 m from the transect at multiple points, using 5-m lengths of Kevlar line, held orthogonal to the transect. Boundary decisions regarding whether a tree was considered in or out of the belt transect were as follows: if more than 50 percent of the rooted stem was in the quadrat, it was included; if not, it was excluded. Decision rules also had to be established for measuring stems at breast height (see SOP 9).

Population Census of Legacy Riparian Trees

Legacy riparian trees, cottonwood in particular, were present within all pilot sample reaches as small isolated stands or scattered individuals. We compared density and basal area estimates of legacy trees obtained from belt transects with the values determined from census counts. All legacy trees in the sampling reach were counted and measured for diameter at breast height (dbh). Breast height is defined as being 1.37 m above the ground surface. Census area was calculated by multiplying reach length by average transect width. Census methods are ideal for monitoring since they provide a true estimate of the population without sampling error, assuming the census is accurate (Elzinga and others, 1998). Legacy trees at the pilot sites were well suited for a census because (1) the census area of the reach was constrained within relatively narrow valleys, (2) there were few individuals within the census area, and (3) they were distinctively large and easy to spot while walking the reach.

Plant Species Identification

Plants were identified by sight in the field. When a species call was tentative, it was indicated as such by a question mark, and to minimize the collection of specimens, these species were identified or verified in the field whenever possible using the following floras: *Arizona Flora* (Kearney and Peebles, 1960), *A Utah Flora* (Welsh and others, 2003), *Intermountain Flora* (Cronquist and others, 1994), *Flowering Plants of New Mexico* (Ivey, 1999).

Unknown species were labeled on the datasheets with unique descriptive names and number codes, and specimens, collected outside of the sample area when possible, were correspondingly labeled and pressed. The pressed unknowns were taken to Herbaria at Northern Arizona University or Colorado State University for subsequent identification. We used the USGS Plants Database (*http://plants.usda.gov/*) as our taxonomic authority in preparing final species lists.

Field Data

Field Data Collection and Entry

Field data were entered by hand on forms that had been designed in advance and modified based on field experience following each pilot study. Current drafts of the field forms are provided in the appendixes of SOP nos. 8, 9, and 10. Field data were entered into Xcel spreadsheets from the field forms and printouts of the electronic files were proofread for errors, checked against the field forms, and corrected in the Xcel file. Updates to the species lists were also entered at this time.

Data Analyses

Statistical summaries and analyses were performed on data and sampling times collected for the nested quadrats, line intercept, belt transects, and riparian legacy tree census. The analyses and decision rules associated with each of these procedures are summarized in table 6.

Table 6. Summary of data analyses and decision rules governing those procedures.

Analyses	Decision rules for procedures
All except species area curves	SAS version 9.1, MEANS, FREQ, and UNIVARIATE procedures used to generate summary statistics.
Species area curves	SAS version 9.1 used to convert Xcel data files for species area curve (SAC) analysis in PCORD (for the 1-m^2 and 10-m^2 quadrats only). Then graph SACs for shrub and herb species (with and without rare species) as a function of (1) number of quadrats and (2) minutes of sampling effort. Rare species were defined as having only a single occurrence at a site.
Species area curves (sampling effort)	Sampling effort is measured in minutes based on estimates of three components: time to layout transects, time to move among quadrats, and time to sample quadrats. Average measured transect setup time was 40 minutes per transect with 11 transects at each site. Average travel time between quadrats was 0.5 minutes per quadrat. We measure total time to sample each fully nested (0.01, 0.1, 1, and 10 m^2) quadrat set and calculated an average time per nested set at each site. We then measured relative time for the different size quadrats on a trial set of nested quadrats to determine a set of proportions (summing to 1) that break the average

Table 6. Summary of data analyses and decision rules governing those procedures. Continued

	time for a nested quadrat down into the average time for each quadrat size. We divided the total time required to setup all transects at a site by the full number of quadrats we sampled at that site in order to get a transect setup time per quadrat. We then constructed species-effort curves using a calculation of number of quadrats multiplied by the per quadrat time (transect setup, travel among quadrats, and sampling time). Using this portioning of time per quadrat, the ratios between sampling effort for 10-m^2 versus 1-m^2 quadrats was 1.96, 2.14, 1.91, and 2.49 minutes at each site, with an average across sites of 2.12 minutes.
Tables by sub-classifications	In many tables, it was necessary to create records with a zero value for transects for sites where a particular subgroup only occurred on some transects. Records were created ONLY for those subclasses that occurred at that site. Subclasses included are size classification and species.
Intercept total cover	Units summarized are on a transect level. Sum over start/stop to achieve a value for each individual transect. Since start/stop overlap, these percent-covers can be greater than 100 percent.
Intercept canopy cover	Units summarized are the individual start/stop values.
Total intercept confidence intervals	Estimation with accumulating numbers of transects. For each number of transects j, j=1…11, j randomly selected without replacement transects selected to be summarized.
Individual canopy cover confidence intervals	Same procedure as total cover.
Estimating sample sizes at 10 and 20 percent precision	Sample size estimates were calculated using PASS (power and sample size; *http://www.ncss.com*). For these analyses, we define estimation precision as one-half the width of the 95 percent confidence interval for the mean.
Tables by belt size	Site averages are broken down by belt size to avoid double counting (since information from the 10-m belt is also included in the 20-m belt).
Differences between belt sizes	Sign rank test for differences, using SAS version 9.1, UNIVARIATE procedure.
Basal area	Cross-sectional area was calculated for each stem. Values summarized are total cross-sectional area at a transect level (may be broken down by classification, but value is still per transect).
Density	Number of stems counted, again at the transect level.
Intercept times	ARCH, BAND, and GLCA only.
10-m belt times	For GLCA and ARCH, time for a 10-m belt is assumed to be one-half the 20-m belt time. BAND 10-m belt also used.
20-m belt times	Only GLCA and ARCH have 20-m belt times.
Quadrat times	Times summarized on a per quadrat and per transect level.
Census	Census area calculated by average transect length × reach length. Average transect length calculated by eliminating any records that contained the words "UPLAND" or "COLLUVIAL" in surface type from individual transect lengths. CACH—select only SPP=POPDEL and DBH >50 cm. ARCH—only use legacy trees excel data to determine census value.

RESULTS

Reach Selection and Transect Layout

Final reach lengths and comments regarding the establishment of each sampling reach are presented in table 7. Reach lengths ranged from the minimum of 300 m to 580 m. At GLCA, transect 5 had to be repositioned, according to the rules described above in the discussion on methods for transect layout and illustrated in figure 2, to avoid overlapping with adjacent transects. At two sites, transects ending at vertical sandstone walls raised the issue of how to secure transect endpoints in such situations. Further, establishing the tag-line on transects

Table 7. A listing of study reach lengths by site. Comments relating to the establishment of the study reaches are included.

Site	Reach length (m)	Comments
ARCH	300	Variable bottomland elevations across the canyon made running the tag-line difficult. Transect tag-line often extended in two stages, running across the flood terraces to the terrace edge closest to the channel and then running a separate line across the portion of the channel that was lower in elevation. Attaching the tag-line where the transect ends at a sheer canyon wall is an important issue. Attaching to some kind of cryptic climbing bolt or attachment would be ideal, but installing such devices would be a concern at many parks.
BAND	300	It took approximately three hours to establish the study reach. It was very difficult to walk along and across the channel due to large amounts of coarse woody debris (CWD). Approximately one-half hour was required to establish transect 1.
CACH	300	GRTS pt. 3 selected by network was only 21 m in width, so the site at GRTS pt. 4 was examined; it was only 16 m and it was discussed whether these points should be rejected because valley width was less than 25 m. The next set of GRTS points, in a wider portion of the canyon, was considered, but ultimately opted not to since the network is specifically interested in the reach type that pts. 3 and 4 include.
GLCA	580	The first GRTS sample point was rejected because >25 percent of the reach was in a bedrock valley setting. The second GRTS point met selection criteria. Establishing transects was the most time consuming part of the sampling process, often taking more than an hour. The primary reason for this was that many transects were from 75 to over 100 m in length and it was difficult to keep the tag-line straight and taught through the trees and CWD. It will continue to be a problem to setup such long transects, especially if new patches of woody vegetation establish on surfaces spanned by the transects. Transects were adjusted within 1 m of the pre-selected transect location in order to maintain a reasonably clear line across the riparian zone. Sliding transects in this way has the effect of biasing the surface roughness estimates to be lower than they would be if allowed to bend around stems and CWD. However, there was consensus that the basal roughness/gap intercept approach did not adequately capture what was happening in the reach relative to flow roughness. As at ARCH, more than one transect ended at vertical sandstone wall. In establishing transects, one had to be repositioned because of a sharp bend in the channel.

approaching or exceeding 100 m in length was difficult because of intervening tree stems and wracks of coarse woody debris.

Nested Quadrats

Species Richness, Frequency, and Species Area Curves

Table 8 summarizes the total number of species observed in each quadrat size as well as the number of rare species observed at each pilot site. For a complete listing of all species encountered, see appendix A. Rare species are defined as those having a single occurrence at a site. Because quadrats were nested, the 10-m^2 quadrats contained all of the species observed at a site. Thus, there were no species unique to smaller plots. BAND and CACH had similar and a relatively high number of species (128 and 130, respectively) whereas ARCH and GLCA had similar but low numbers of species (52 and 58, respectively). The contrast in species richness in part results from above average monsoonal precipitation at BAND (and likely CACH) and flash flooding immediately prior to sampling ARCH and GLCA. CACH had the greatest number of rare species (40), in part because grazing had removed flowering material, making positive species identification difficult. However, rare species accounted for 35 percent to 47 percent of the species total across all sites.

Table 8. Richness estimates from 1-m^2 and 10-m^2 quadrats across four site samples in the 2006 riparian pilot study. Rare species are defined as having a single occurrence at a site.

Site	Total number of quadrats	Total number species observed	1-m^2 quadrats			10-m^2 quadrats		
			Number species observed	Number rare species	No. species excluding rare species	Number species observed	Number rare species	No. species excluding rare species
ARCH	93	52	31	10	21	52	23	29
BAND	88	128	83	40	43	128	45	83
CACH	79	130	80	36	44	130	60	70
GLCA	135	58	41	19	22	58	22	36

Table 9 contrasts the utility of the 1-m^2 and 10-m^2 quadrats for capturing rare species at each pilot site. Numbers of rare species are naturally high in riparian areas, and 10-m^2 quadrats were more efficient at accumulating additional rare species compared with 1-m^2 quadrats. Detailed information on species frequencies are described below.

Overall frequencies were low in all four pilot sites (tables 10–13), which reflects the patchy nature of riparian vegetation in these narrow canyon settings. Very few species, across all sites, reached the desired 30 percent frequency range in either the 1-m^2 or the 10-m^2 quadrat sizes, which is, again, related to the patterns of riparian vegetation in the bottomland, typically linked to flood disturbance and moisture availability. BAND and CACH were relatively species-rich and had the greatest number of species that reached the 30 percent frequency range. Species diversity was diminished at ARCH and GLCA, resulting from recent floods. No species at ARCH and only one species at GLCA (*Bromus tectorum*) reached the 30 percent frequency range, and there were few species overall that occurred in more than 10 percent of the quadrats. In all cases, the 10-m^2 quadrats had higher percent frequency for a species than the other quadrat sizes.

Table 9. Additional information on rare species detection in the 1-m^2 and 10-m^2 quadrats.

Site	Number additional species in 10-m^2 quadrats	Percent species unique to 10-m^2 quadrats	Number rare species in 1-m^2 quadrats with >1 occurrence in 10-m^2 quadrats	Number species unique to 10-m^2 quadrats with >1 occurrence	Number rare species unique to 10-m^2 quadrats
ARCH	21	40.38	4	4	17
BAND	45	35.15	18	22	23
CACH	50	38.46	19	7	43
GLCA	17	29.31	9	5	12

Table 10. Species found in >10 percent of 88 quadrats at Capulin Creek, Bandelier National Monument, 2006, in descending order of frequency in the 10-m^2 quadrats. Twenty eight out of 120 species (23.3 percent) total are included in the table. Shading indicates the quadrat size in which a species reached >30 percent frequency. Additional species are included as indicators of relatively common species that are not adequately captured by the tested quadrat sizes. Gram=graminoid habit.

Species	Habit	% freq 0.01 m^2	% freq 0.1 m^2	% freq 1 m^2	% freq 10 m^2
Lactuca serriola	Forb	0.00	1.14	17.05	47.73
Forestiera neomexicana	Shrub	0.00	0.00	0.00	46.59
Bromus tectorum	Gram	13.64	23.86	31.82	45.45
Taraxacum spp	Forb	3.41	3.41	22.73	40.91
Geranium caespitosum	Forb	6.82	11.36	20.45	37.50
Parthenocissus quinquefolia	Vine	1.14	5.68	13.64	37.50
Verbascum thapsus	Forb	0.00	2.27	14.77	36.36
Elymus elymoides	Gram	1.14	6.82	19.32	31.82
Piptatherum micranthum	Gram	2.27	6.82	15.91	30.68
Bromus inermus	Gram	1.14	4.55	11.36	30.68
Tragopogon spp	Gram	1.14	4.55	11.36	28.41
Brickellia brachyphylla	Forb	1.14	2.27	10.23	28.41
Dactylis glomerata	Gram	3.41	3.41	17.05	25.00
Conyza canadensis	Forb	1.14	1.14	5.68	20.45
Bahia dissecta	Forb	0.00	1.14	5.68	19.32
Clematis ligusticifolia	Vine	2.27	3.41	10.23	18.18
Cicuta douglasii	Forb	0.00	0.00	6.82	18.18
Bromus ciliatus	Gram	0.00	2.27	6.82	17.05
Equisetum arvense	Gram	0.00	1.14	7.95	17.05
Galium aparine	Forb	1.14	2.27	3.41	14.77
Poa combo (pratensis/compressa)	Gram	0.00	0.00	7.95	14.77
Agrostis stolonifera	Gram	0.00	2.27	5.68	13.64
Chenopodium fremontii	Forb	0.00	0.00	3.41	13.64
Elymus canadensis	Gram	0.00	1.14	6.82	12.50
Urtica dioica	Forb	0.00	0.00	3.41	12.50
Rosa woodsii	Shrub	0.00	0.00	0.00	12.50
Artemisia ludoviciana	Forb	0.00	0.00	2.27	11.36
Cirsium vulgare	Forb	0.00	0.00	1.14	11.36

Table 11. Species found in >10 percent of 74 quadrats at Tsaile Creek, Canyon de Chelly National Monument, 2006, in descending order of frequency in the 10-m^2 quadrats. Thirty three out of 135 species (24.4 percent) total are included in the table. Shading indicates the quadrat size in which a species reached >30 percent frequency. Additional species are included as indicators of relatively common species that are not adequately captured by the tested quadrat sizes. Gram=graminoid habit.

Species Name	Habit	% freq 0.01 m^2	% freq 0.1 m^2	% freq 1 m^2	% freq 10 m^2
Medicago lupulina	Forb	11.39	27.85	50.63	77.22
Poa sp	Gram	22.78	30.38	49.37	62.03
Equisetum laevigatum	Gram	5.06	15.19	39.24	60.76
Symphyotrichum adscendens	Forb	6.33	16.46	39.24	59.49
Erigeron flagellaris	Forb	6.33	25.32	37.97	51.90
Taraxacum officinale	Forb	0.00	7.59	25.32	51.90
Poa palustris	Gram	18.99	22.78	35.44	44.30
Heterotheca villosa	Shrub	1.27	15.19	29.11	43.04
Achillea millefolium	Forb	5.06	7.59	13.92	34.18
Salix exigua	Shrub	2.53	8.86	21.52	32.91
Plantago lanceolata	Forb	0.00	1.27	6.33	29.11
Agrostis stolonifera	Gram	11.39	15.19	18.99	25.32
Artemisia ludoviciana	Forb	1.27	2.53	8.86	25.32
Trifolium repens	Forb	2.53	5.06	11.39	24.05
Gutierrezia sarothrae	Shrub	1.27	3.80	8.86	24.05
Eleocharis palustris	Gram	1.27	2.53	7.59	22.78
Melilotus sp.	Forb	1.27	3.80	10.13	21.52
Melilotus alba	Forb	0.00	1.27	3.80	20.25
Melilotus officinalis	Forb	0.00	2.53	6.33	18.99
Mentha arvensis	Forb	1.27	1.27	3.80	18.99
Bromus tectorum	Gram	6.33	7.59	11.39	17.72
Equisetum arvense	Gram	2.53	5.06	6.33	17.72
Rosa woodsii var ultramontana	Shrub	0.00	2.53	6.33	17.72
Plantago major	Forb	0.00	0.00	6.33	15.19
Juncus baliticus var. montanus	Gram	1.27	1.27	5.06	15.19
Ipomopsis aggregata	Forb	0.00	0.00	3.80	15.19
Quercus gambelii	Shrub	0.00	0.00	5.06	13.92
Rumex crispus	Forb	0.00	0.00	2.53	12.66
Pseudotsuga menziesii	Tree	0.00	0.00	1.27	11.39
Rudbeckia lacinata	Forb	0.00	0.00	1.27	11.39
Elymus elymoides	Gram	0.00	1.27	6.33	10.13
Senecio lobed	Forb	0.00	0.00	3.80	10.13
Prunella sp	Forb	0.00	1.27	2.53	10.13

Table 12. Species found in >10 percent of 135 quadrats at Coyote Gulch, Glen Canyon National Recreation Area, in descending order of frequency in the 10-m^2 quadrats. Eight out of 62 species (12.9 percent) total are included in the table. Shading indicates the quadrat size in which a species reached >30 percent frequency. Additional species are included as indicators of relatively common species that are not adequately captured by the tested quadrat sizes. Gram=graminoid habit.

Species Name	Habit	% freq 0.01 m^2	% freq 0.1 m^2	% freq 1 m^2	% freq 10 m^2
Bromus tectorum	Gram	11.11	20.00	41.48	59.26
Melilotus spp	Forb	2.96	5.19	14.07	25.93
Salix exigua	Shrub	0.00	1.48	2.22	20.74
Equisetum hyemale	Gram	3.70	7.41	15.56	18.52
Chrysothamnus nauseosus	Shrub	0.00	0.00	2.96	17.04
Artemisia ludoviciana ssp. mexicana	Forb	0.74	2.96	6.67	16.30
Baccharis salicifolia	Shrub	0.00	0.00	0.00	11.11
Elymus canadensis	Gram	0.00	0.74	4.44	10.37

Table 13. Species found in >10 percent of 93 quadrats at Courthouse Wash, Arches National Park, in descending order of frequency in the 10-m^2 quadrats. Fourteen out of 51 species (27.5 percent) total are included in the table. Additional species are included as indicators of relatively common species that are not adequately captured by the tested quadrat sizes. Gram=graminoid habit.

Species name	Habit	% freq 0.01 m^2	% freq 0.1 m^2	% freq 1 m^2	% freq 10 m^2
Equisetum hyemale	Gram	3.23	9.68	19.35	26.88
Heterotheca villosa	Shrub	1.08	6.45	12.90	22.58
Euthamia occidentalis	Forb	1.08	2.15	7.53	21.51
Chrysothamnus nauseosus	Shrub	0.00	0.00	2.15	21.51
Juncus balticus	Gram	4.30	6.45	15.05	20.43
Elymus canadensis	Gram	1.08	4.30	12.90	20.43
Populus fremontii	Tree	0.00	1.08	3.23	18.28
Achnatherum hymenoides	Gram	0.00	1.08	6.45	16.13
Sporobolus cryptandrus	Gram	1.08	2.15	5.38	13.98
Distichlis spicata	Gram	1.08	6.45	9.68	12.90
Senecio spartioides	Forb	0.00	1.08	5.38	12.90
Unknown Aster, blue	Forb	0.00	1.08	2.15	12.90
Melilotus species	Forb	0.00	1.08	4.30	11.83
Salix exigua	Shrub	0.00	0.00	0.00	11.83

Species area curves for herbaceous and shrub species were generated for the two largest quadrat sizes (1 m^2 and 10 m^2), based on a species' presence in the sample quadrat. In this analysis, we excluded all quadrats that fell outside of the riparian zone (that is, were dominated by upland plant species). As would be expected, the number of species increases more rapidly for the 10-m^2 quadrats if equal numbers of quadrats are sampled (fig. 7). This was especially true at BAND and CACH, where species richness was highest and none of the curves have begun to asymptote. Sampling efficiency is also sensitive to rare species, and figure 8 illustrates the effect of eliminating species with only a single occurrence. These results suggest that with the exception of rare species, both the 1-m^2 and 10-m^2 quadrats did an adequate job of characterizing species richness at sites with comparatively low numbers of species (ARCH and GLCA; table 8), whereas only the 10-m^2 quadrats adequately characterized species richness at sites with higher numbers of species (BAND and CACH; table 8).

Sampling effort was measured in minutes based on estimates of three components: (1) time to layout transects, (2) time to move among quadrats, and (3) time to sample quadrats. Average measured transect setup time was 40 minutes per transect with 11 transects at each site. Average travel time between quadrats was 0.5 minutes per quadrat. We measured total time to sample each fully nested (0.01, 0.1, 1, and 10 m^2) quadrat set and calculated an average time per nested set at each site. We then measured relative time for the different size quadrats on a trial set of nested quadrats to determine a set of proportions (summing to 1) that break the average time for a nested quadrat down into the average time for each quadrat size.

We did this by dividing the total time required to setup all transects at a site by the full number of quadrats we sampled at that site in order to get a transect-setup time per quadrat. We then constructed species-effort curves using a calculation of number of quadrats multiplied per quadrat time (transect setup, travel between quadrats, and quadrat sampling time). Using this portioning of time per quadrat, the ratios between effort for 10-m^2 versus 1-m^2 quadrats was 1.96, 2.14, 1.91, and 2.49 for each of the four sites, with an average across sites of 2.12. Based on this formulation of sampling effort, the 10-m^2 quadrats were somewhat more effective at characterizing number of species at three of the sites (ARCH, BAND and CACH) when rare species were included (fig. 9). With the exclusion of rare species, the 1-m^2 and 10-m^2 quadrats were comparable in accumulating species per sampling, except at BAND, the most species-rich site (fig. 10).

Shrub Cover in the 10-m^2 Quadrats

Shrub cover, summarized in table 14, was evaluated for the 10-m^2 quadrats. Similar to frequencies of herbaceous species, shrub cover was highly variable both by species and by site because of the naturally patchy distribution of shrubs in the riparian zone. Our results suggest that the number of 10-m^2 quadrats at a site are sufficient to characterize only a few riparian shrub species, with relatively uniform cover, at 20 percent precision. This was especially true at GLCA, which had the greatest number of quadrats distributed across a relatively wide flood plain. We also estimated shrub cover using the line-intercept technique and a comparison of these two methods is provided in the *Line Intercept* section below.

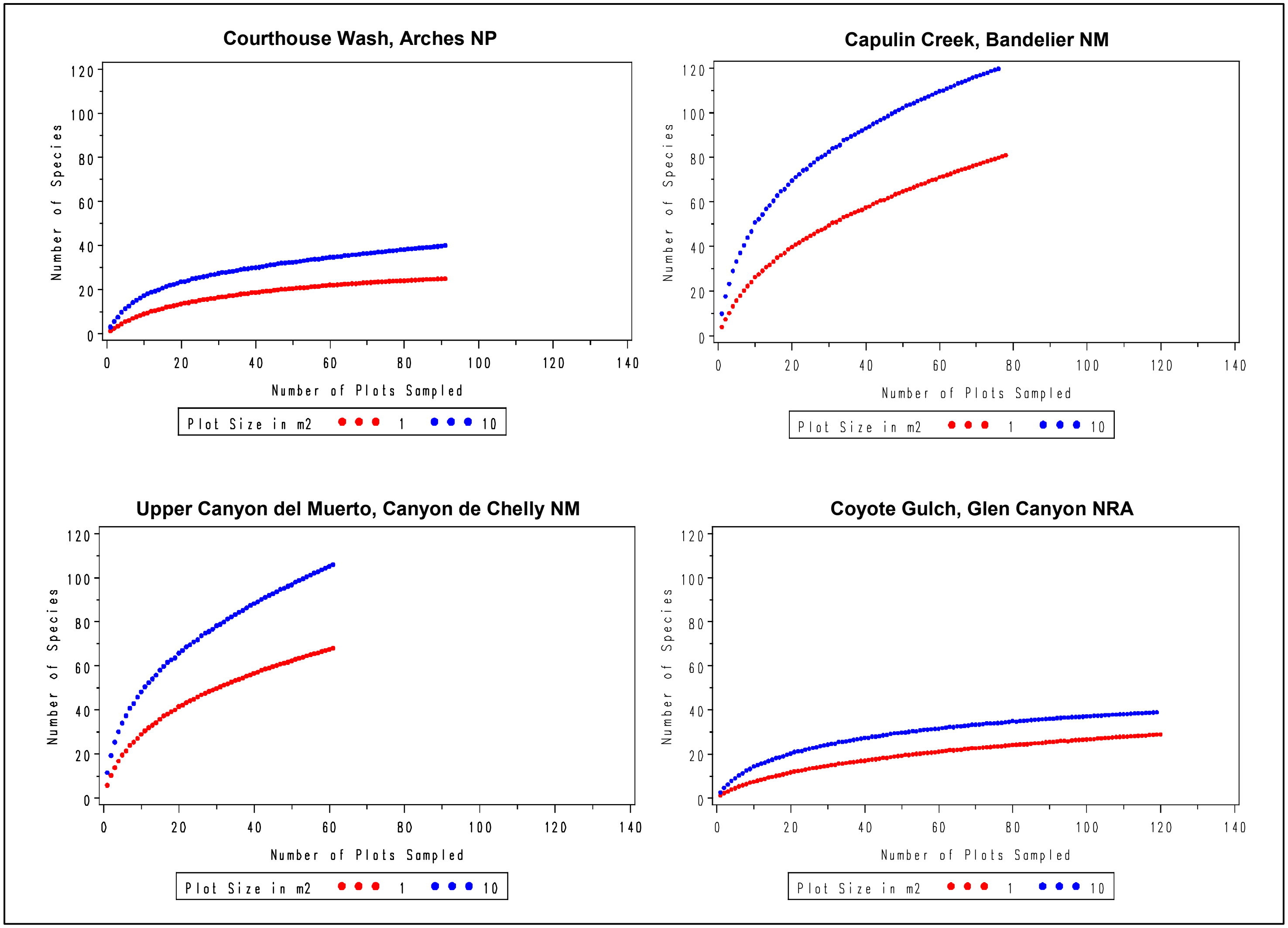

Figure 7. The number of herbaceous and shrub species encountered versus the number of quadrats sampled, for two quadrat sizes at each of the four pilot sites. Upland quadrats are excluded. Quadrat sizes are as follows: red=1.0 m^2 and blue=10 m^2.

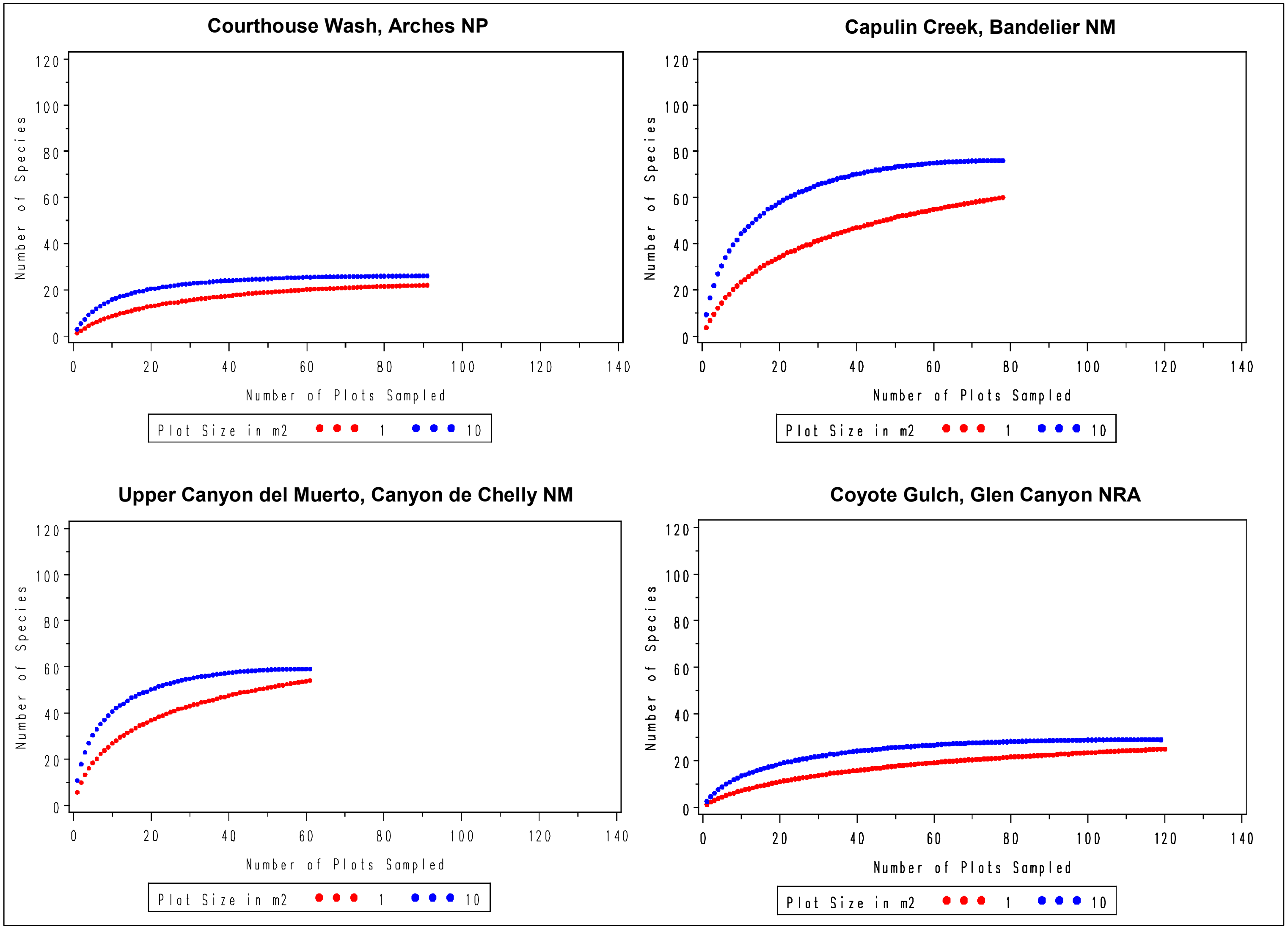

Figure 8. The number of herbaceous and shrub species encountered versus the number of quadrats sampled, for two quadrat sizes at each of the four pilot sites. Upland quadrats and species with only one occurrence are excluded. Quadrat sizes are as follows: red=1.0 m^2 and blue=10 m^2.

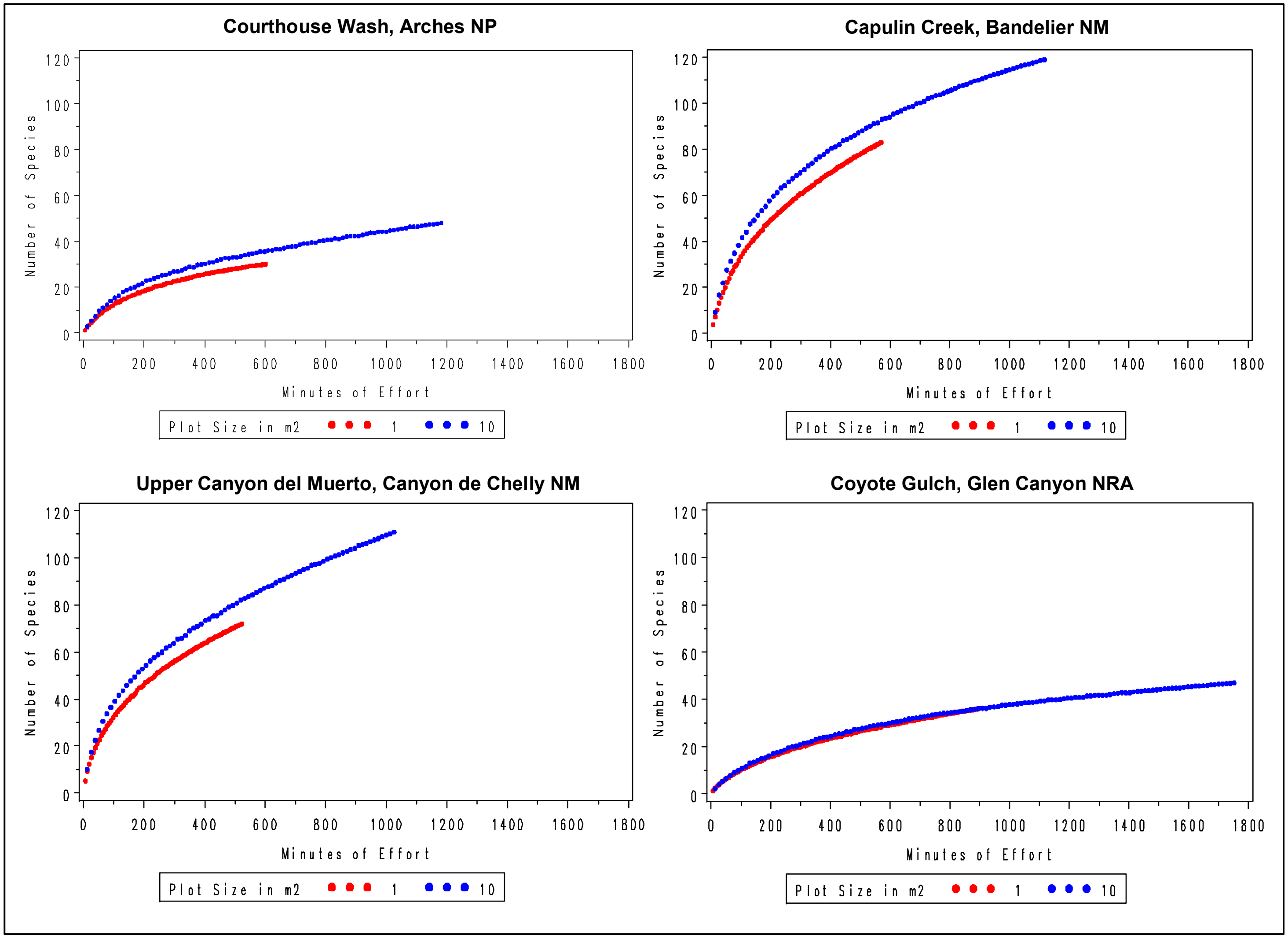

Figure 9. The number of herbaceous and shrub species encountered versus minutes of sampling effort for two quadrat sizes at each of the four pilot sites. Sampling effort is based on time to layout transects, time to move between quadrats, and time to sample quadrats. Upland quadrats are excluded. Quadrat sizes are as follows: red=1.0 m^2 and blue=10 m^2.

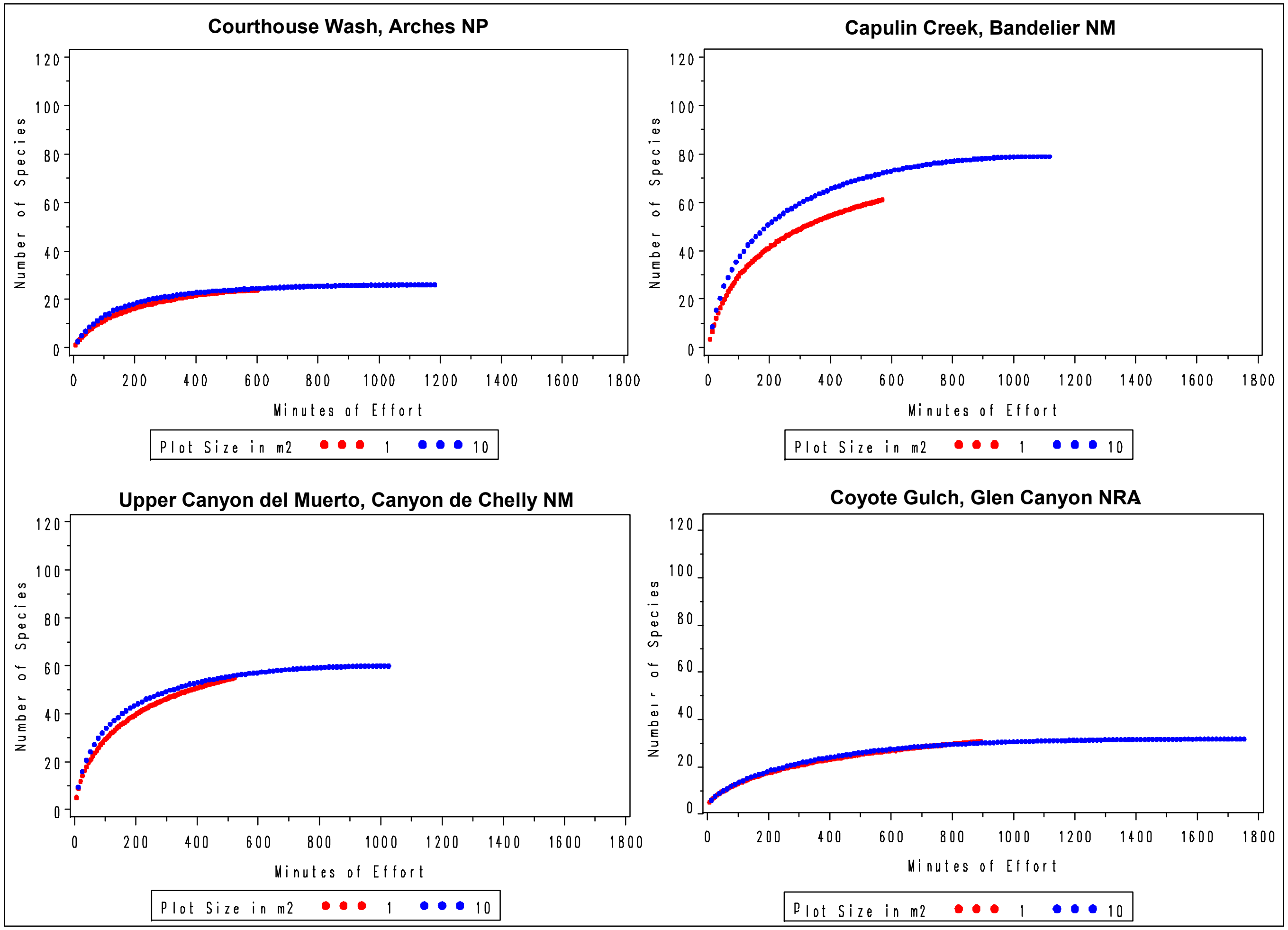

Figure 10. The number of herbaceous and shrub species encountered versus minutes of sampling effort for two quadrat sizes at each of the four pilot sites. Sampling effort is based on time to layout transects, time to move between quadrats, and time to sample quadrats. Upland quadrats and species with only one occurrence are excluded. Quadrat sizes are as follows: red=1.0 m^2 and blue=10 m^2.

Table 14. Percent cover of all shrub species, by site, from the 10-m^2 quadrats and sample size (quadrats) required to achieve 10 and 20 percent precision in estimates of site-level means.

Site (total no. of quadrats)	Species	n*	Mean	Std. dev.	Lower 95% CI	Upper 95% CI	CV	Sample size (by precision)	
								10%	20%
ARCH (93)	CHRNAU	23	2.33	3.14	0.97	3.69	135.11	698	177
	SALEXI	11	14.32	24.05	-1.84	30.47	167.96	1084	274
	BACSAL	3	5.17	4.04	-4.87	15.21	78.22	237	62
	CHRVIS	1	7.50				0.00		
	ARTTRI	1	0.50				0.00		
BAND (88)	FORNEO	40	15.70	21.47	8.83	22.57	136.74	719	183
	PTETRI	8	2.63	6.01	-2.40	7.65	228.97	2007	504
	RHUTRI	8	3.13	3.62	0.10	6.15	115.93	517	131
	ROSWOO	11	9.23	7.17	4.41	14.04	77.71	235	61
	QUEGRI	2	4.00	4.95	-40.47	48.47	123.74	591	150
	ARTTRI	1	7.50				0.00		
CACH (79)	SALEXI	26	19.23	22.29	10.23	28.23	115.89	519	132
	CHRDEP	7	3.50	3.74	6.96	0.04	106.90	442	113
	GUTSAR	19	1.61	2.62	0.34	2.87	163.37	1018	257
	RHUTRI	7	11.21	12.92	-0.73	23.16	115.20	513	130
	ROSWOO	14	3.00	3.48	0.99	5.01	116.02	520	132
	CORSER	1	7.50				0.00		
	SYMORE	2	4.00	4.95	-40.47	48.47	123.74	591	150
	SALLAS	4	13.25	16.50	-13.01	39.51	124.53	599	152
	ARTTRI	1	0.50				0.00		
GLCA (135)	RHUTRI	3	11.83	9.82	-12.55	36.22	82.94	268	69
	BACSAL	19	11.50	10.26	6.56	16.44	89.20	309	79
	SALEXI	28	11.46	12.02	6.80	16.13	104.87	426	109
	CHRNAU	23	5.63	5.05	3.45	7.81	89.66	312	80

*Number of quadrats in which a species occurred.

For each site, we also evaluated the distribution of total shrub cover by geomorphic surface (table 15). Each 10-m^2 quadrat was assigned to a surface based on the distribution of surfaces recorded along each transect as line-intercept data. If approximately 75 percent of a quadrat fell on a single surface, then it was considered representative of that surface. Quadrats with less than 74 percent cover on any one surface were considered transitional and were grouped accordingly in table 15. Total shrub cover was sparse at all the sites and distributed unevenly across geomorphic surfaces. Only the flood plain had shrub cover at all four sites. The active channel shelf, typified by *Salix* and/or *Baccharis* species cover, also had relatively high or frequent shrub cover at all sites, except CACH. Here, upstream flow regulation appears to have greatly limited shrub recruitment on existing geomorphic surfaces. Again, the inherently patchy and non-uniform distribution of shrub cover along the relatively narrow riparian corridors at the pilot sites contributes to high variability in shrub cover estimates. This is especially true when analyzed at the scale of geomorphic surfaces, most of which were less than 10 m in width (figs. 11–14), and very high sample sizes were required for cover estimates with 20 percent precision. Only on the relatively wide flood-plain surfaces at GLCA did the number of flood-plain quadrats exceed the number of quadrats estimated as necessary for a 20 percent level of precision (table 15).

Nested Quadrats and Geomorphic Surfaces

To track the distribution of systematically placed nested quadrats by geomorphic surface, we recorded the occurrence of each 1-m^2 quadrat by surface at each site (table 16). The presence of specific surface types varied by site, and the number of quadrats per surface was a function of the percent of the bottomland each surface occupied. For example, Coyote Gulch, at GLCA is a comparatively wide alluvial valley containing a large number of quadrats on the flood plain. Conversely, riparian terraces were narrow, infrequent or absent at some sites resulting in very few occurrences of quadrats on this surface type. Transitional surfaces (table 2), which were typically narrower and less common than the dominant surfaces, had even fewer occurrences (table 16).

Because nested quadrats are placed systematically along transects, a certain number of quadrats inevitably span two or more different surface types. Table 17 presents the number and percent of all 1-m^2 and 10-m^2 quadrats at each site that straddled two or more geomorphic surfaces. Approximately 10 to 15 percent of the 1-m^2 quadrats straddled two or more surfaces compared with 25 to 30 percent of the 10-m^2 quadrats. Of these, more than half of both quadrat sizes included two or more surfaces when quadrats were place in or adjacent to the channel, where surfaces tended to be narrower (see Geomorphic Surface Cover section below).

Geomorphic Surface Cover

Figures 11–14 summarize the distribution of the most common geomorphic surfaces across the four pilot sites. Each site also had infrequent or transitional surfaces, which are described below. All sites were dominated by the same general geomorphic surface features, in different proportions. Depositional bars were relatively small at all sites, typically narrower than 5 m. The flood plain (see fig. 1) was the dominant surface feature at three sites, ranging from an average of 6 m in width at CACH to an average of 15 m at GLCA. At BAND, a relatively narrow channel, incised into recent alluvial deposits resulting from the Dome wildfire, averaged only 3 m in width. Riparian terraces and terraces average 7 m and 5 m in width at CACH and BAND, respectively.

Table 15. Percent total shrub cover, by geomorphic surface, from the 10-m^2 quadrats and sample size (quadrats per surface) required to achieve 20 percent precision in estimates of surface-level means. Parentheses after site code indicate the total number of quadrats at each site.

Surface	ARCH (93)				BAND (88)				CACH (79)				GLCA (135)			
	n*	Mean	SD	n for 20%	n	Mean	SD	n for 20%	n	Mean	SD	n for 20%	n	Mean	SD	n for 20%
Active channel shelf	13	6.82	18.62	716	6	0.77	2.14	740					7	3.00	5.39	313
Channel									1	1.59						
Channel bed	9	0.05			3				1				13	1.33	4.06	895
Cut bank					1	3.43										
Depositional bar	2	0.05														
Flood plain	19	2.80	7.73	732	32	5.66	5.02	78	42	9.57	15.01	239	83	8.69	5.34	39
Flood plain (lower)	20	0.39	1.12	793												
Flood plain (upper)	16	1.05	2.45	526												
Flood-plain bank	2	0.73	2.25	913									3	0.73	2.15	834
Flood-plain bank (lower)	2	1.36	3.03	481												
Flood-plain bank (upper)	1															
Riparian terrace	2	0.68							12	1.31	2.4	325				
Riparian terrace riser																
Terrace					21	3.55	4.75	175	1				1	0.05		
Terrace riser					8				8	4.15	12.36	852	12	1.77	2.92	264
Transitional quadrats	7	1.14	3.05		17	1.09	2.57		14	15.41	19.45		12	3.58	7.39	

*Total number of quadrats on each geomorphic surface.

Table 16. The distribution of 1-m^2 quadrats for geomorphic surfaces at each site. Parentheses under site code indicate total number of quadrats. Note that not all surfaces were present at all sites.

Dominant surfaces	ARCH (n=93)	BAND (n=88)	CACH (n=79)	GLCA (n=135)
	Number of 1-m^2 quadrats			
Active channel shelf	18	19		11
Channel bed	11	1	10	15
Depositional bar	1			
Flood plain	20	33	48	83
Flood plain (lower)	20			
Flood plain (upper)	17			
Riparian terrace	2		7	
Terrace		23		3
Transitional surfaces	**Number of 1-m^2 quadrats**			
Bedrock				1
Cutbank		1		
Flood-plain bank (lower)	2			
Flood-plain bank (upper)	2	1		9
Riparian terrace riser			6	
Terrace riser		8	8	12

Table 17. Number and percent of all 1-m^2 and 10-m^2 quadrats at the four riparian sites sampled in the 2006 pilot that straddled two or more geomorphic surfaces. Of those quadrats intersecting two or more surfaces, the number and percent of those quadrats that were located adjacent to the channel also are tabulated.

Site	Total number of quadrats per site	Number (percent) of quadrats straddling two or more geomorphic surfaces		Number (percent) of quadrats straddling two or more geomorphic surfaces adjacent to channel	
		1 m^2	10 m^2	1 m^2	10 m^2
ARCH	93	9 (9.6)	24 (25.8)	6 (66.7)	12 (50.0)
BAND	88	14 (15.9)	28 (31.8)	10 (71.4)	16 (57.1)
CACH	79	12 (15.2)	23 (29.1)	10 (83.3)	15 (65.2)
GLCA	135	18 (13.3)	31 (22.9)	9 (50.0)	13 (41.9)

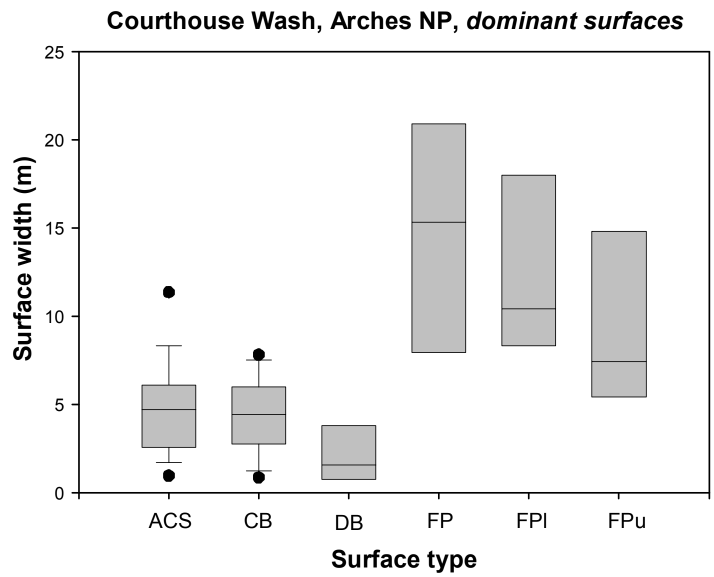

Figure 11. Average width of major geomorphic surface types as measured by line intercept along 11 transects at ARCH. Surface types are as follows: ACS=active channel shelf, CB=channel bed, DB=depositional bar, FP=flood plain, FPl=lower flood plain, FPu=upper flood plain.

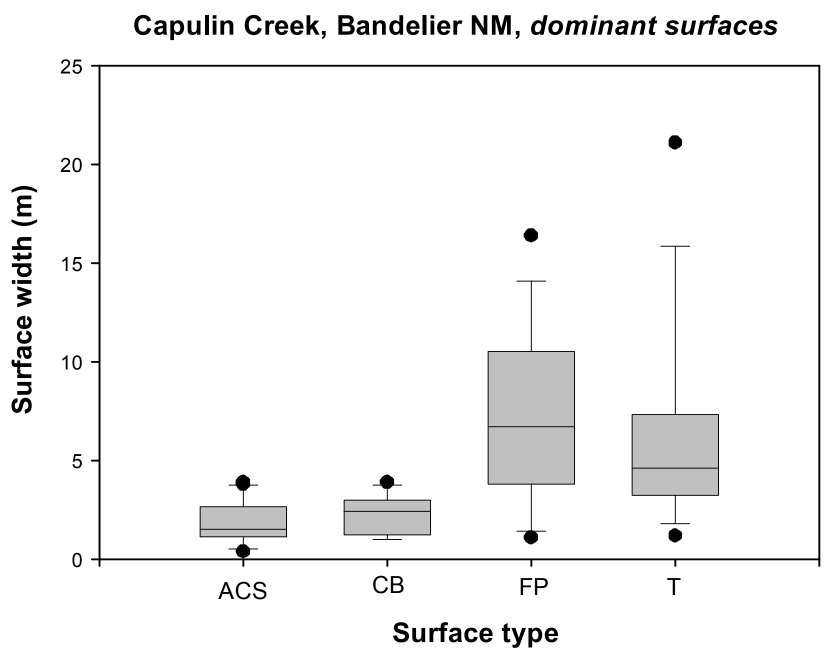

Figure 12. Average width of major geomorphic surface types as measured by line intercept along 11 transects at BAND. Surface types are as follows: ACS=active channel shelf, CB=channel bed, FP=flood plain, T=terrace.

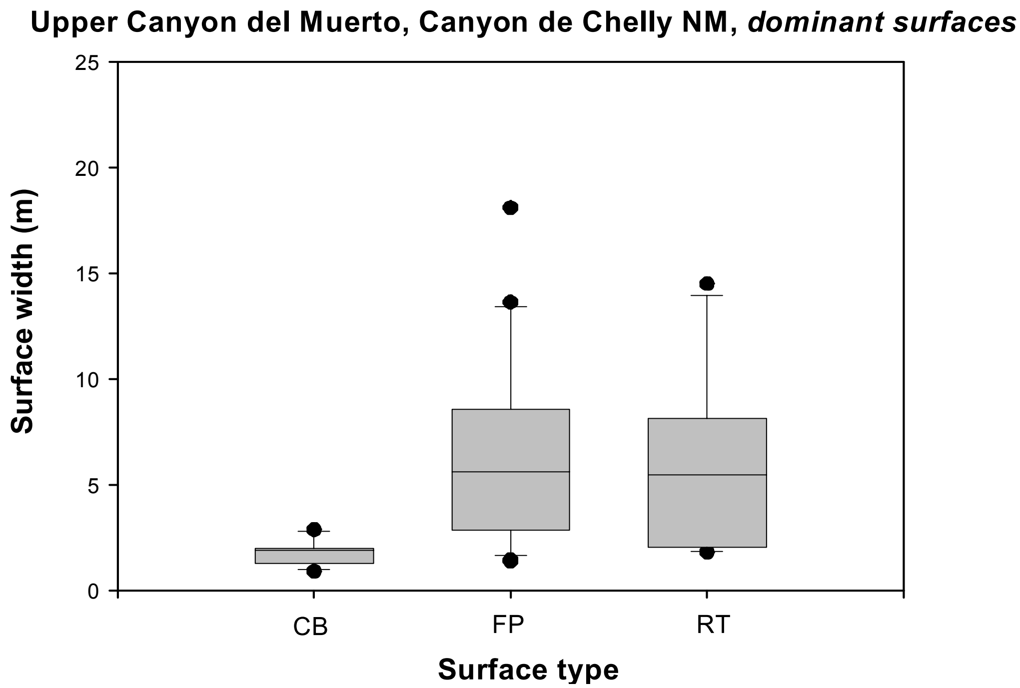

Figure 13. Average width of major geomorphic surface types as measured by line intercept along 11 transects at CACH. Surface types are as follows: CB=channel bed, FP=flood plain, RT=Riparian terrace.

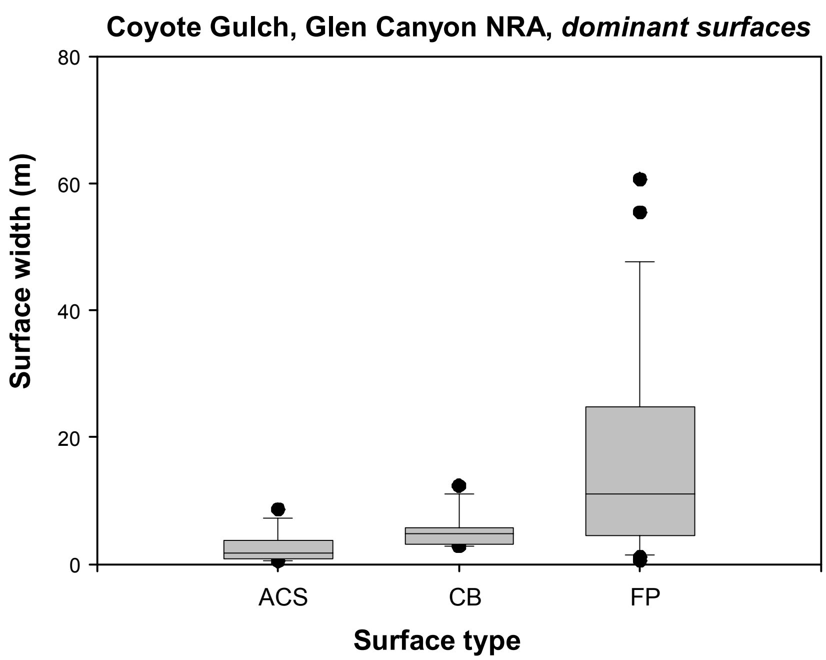

Figure 14. Average width of major geomorphic surface types as measured by line intercept along 11 transects at GLCA. Surface types are as follows: ACS=active channel shelf, CB=channel bed, FP=flood plain. Note scale of Y-axis differs from figures for the other sites.

Transitional or infrequent geomorphic surfaces are presented in table 18. With the exception of terrace risers, transitional surfaces were encountered less frequently than the dominant surface types (table 2), and they were relatively narrow. Trails were notable features at CACH and GLCA. Because head pins are located on upland surfaces when possible, terraces or terrace risers are expected to represent a small proportion of each transect, except at ARCH where the riparian zone was constrained within a narrow bedrock canyon.

Line Intercept

Total Woody Cover

The line-intercept method was used to measure cover of woody trees and shrubs as well as geomorphic surfaces. Cover is expressed as a proportion of the total length of the sample transect. Since transects spanned the riparian zone at each site, cover is, in essence, the proportion of the riparian zone or bottomland occupied by a cover type. Across sites, there was notable variability in total cover of woody species (fig. 15, table 19). ARCH and CACH had total covers representing less than half of the riparian zone, whereas GLCA and BAND had mean total covers of 69 percent and 73 percent, respectively.

Total cover was variable, especially at CACH, where one transect had no woody cover, in contrast to other transects that had comparatively high cover values for *Salix exigua*, the dominant woody species at this site. In general, tree cover at CACH was sparse.

Table 18. Number of occurrences and mean width (m) of transitional and infrequent geomorphic surfaces (see table 2) detected using line-intercept method, at each site. Parentheses under site code provide average transect length at each site.

Surface type	ARCH (40.3 m)		BAND (27.0 m)		CACH (23.4 m)		GLCA (60.2 m)	
	n*	mean width (m)	n	mean width (m)	n	mean width (m)	n	mean width (m)
Bedrock							3	1.80
Colluvium							2	2.55
Cutbank			1	3.10				
Flood-plain bank	6	2.29					6	1.79
Flood-plain bank (lower)	2	5.85						
Flood-plain bank (upper)	2	1.75						
Riparian terrace	2	8.33						
Riparian terrace riser	1	1.80			1	1.90		
Upland terrace							1	1.6
Terrace riser			4	7.59	13	2.37	26	2.57
Terrace-slope toe							1	1.80
Trail					9	0.44	1	1.80
Upland							1	1.10

*Number of occurrences during intercept sampling of all 11 transects.

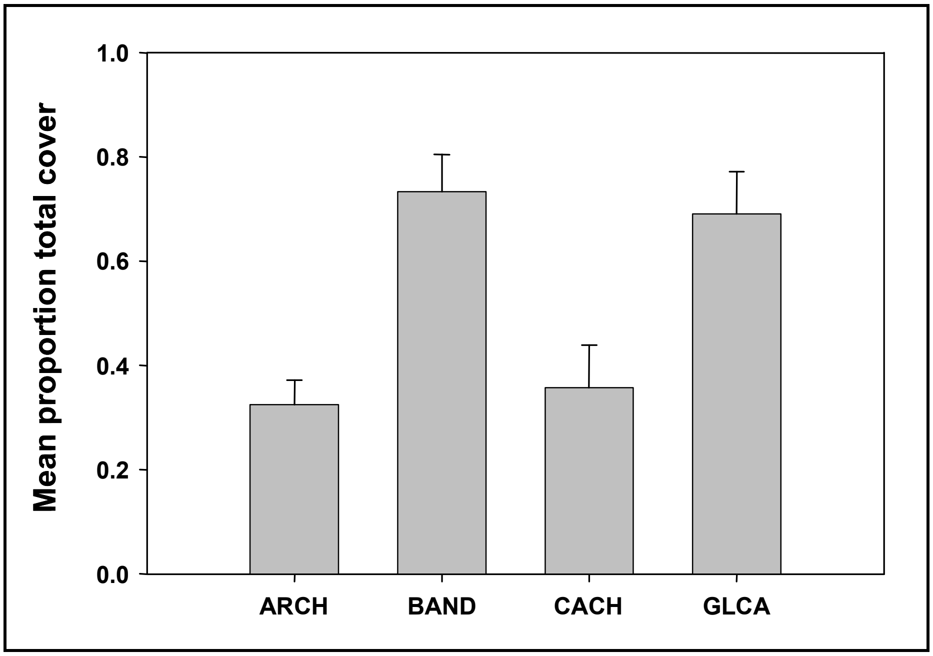

Figure 15. Proportion ± standard error of total woody cover at each site averaged across 11 sample transects from line intercept.

Table 19. Summary of total cover (mean, standard error (SE), and 95% confidence interval (CI)) for woody species across all transects (n=11) at each pilot site sampled.

Site	Number of transects	Mean	Standard deviation	SE Mean	Lower 95% CI	Upper 95% CI
ARCH	11	0.32464	0.15698	0.047330	0.21918	0.43010
BAND	11	0.73357	0.23518	0.070910	0.57557	0.89157
CACH	11	0.35754	0.27108	0.081733	0.17543	0.53966
GLCA	11	0.69034	0.27049	0.081557	0.50862	0.87206

In spite of high overall variability in mean total cover, a plot of the mean and standard error of the mean, recalculated after the addition of each successive and randomly selected transect, indicates that mean total cover, and the variance around that mean, appear to stabilize after the eighth or ninth transect sampled (fig. 16). Thus, the sampling of cover using the line-intercept method at each of the 11 transects in a sample reach provides a reasonably good estimate of total riparian zone woody cover.

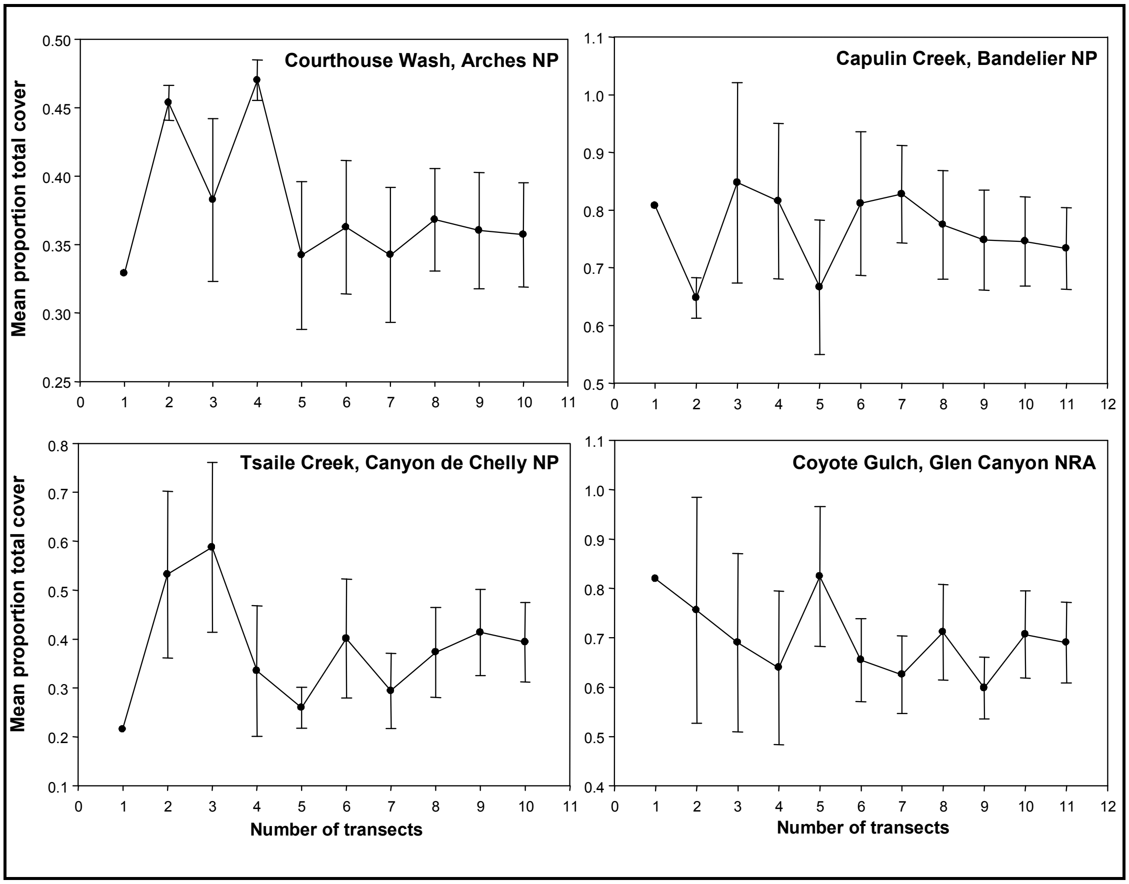

Figure 16. Plot of the mean proportion of the riparian zone with woody cover, as measured by the line-intercept method, along 11 transects at each of the pilot study sites. Mean and standard error of the mean were recalculated with the one-by-one addition of each transect with recorded cover. See table 5 for additional statistics.

Total cover was further broken down by size and height class to reflect vertical structural diversity for trees and shrubs at each site (figs. 17 and 18). All sites show the same general pattern with cover in all size classes; the majority of which occurs in the pole and overstory size classes. BAND had relatively high cover of pole-size alder (*Alnus oblongifolia*), which lined the channel throughout the sample reach and likely represents recruitment following the Dome wildfire in 1996 (Veenhuis, 2002). It was noted, but not recorded, that the reach included five to ten large, dead alder stems that had presumably been killed by fire. GLCA had high cover of overstory cottonwoods, which dominated the wide flood plain at the downstream end of the sample reach. Shrub cover was more variable across sites. CACH had high cover of tall sand bar willow (*Salix exigua*).

Total proportional cover by species across sites also was variable, and this variability was as much a function of the number of transects at which a species occurred as the uniformity of cover across transects where it was encountered (table 20). For example, sand bar willow

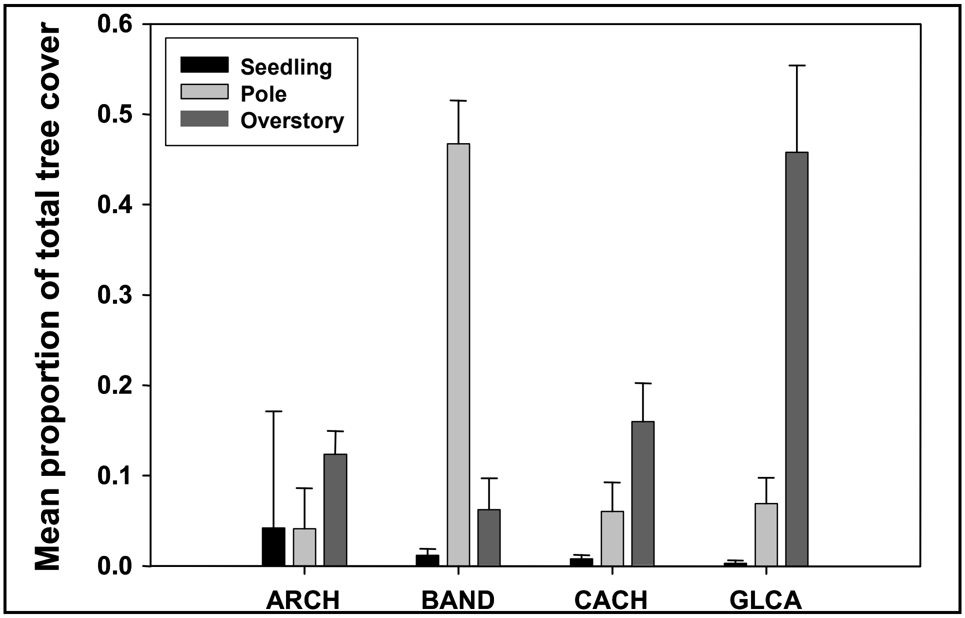

Figure 17. Plot of the mean proportion of the riparian zone tree cover by size class for the four pilot study locations. Error bars are standard error of the mean.

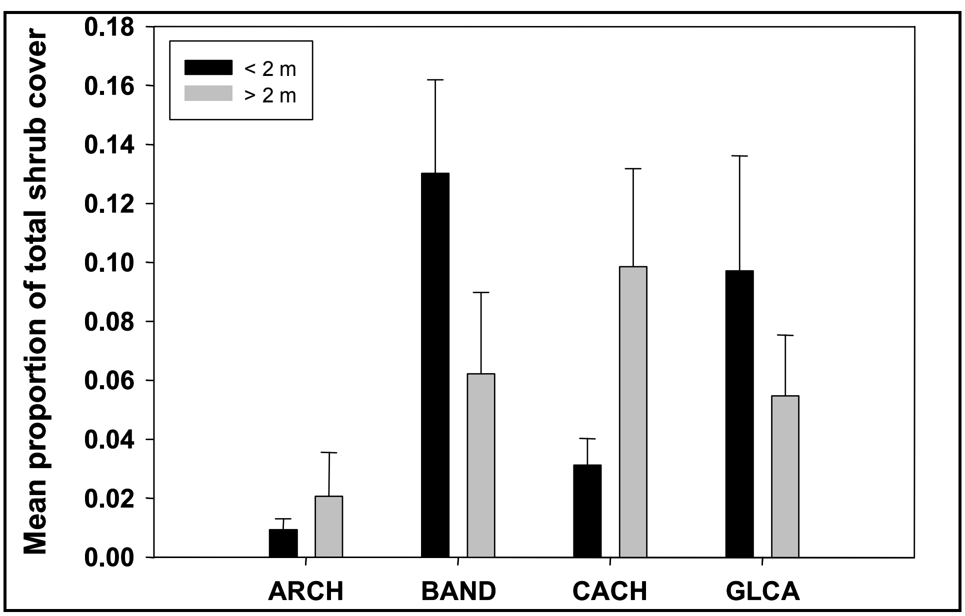

Figure 18. Plot of the mean proportion of the riparian zone shrub cover by height class for the four pilot study locations. Error bars are standard error of the mean.

Table 20. Summary of mean total cover (with 95% confidence interval (CI)) for each woody species (spp) sampled, ranked by the number of transects on which the species occurred.

SPP	Number of occurrences	Mean	Standard deviation	Lower 95% CI	Upper 95% CI	Coefficient of Variation
POPFRE	19	0.39751	0.17556	0.31289	0.48212	44.16
SALEXI	18	0.11021	0.12309	0.049	0.17143	111.69
ACENEG	12	0.13775	0.1338	0.05274	0.22276	97.13
QUEGAM	11	0.0741	0.07163	0.02598	0.12222	96.67
ALNOBL	10	0.3724	0.13141	0.2784	0.46641	35.29
FORNEO	10	0.14906	0.08414	0.08887	0.20925	56.45
SALGOO	9	0.14057	0.11518	0.05204	0.22911	81.94
RHUTRI	8	0.04487	0.05624	-0.00215	0.09189	125.34
ROSWOO	6	0.10087	0.08217	0.01464	0.18711	81.46
BACSAL	5	0.1028	0.07787	0.00611	0.19948	75.75
JUNSCO	5	0.10313	0.08638	-0.00413	0.21038	83.76
CHRDEP	4	0.02428	0.01074	0.00718	0.04137	44.23
JUNMON	4	0.16097	0.16663	-0.10417	0.42611	103.52
PSEMEN	4	0.16447	0.04726	0.08927	0.23966	28.73
PTETRI	3	0.01684	0.01669	-0.02461	0.0583	99.11
BACC	2	0.02232	0.00159	0.008	0.03664	7.12
CHRNAU	2	0.02832	0.01509	-0.10725	0.1639	53.28
PINPON	2	0.28487	0.03724	-0.04968	0.61942	13.07
ARTTRI	1	0.09865	.	.	.	.
BACEMO	1	0.00607	.	.	.	.
FRAANA	1	0.00448	.	.	.	.
JUNOST	1	0.03856	.	.	.	.
PHIMIC	1	0.00627	.	.	.	.
PINEDU	1	0.0129	.	.	.	.
POPDEL	1	0.01119	.	.	.	.
PSME	1	0.0694	.	.	.	.
QUEGR	1	0.04396	.	.	.	.
RAMBET	1	0.01282	.	.	.	.
SALLAE	1	0.24523	.	.	.	.

(*Salix exigua*), which occurred on 18 transects had a high coefficient of variation primarily because it exhibited high cover values on some transects (for example, at CACH) with little or no cover on other transects. In contrast, ponderosa pine, which had a low coefficient of variation, occurred on only two transects (BAND), each as single, large stems with similar crown cover values.

Comparing Line-Intercept Versus 10-m^2 Quadrats for Estimating Shrub Cover

Table 21 compares estimates of mean percent shrub cover from the 10-m^2 quadrat and line-intercept data. Estimates were similar despite relatively high variability in shrub cover. Site, but not method, had a significant effect on mean percent shrub-cover values (table 22). Post hoc tests (Tukey's HSD) indicate that ARCH, which had only sparse shrub cover, was significantly different from the other three pilot sites.

Table 21. Percent shrub cover from the 10-m^2 quadrat and the line-intercept method and sample size (transects) required to achieve 10 and 20 percent precision in estimates of site-level means. In these analyses, quadrat data were first averaged for each transect and then by site.

Site	Method	n	Mean	Standard deviation	Coefficient of variation	Sample size (by precision)	
						10%	20%
ARCH	10-m^2 quadrat	11	5.43	6.54	120.44	558	140
	intercept	11	3.00	5.16	171.82	1137	285
BAND	10-m^2 quadrat	11	11.09	8.74	78.8	239	60
	intercept	11	18.98	10.83	57.08	128	34
CACH	10-m^2 quadrat	11	9.55	9.12	95.48	353	91
	intercept	11	12.97	12.74	98.29	374	96
GLCA	10-m^2 quadrat	11	9.05	5.11	56.51	125	34
	intercept	11	15.16	17.84	117.65	535	136

Table 22. Analysis of variance for effects of site and sampling method on percent shrub-cover values. Only site had a significant effect on percent cover values. The effects of method and the interaction of site and method were nonsignificant. SS = sums squares; df = degrees of freedom; MS = mean squares.

Effect	SS	df	MS	F	p
Site	1326.68	3	442.23	4.86	0.0038
Method	179.90	1	179.90	1.98	0.16
Site * method	294.83	3	98.28	1.08	0.36
Error	7194.77	79	91.07		

Comparing Line-Intercept and Survey Data

Figure 19 compares the geomorphic surface data, collected using the line-intercept method, to the total station survey of transect nine at BAND. The active channel shelf, as defined here, has an average elevation of 0.6 m relative to the channel thalweg. In contrast, the flood plain has an average elevation of 1.5 m above the thalweg. Defining mean elevations for surface features and monitoring surface- and ground-water stage elevations over time, allows for establishment of quantitative expressions that link and define surface features in terms of surface and ground-water dynamics. For example, where these relationships have been quantified, active channel shelves are typically inundated from 5 to 25 percent of the time and flood plains are inundated by floods with average return times of 1 to 3 years (Hupp and Osterkamp 1985; Hupp, 1988).

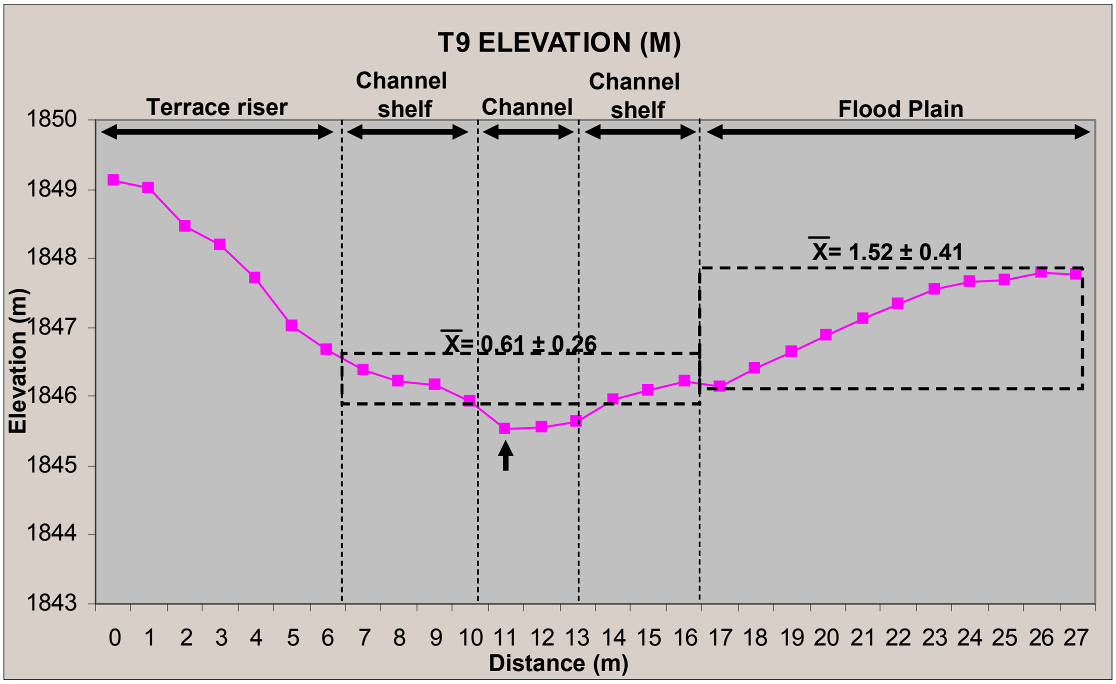

Figure 19. Overlay geomorphic surfaces determined from line-intercept sampling on topographic survey information at BAND, transect 9.

Belt Transects and Riparian Forest Structure

Comparing Tree Quadrats Versus Belt Transects

The results of a comparison between estimates of stand structure using 5-m × 20-m tree quadrats versus 10-m-wide belt transects, are summarized in table 23. The comparison, based on two transects at BAND, makes clear that estimates of density for quadrats and belt transects are very close for both transects as is the estimate of basal area (BA) for transect 1. The higher estimate of BA at transect 7 resulted from the inclusion of a single large ponderosa pine in the quadrat. Based on the largely comparable results, and the fact that quadrats took an average of 45 minutes longer to setup, the decision was made to use belt transects to estimate riparian forest-stand structure for the remainder of the transects at BAND, as well as for the other pilot sites.

Table 23. Comparison of sampling measures and sampling times for riparian forest-stand structure, using 5-m × 20-m tree quadrats versus 10-m wide belt transects. The comparison was made at two transects within the sampling reach of Capulin Creek, BAND.

Sampling metrics	Quadrat-T1	Belt-T1	Quadrat-T7	Belt-T7
Basal area (m^2/ha)	0.55	0.62	0.92	0.36
Density (stems/ha)	0.19	0.17	0.18	0.18
Setup time (total, min)	00:60	-	00:28	-
Sample time (total, min)	00:18	00:20	00:11	00:13

Comparing 10-m Versus 20-m Wide Belt Transects

Figure 20 compares estimates of mean basal area and stem density, respectively, at ARCH and GLCA, where we made direct comparisons between 10-m and 20-m belt transects. These estimates appear comparable across a range of basal areas and stem density values. The sampling efficiency of 10-m and 20-m-wide belt transects were next compared statistically. Table 24 provides results from a sign-rank test comparing estimates of basal area and stem density, based on measurements from 10-m and 20-m belt transects. We used the more conservative sign-rank test because it is more appropriate for data that are collected using repeated measures. In addition to comparability of estimates for basal area and stem density, 10-m belts took an average of 15 minutes to sample compared to an average to 31 minutes for the 20-m belts (table 25).

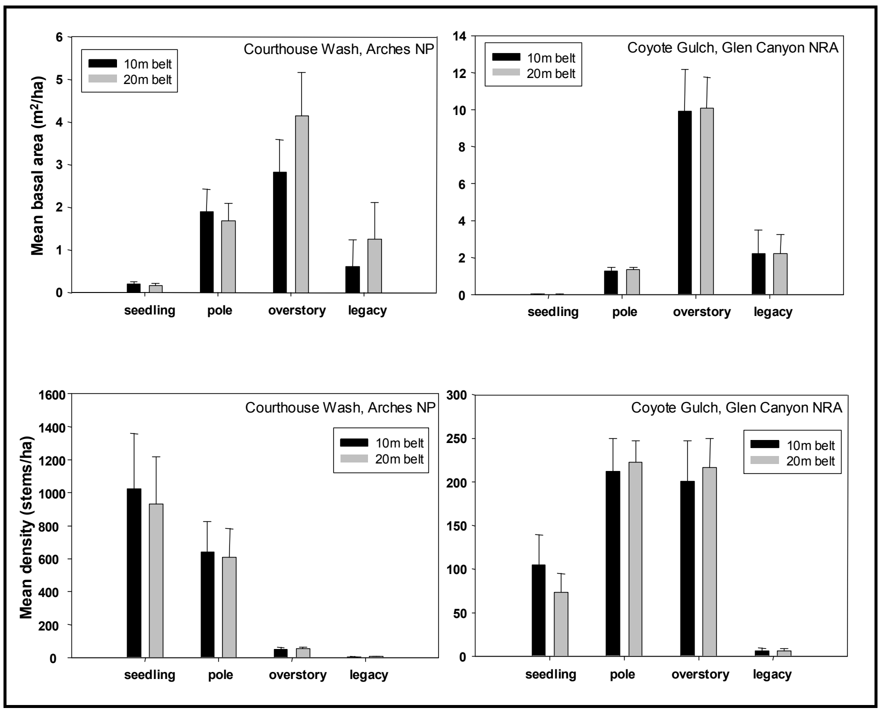

Figure 20. Direct comparisons of mean basal area (m^2/ha) and stem density (stems/ha) as measured in 10-m and 20-m belt transects at ARCH and GLCA.

Table 24. Results of a nonparametric signed-rank test comparing estimates of tree basal area and stem density obtained using 10-m and 20-m wide belt transects.

Site	Tree basal area (m^2/ha)		Tree stem density (stems/ha)	
	Signed-rank statistic, difference	p-value of signed-rank statistic	Signed-rank statistic, difference	p-value of signed-rank statistic
ARCH	15.0	0.20605	-12.5	0.23242
GLCA	-5.5	0.62500	-7.5	0.49219

Table 25. Summary of sampling times for 10-m versus 20-m belt transects for estimating riparian forest-stand structure.

Belt size (m)	Site	Number of transects	Total time	Mean	Standard deviation	SE Mean
10	ARCH	10	2:53:30	0:17:21	0:12:32	0:03:58
	BAND	10	2:15:00	0:13:30	0:03:04	0:00:58
	GLCA	11	2:34:30	0:14:03	0:06:54	0:02:05
20	ARCH	10	5:47:00	0:34:42	0:25:04	0:07:55
	GLCA	11	5:09:00	0:28:05	0:13:49	0:04:10

Overall Results—10-m Belt Transects

Stand structure across all pilot sites is summarized for basal area (fig. 21) and stem density (fig. 22) using data from the 10-m belt transects. Stem-basal area varies widely across stem-size classes both within and among sites. In general, basal area is greatest in the overstory-size class with many large cottonwoods at GLCA accounting for nearly five times the basal area compared with the other sites (fig. 21). At BAND, basal area in the pole and legacy tree-size classes exceeds that at the other sites; although variance is high, especially for legacy trees. The comparatively high basal area for legacy-size trees (>50 cm, dbh) at BAND is the result of a few very large ponderosa pines. Whereas ponderosa pine occupies upland sites across the Colorado Plateau, they do occasionally occur on flood-plain and riparian terrace surfaces throughout the region. High pole-size-class basal area at BAND resulted from high densities of alder stems (fig. 22), which, as noted earlier, likely established following the Dome wildfire in 1996. Finally, comparatively high densities of seedling and pole-size stems at ARCH, suggest that there has been relatively recent active recruitment of stems at this site. This pattern contrasts with CACH and GLCA, where low densities of seedlings and poles indicate that there is little active recruitment at these sites.

Table 26 summarizes basal area data for pole-size trees by site. Both GLCA and CACH exhibit high variability in basal area of this size class, but the large number of poles at ARCH and BAND, due to relatively recent recruitment events, contributed to low variability at these sites. At CACH, only 2 percent of the pole-size trees captured in the 10-m belt were riparian species. Douglas fir (*Pseudotsuga menziesii*), pinyon pine (*Pinus edulis*), and *Juniperus* species account for the majority of the pole basal area at CACH. Table 27 provides species-specific information by site.

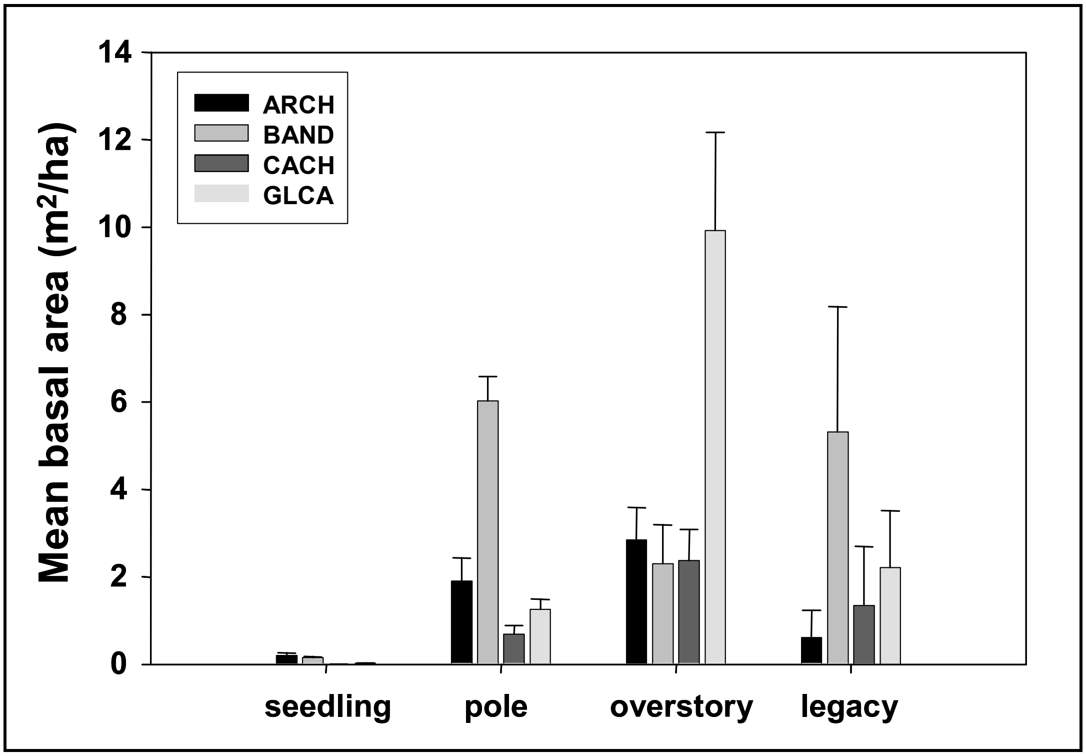

Figure 21. Mean ± standard error (SE) basal area (m^2/ha), by tree-size class, at all pilot sites.

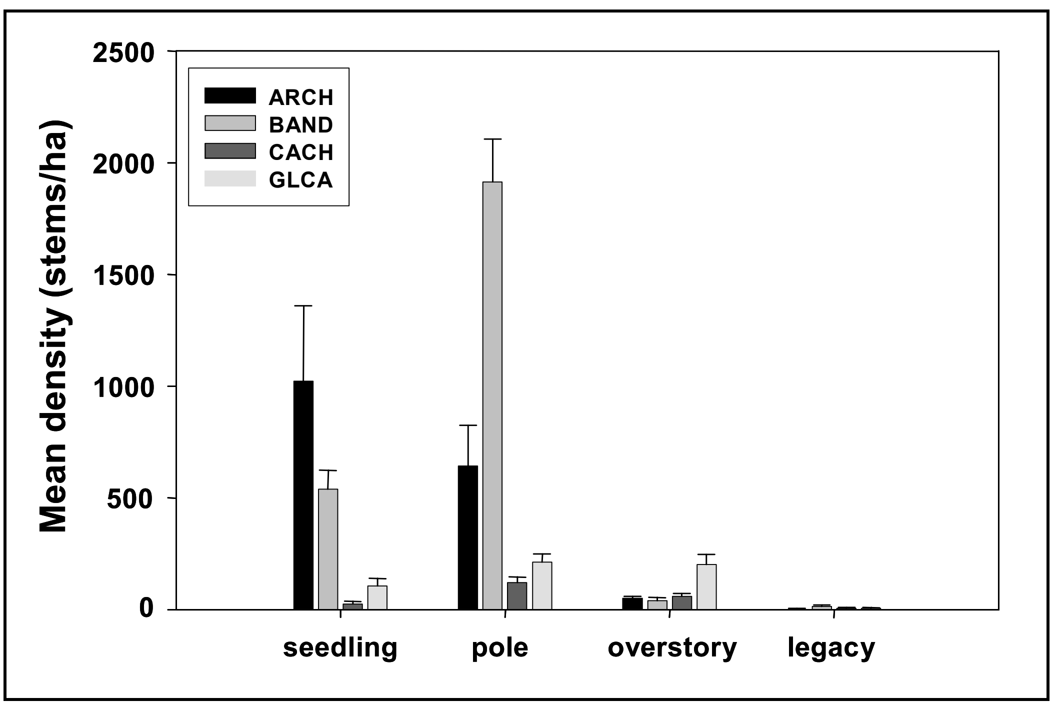

Figure 22. Mean ± standard error (SE) stem density (stems/ha), by tree size class, at pilot sites.

Table 26. Basal area (m^2/ha) of pole-size stems, averaged by site.

Site	n	Mean basal area	Standard deviation	Lower 95%CI	Upper 95% CI	Coefficient of variation
ARCH	11	0.0856	0.036	0.0614	0.1098	42.06
BAND	11	0.123	0.0296	0.1031	0.1429	24.09
CACH	11	0.4037	0.6347	-0.0227	0.8301	157.23
GLCA	11	0.1055	0.079	0.0524	0.1586	74.88

Table 27. Basal area (m^2/ha) of pole-size stems by species and site.

Site	Species	n	Mean	St dev.	Lower 95% CI	Upper 95% CI	CV	Sample size (by precision)	
								10	20
ARCH	POPFRE	270	0.0759	0.0822	0.066	0.0857	8.22	453	116
ARCH	JUNMON	2	0.1504	0.0282	-0.1033	0.4042	18.77	16	6
ARCH	ACENEG	2	0.0432	0.0076	-0.0251	0.1114	17.61	15	6
ARCH	CELRET	1	0.0634						
BAND	ALNOBL	397	0.1332	0.1206	0.1213	0.1451	90.53	318	82
BAND	ACENEG	156	0.077	0.0866	0.0606	0.0674	78.7	489	124
BAND	BETOCC	8	0.1142	0.0823	0.0454	0.183	72.08	202	53
BAND	SALIRO	7	0.048	0.0118	0.0371	0.0589	24.5	26	9
BAND	QUEGAM	1	0.0204						
BAND	QUEGRI	1	0.0193						
CACH	JUNMON	9	0.4082	0.6024	-0.0548	0.8712	147.56	837	212
CACH	PSEMEN	8	0.4147	0.5055	-0.0079	0.8373	121.9	1173	574
CACH	QUEGAM	6	0.7499	1.2467	-0.5584	2.0582	166.24	1062	268
CACH	JUNSCO	4	0.2456	0.2037	-0.0785	0.5697	82.94	267	69
CACH	PINEDU	2	0.0628	0.027	-0.1794	0.3049	42.94	74	21
CACH	ALNOBL	2	0.531	0.3043	-2.2027	3.2647	57.3	129	34
GLCA	POPFRE	57	0.103	0.0981	0.077	0.1291	95.27	351	90
GLCA	SALGOO	52	0.1074	0.0991	0.0798	0.135	92.27	330	85
GLCA	ACENEG	16	0.0697	0.0583	0.0386	0.1008	83.74	272	70
GLCA	QUEGAM	8	0.0537	0.0869	-0.0189	0.1264	161.72	1006	254
GLCA	AMEUTA	5	0.1025	0.0352	0.0589	0.1462	34.31	48	3
GLCA	JUNOST	2	0.1402	0.0097	0.0534	0.2271	6.89	2	2
GLCA	TAMRAM	1	0.0282						

Census Counts for Riparian Legacy Trees

Legacy trees, primarily cottonwoods, were found at all pilot sites. At BAND, there were large alders, some of near legacy diameter (>50 cm, dbh), all of which were dead and presumably killed by the Dome wildfire in 1996. BAND also was the only site with large, legacy-size ponderosa-pine stems on riparian terrace surfaces. Although these trees likely established on flood-plain surfaces, we did not include these individuals in the census of legacy trees. We included only those species that are largely restricted to riparian zones; therefore, the census was of riparian legacy trees. BAND was the only site without living riparian legacy trees.

The number of riparian legacy trees ranged from five at ARCH to 17 at GLCA and mean population density ranged from 4.1 stems/ha at ARCH to 14.3 stems/ha at CACH. Mean population basal area ranged from 1.1 m^2/ha at ARCH to 6.3 m^2/ha at CACH (table 28).

Estimates of mean population stem density and basal area for riparian legacy trees were calculated at the three sites where they occurred, based on the 10-m belt transects. At ARCH and CACH only a single legacy tree fell within the sampling area of the belt transects; thus, estimates represent a single observation. Based on the belt transects, population-mean stem density was underestimated at ARCH and CACH by 28 percent and 65 percent, respectively. The population mean was overestimated at GLCA, but was well within the standard error of the mean (fig. 23). Estimates of basal area paralleled those of stem density (fig. 24).

Table 28. Summary of complete reach-scale stand census of riparian legacy trees at three of the pilot study sites. Census area was defined as reach-averaged transect distance (average reach width) by reach length. All riparian legacy trees were counted and measured for diameter at breast height (dbh). Stem density (stems/ha) and stand basal area (m^2/ha) were then summarized for the reach.

Site	Reach length (m)	Average transect distance (m)	Area of census (hectares)	Number of legacy trees	Census density of legacy trees (stems/ha)	Total basal area (m^2)	Census basal area: total basal area/area of census (m^2/ha)
ARCH	300	40.25	1.21	5	4.13	1.31	1.09
CACH	300	23.32	0.70	10	14.28	4.39	6.27
GLCA	580	59.38	3.44	17	4.94	7.81	2.27

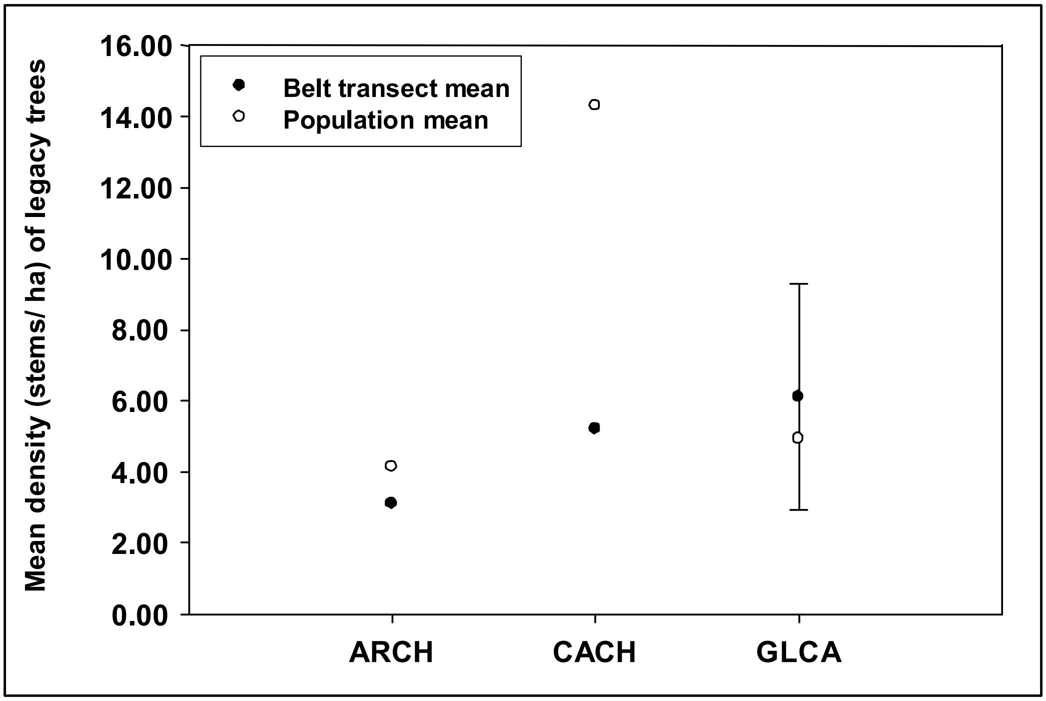

Figure 23. Comparison of mean stem density (stems/ha) for riparian legacy trees as measured by reach-scale population census (open circles) versus estimates from 10-m belt transects (closed circles). Error bar represents standard error of the mean.

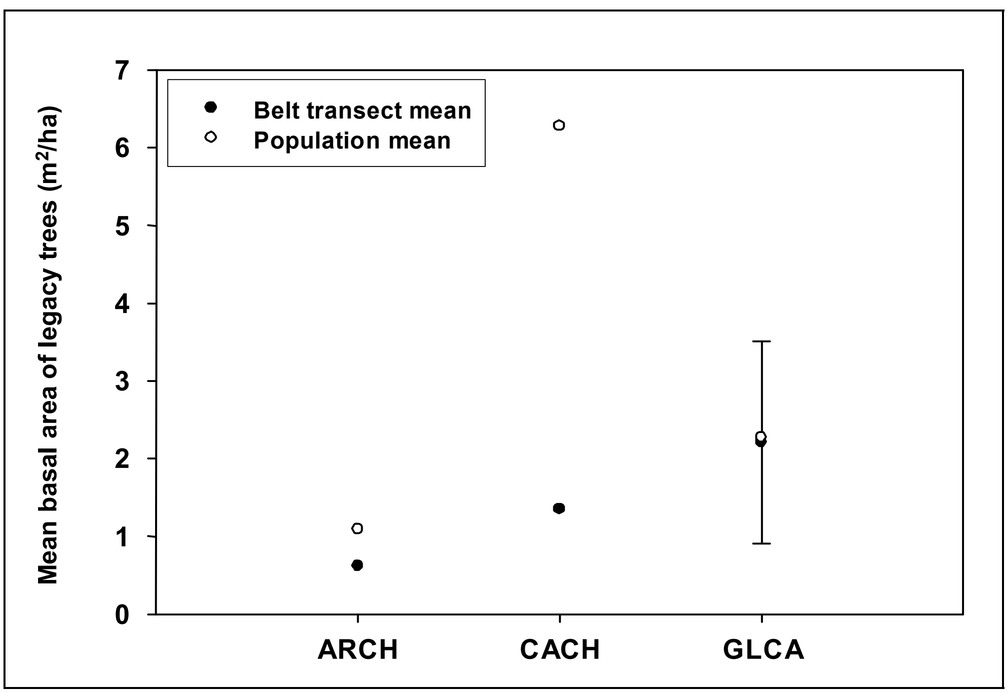

Figure 24. Comparison of mean stand basal area (m^2/ha) for riparian legacy trees as measured by reach-scale population census (open circles) versus estimates from 10-m belt transects (closed circles). Error bar represents standard error of the mean.

Sampling Times

Sampling times per method are summarized in table 29 for all pilot sites. Total travel time varies significantly by site and only ARCH did not require backpacking to the sample reach. Total reach layout time ranged from an hour at ARCH, where the channel was relatively clear of vegetation and debris, to three hours at BAND, where travel near the channel is difficult due to large amounts of course woody debris. Mean transect setup times were similar across sites, although a few transects at GLCA were over 100 m and took a significant amount of time to establish (>1 hour). Mean sampling times for nested quadrats were also similar, except at CACH where recent flooding and heavy grazing made plant identification difficult, thus increasing mean sampling time significantly. Conducting line intercept and 10-m-belt transect sampling did not result in significantly different mean sampling times between sites. Mean sampling time for line intercept ranged from 10:44 minutes per transect at BAND to 35:00 minutes at ARCH. However, it should be noted that collection times at ARCH were for two people, whereas three people were involved in sampling at the other sites.

Table 29. Summary of sampling times for each method at all four pilot sites. Note that all sampling at ARCH was conducted by two people. Sampling at BAND was by conducted three people at all but three transects, where a fourth person participated. All data at CACH and GLCA were collected by four people, with the exception of four transects at GLCA that were sampled by a team of two.

Site	Mean transect length (m)	Total time			Mean time			
		Travel to site	Reach layout	Legacy tree census	Transect setup	Quadrat sampling	Line intercept	10-m belt transect
ARCH	40.25	0:15:00	1:00:00	0:12:00	0:25:00	0:09:29	0:35:00	0:17:21
BAND	26.95	2:30:00	3:00:00	0:00:00	0:30:00	0:11:59	0:10:44	0:13:30
CACH	23.42	1:00:00	0:30:00	-----	0:20:00	0:19:51	0:20:44*	-----
GLCA	60.17	3:00:00	2:00:00	0:10:00	0:40:00	0:06:11	0:20:27	0:14:03

*Sample time includes collecting sparse 10-m belt transect data.

Discussion

Reach Selection and Transect Layout

The role of GRTS in selecting sites for long-term riparian monitoring is still an open question. GRTS points were used to select pilot sampling sites at BAND, CACH, and GLCA, with the use of rule sets allowing rejection of sample reaches that included distinctly different valley settings or large tributary junctions. Rule sets also were established for determining sample reach length along with definition of minimum and maximum reach lengths.

Layout of transect locations can be time consuming if the channel and flood plain have high volumes of coarse woody debris, like BAND, or if the channel is sinuous, causing transect overlap. Rules were established to prevent overlap of adjacent transects and sample areas associated with those transects.

Establishment of transect endpoints and alignment can be difficult, especially for transects in excess of 100 m in length. Monumenting and relocation of head pins is also a question that needs further consideration, especially in deep canyons with poor GPS reception and transects that end at bedrock valley walls. However, establishing semipermanent endpoints is critical to implementing efficient, spatially repeatable long-term monitoring.

Nested Quadrats

Species Richness

Species diversity ranged widely across sites from highs of 128 and 130 at BAND and CACH, respectively, to lows of 52 and 58 at ARCH and GLCA, respectively. These differences result in part from above average monsoonal precipitation at BAND to flash flooding at ARCH and GLCA immediately prior to sampling. Thus, these values reflect the range of natural variation in species richness that might be expected to occur at a site over time in these physically dynamic systems. A distinctive feature of richness across all sites was the high percentage of rare species, defined here as species having a single occurrence at a site. Rare species represented from 33 percent to 47 percent of the species total across the four pilot sites. This is significant, since rare species are difficult to quantify using metrics like frequency and cover and have strong influence on species area curves, as discussed below.

Species Frequency

Our data show that the two smallest quadrat sizes, 0.01 m^2 and 0.1 m^2, rarely had any species that occurred in the desired frequency range and can be omitted from the monitoring protocol. Few species fell within the 30–70 percent range in the 1-m^2 quadrats, but this quadrat size appears to be useful at the Tsaile Creek (CACH) site. We recommend continuing to collect information at the 1-m^2 scale and re-evaluating its usefulness after more data are available from different types of sites. The 10-m^2 quadrat is adequate for monitoring changes in frequencies of very common species at all sites. However, less common species do not occur with enough frequency even in the largest quadrats to allow for adequate monitoring of changes in frequency over time. Species that fall within the desired frequency range make up only about 10–25 percent of the total species at each site.

Species Area Curves

Species area curves can be used to determine sampling adequacy in characterizing plant communities. Generally, an area that is relatively uniform is over-sampled, at random. This sample is then subsampled to determine the point at which additional samples contribute only minor increases in the number of new species found (McCune and Grace, 2002). These assumptions are questionable in riparian settings because high patch disturbance and sharp environmental gradients create strong patterns in the distribution of vegetation. Because riparian vegetation is often highly patterned by hydrologic disturbance gradients (Auble and others, 2005) and because quadrats were sampled systematically along cross-valley transects, species accumulation rates in these pilot studies would be expected to be relatively high.

Species accumulation rates for herbs and shrubs in the riparian zone were relatively high, especially at BAND, where above-average monsoonal precipitation had notably increased species cover and diversity (C. Allen, USGS, Bandelier, New Mex., *oral personal commun.*). In contrast, species cover and diversity were comparatively low at ARCH and GLCA, where flooding prior to sampling had removed and buried species across the riparian zone (see Range of Natural Variability subsection). When rare species were included in the species accumulation curves for herbs and shrubs, neither the 1-m^2 nor 10-m^2 quadrats adequately characterized site species diversity, especially at BAND and CACH. However, when rare species were excluded from the analysis, the species accumulation curves indicate that the 10-m^2 quadrats represented overall species diversity across all sites, requiring 40–60 quadrats at ARCH, CACH, and GLCA and 60–80 quadrats at BAND. Based on these results, we suggest that rare species are not adequately assessed using quadrats of the size and number used in the pilot studies.

We also used sampling effort in minutes to compare different sampling intensities for 1-m^2 and 10-m^2 quadrats. There are valid arguments for using this, or other, approaches in partitioning sampling effort across quadrats. However, the general behavior is that as more up-front, "fixed" effort is included in a per quadrat calculation of effort (such as, transect setup, camping time at a site, travel time to a site, and office planning) the less relatively important differences in actual quadrat sampling time become in the overall comparison. Based on our comparison, the 10-m^2 quadrats were, overall, the most efficient at characterizing diversity of more common species, in terms of sampling effort, particularly at sites with relatively high numbers of species (>100 species).

Based on our pilot study results, we conclude that at sites with low species numbers (<60 species total), 40–60 10-m^2 quadrats, would be sufficient to characterize overall species diversity for relatively common species. At sites with higher total numbers of species (>100), 60–80 10-m^2 quadrats would be required to characterize overall species diversity. Rare species of interest should be monitored using alternative approaches, such as a site inventory and/or mapping (see Elzinga and others, 1998).

Nested Quadrats and Geomorphic Surfaces

Systematic placement of quadrats along transects provide a number of advantages for long-term monitoring, including repeatability and proportional sampling of the bottomland. Further, the 10-m^2 quadrats have been shown here to be the most efficient in terms of characterizing species richness for herbs and shrubs as well as being suitable for monitoring changes in frequency of relatively common species. However, in riparian systems, vegetation patterns are structured by cross-valley physical disturbance and moisture gradients. Distinct vegetation distribution patterns are shown to relate to specific geomorphic landforms and develop primarily in response to hydrologic variables such as inundation duration, flooding frequency, and depth to the alluvial water table (Hupp and Osterkamp, 1985; Stromberg and others, 2006). Integrated monitoring of riparian ecosystems requires linkages among hydrologic, geomorphic, and vegetation metrics. However, relating vegetation to specific geomorphic surface types through the systematic placement of large quadrats becomes problematic along small streams like those examined in this pilot where important geomorphic surfaces are often narrow and discontinuous. For example, the active channel shelf ranged from <1 to <5 m in width across sites. Our results indicate that a large number of the 10-m^2 quadrats span two or more geomorphic surfaces, especially adjacent to the channel. This makes resolution of any species affinities with distinct geomorphic landforms difficult. Thus, we provide the following amendment to improve characterization of herbaceous and shrub species on narrow, near-channel surfaces. For any distinct geomorphic surface adjacent to the channel and less than 5 m in width, establish a second transect perpendicular to the first in the approximate center of the surface. Along the second transect locate four 0.5-m by 1-m quadrats, typically two upstream and two downstream from the main transect. Establish these quadrats within 10 m of the main transect and in them record cover and frequency of herbs and cover of shrubs (see SOP 8 for additional methodological details).

Shrub Cover in the 10-m^2 Quadrats

As with frequency of herbaceous and shrub species, shrub cover was highly variable by species and by site owing to inherently patchy distribution and wide ranges in cover values for many species. This variation was evident in estimates of cover using the line-intercept and 10-m^2 quadrats, which yielded similar results that were not statistically different. Using shrub cover data from 10-m^2 quadrats, we determined that only at GLCA, where a total of 135 quadrats were needed to sample the comparatively wide bottomland, were quadrat numbers adequate to characterize shrub cover for most of the common species with 20 percent precision. Whereas the minimal spacing between 10-m^2 quadrats was used at BAND and CACH; the bottomland was so narrow (mean transect length=27 m and 23.4 m, respectively) that the total number of quadrats at these sites (88 and 79, respectively) was approximately half of what is needed to characterize shrub cover with 20 percent precision. Based on these results, it appears that for sites in narrow valley settings where riparian zones average less than approximately 40 m, the number of 10-m^2 quadrats systematically placed on 11 transects will not provide shrub cover estimates at 20 percent precision. In such cases, additional sample reaches should be added in order to attain a minimum of 130 to 140 10-m^2 shrub quadrats.

Line Intercept

In spite of relatively high natural variability in the data and potential imprecision associated with making highly repeatable line interception calls (Elzinga and others, 1998), this method appears to be an efficient way of describing and monitoring cross-valley scale change in cover of woody vegetation and geomorphic surface types. Variance in total cover estimates stabilized somewhere between eight and nine transects, depending on the site, and sampling times ranged from approximately 11 minutes to 35 minutes per transect. Larger scale changes in surface types, like that associated with channel widening and narrowing processes, and accompanying changes in vegetation (Birkeland, 1999), could be well represented using this method. Further, data from this method are likely to scale-up well to remotely sensed estimates of vegetation cover where GIS coverage exists. Estimates of cover by size class for trees and shrubs are likely to have high variance but provide an index of stand structural diversity, which would be important for wildlife species, especially avian populations.

Comparing Line-Intercept and Survey Data

An overlay of the distribution of geomorphic surface data derived from line-intercept sampling on topographic survey information from one of the transects at BAND demonstrated close agreement. Based on this result, it appears that delineation of geomorphic surfaces could be done in conjunction with the topographic survey of each transect, obviating the need to record surface breaks using the line intercept. To include geomorphic surface identifications with the topographic survey, surface breaks and transitional surfaces should be included and identified in the survey job, in addition to systematically spaced survey points (see SOP 5 for survey procedures).

Belt Transects and Riparian Forest Structure

Based on a limited comparison at BAND, it was determined that belt transects provide a more efficient estimate of riparian forest-stand structure (stem density and stand basal area by size class) than do the originally proposed 5-m × 20-m quadrats. The increased efficiency of belts results primarily from reduction in the amount of time involved in laying out belt transects compared with quadrats. However, because of high cross-valley environmental gradients, and strong patterns in vegetation (Hupp and Osterkamp, 1985; Bendix, 1994; Auble and others, 2005), the continuous nature of belt transects also provides a more efficient way of capturing this inherent variability.

A more robust comparison of 10-m to 20-m belt transects at ARCH and GLCA suggests that for wadeable streams in bedrock canyons, 10-m belt transects produce similar stand-structure estimates in less than half the time. Overall results from 10-m belts suggest, however, that estimates for large and/or rare individuals are likely to be highly variable. This is especially true for riparian legacy trees, which occurred in limited numbers at all pilot sites, including BAND, although all the riparian legacy trees at this site had been killed by wildfire. Thus, for infrequent individuals, like legacy trees, a reach-wide census of the population is likely to be the most accurate and efficient method for obtaining stand-structure information on these species.

Census of Riparian Legacy Trees

We compared reach-scale estimates of stem density and stand basal area for legacy trees, using 10-m belt transects, against population means produced by doing a complete census of all riparian legacy trees. These results indicated that the belts tended to underestimate both stem density and basal area with high variance. The total number of legacy trees ranged from five at ARCH to 17 at GLCA. Not counting the time involved in walking the reach to locate trees, the time it took to count and measure dbh on all legacy trees within a reach ranged between 10 minutes and 30 minutes. Given the potential error in estimating stand-structure information on riparian legacy trees, a complete census of the population seems worth the sampling effort.

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Appendix

Appendix A. List of species and location. Site codes follow table 1. Species in bold represent the new synonomy based on the USDA Plants Database.

Spp code	Species name	Family	ARCH	BAND	CACH	GLCA
ACENEG	*Acer negundo*	Aceraceae		x		x
ACHMIL	*Achillea millefolium*	Asteraceae		x	x	
ACHHYE	*Achnatherum hymenoides*	Poaceae	x			x
AGRSTR	*Agrimonia striata*	Rosaceae		x		
AGRSMI	*Agropyron smithii*	Poaceae		x		
AGRTRA	*Agropyron trachycaulum*	Poaceae		x		
AGROSTIS SP	*Agrostis sp*	Poaceae			x	
ARGSTO	*Agrostis stolonifera*	Poaceae	x	x	x	
ALLIUM	*Allium sp*	Liliaceae	x			
ALNOBL	*Alnus oblongifolia*	Betulaceae		x	x	
AMAHYB	*Amaranthus hybridus*	Amaranthaceae		x		
AMBACH	*Ambrosia acanthicarpa*	Asteraceae	x			
AMEUTA	*Amelanchier utahensis*	Rosaceae				x
APOCAN	*Apocynum cannabinum*	Apocynaceae				x
ARTDRA	*Artemesia dracunculus*	Asteraceae		x		
ARTLUD	*Artemesia ludoviciana*	Asteraceae		x		
ARTTRI	*Artemesia tridentata*	Asteraceae	x	x	x	
ARTCAM	*Artemisia campestris*	Asteraceae			x	
ARTFRI	*Artemisia frigida*	Asteraceae		x		
ARTLUD	*Artemisia ludoviciana*	Asteraceae	x		x	x
UNKN - ARTEM green	*Artemisia very green*	Asteraceae		x		
ASTER SP	*Aster species*	Asteraceae				x
BACSAL	*Baccharis salicina*	Asteraceae	x			x
BACC SP	*Baccharis sp*	Asteraceae				x
BAHDIS	*Bahia dissecta*	Asteraceae		x		
BETULA	*Betula occidentalis*	Betulaceae			x	
BORAG SPP	*Boraginaceae sp*	Boraginaceae		x		
BOUCUR	*Bouteloua curtipendula*	Poaceae		x		
BOUERI	*Bouteloua eriopoda*	Poaceae			x	
BOUGRA	*Bouteloua gracilis*	Poaceae		x	x	
BRIBRA	*Brickellia brachyphylla*	Asteraceae		x		
BRICAL	*Brickellia californica*	Asteraceae		x		
BRIGRA	*Brickellia grandiflora*	Asteraceae		x		
BROANO	*Bromus anomalus*	Poaceae		x		
BROCAR	*Bromus carinatus*	Poaceae		x		
BROCIL	*Bromus ciliatus*	Poaceae		x		
BROINE	*Bromus inermus*	Poaceae		x		
BROMUS SP	*Bromus sp*	Poaceae		x	x	
BROTEC	*Bromus tectorum*	Poaceae	x	x	x	x
CALSCO	*Calamagrostis scopulorum*	Poaceae				x

CONVUL SPP	*Calystegia sp*	Convolvulaceae		x		
CARMIC	*Carex microptera*	Cyperaceae		x		
CARPRA	*Carex praegracilis*	Cyperaceae		x		
CAREX SP	*Carex sp*	Cyperaceae			x	
CASLIN	*Castilleja linariifolia*	Scrophulariaceae	x			
CERARV	*Cerastium arvense*	Caryophyllaceae		x		
CERFON	*Cerastium fontanum*	Caryophyllaceae		x		
CHASER	*Chamaesyce serpyllifolia*	Euphorbiaceae			x	
CHAMAESYCE SP	*Chamaesyce sp*	Euphorbiaceae			x	
CHEFRE	*Chenopodium atrovirens*	Chenopodiaceae		x		
CHEGRA	*Chenopodium graveolens*	Chenopodiaceae		x		
CHRDEP	*Chrysothamnus depressus*	Asteraceae			x	
CHRNAU	*Chrysothamnus nauseosus*	Asteraceae	x			x
CHRVIS	*Chrysothamnus viscidiflorus*	Asteraceae	x			
CICDOU	*Cicuta douglasii*	Apiaceae		x		
CIRCHE	*Cirsium chellyense*	Asteraceae			x	
CIRNEO	*Cirsium neomexicanum*	Asteraceae		x		
CIRSIUM SP	*Cirsium sp*	Asteraceae		x	x	
CIRVUL	*Cirsium vulgare*	Asteraceae		x	x	
CLELIG	*Clematis ligusticifolia*	Ranunculaceae	x	x		x
COMDIA	*Commelina dianthifolia*	Commelinaceae		x		
CONCAN	*Conyza canadensis*	Asteraceae	x	x		
CONSCH	*Conyza schidenea*	Asteraceae		x		
CORSER	*Cornus sericea*	Cornaceae			x	
CORAUR	*Corydalis aurea*	Fumariaceae		x		
CYP SPP	*Cyperaceae sp (broad-leaf)*	Cyperaceae		x		
CYPARI	*Cyperus aristatus*	Cyperaceae		x		
CYPESC	*Cyperus esculentes*	Cyperaceae		x		
DACGLO	*Dactylis glomerata*	Poaceae		x	x	
DISSPI	*Distichlis spicata*	Poaceae	x			x
ECHCRU	*Echinochloa crusgalli*	Poaceae			x	
ELEPAL	*Eleocharis palustris*	Cyperaceae			x	
ELYCAN	*Elymus canadensis*	Poaceae	x	x		x
ELYELY	*Elymus elymoides*	Poaceae		x	x	
ELYREP	*Elymus repens*	Poaceae	x			x
ELYMUS SP	*Elymus sp*	Poaceae		x	x	
ELYTRA	*Elymus trachycaulus*	Poaceae		x	x	
EPICIL	*Epilobium ciliatum*	Onagraceae		x		
EPIL SPP	*Epilobium sp*	Onagraceae		x		
EQUARV	*Equisetum arvense*	Equisetaceae		x	x	x
EQUHYE	*Equisetum hyemale*	Equisetaceae	x		x	x
EQULAE	*Equisetum laevigatum*	Equisetaceae			x	x
EQU SP	*Equisetum sp*	Equisetaceae				x
ERIFLA	*Erigeron flagellaris*	Asteraceae		x	x	
ERIG SPP	*Erigeron sp*	Asteraceae		x		
ERIONEURON SP	*Erioneuron sp*	Poaceae			x	
EROCIC	*Erodium cicutarium*	Geraniaceae		x	x	
EUPDEN	*Euphorbia dentata*	Euphorbiaceae		x		

EUTOCC	*Euthamia occidentalis*	Asteraceae	x			x
FESARI	*Festuca arizonica*	Poaceae		x		
FESTOCT	*Festuca octoflora*	Poaceae			x	
FESTUC SPP	*Festuca sp*	Poaceae		x		
FORNEO	*Forestiera neomexicana*	Oleaceae		x		
GALAPA	*Galium aparine*	Rubiaceae		x		
GALIUM SP	*Galium sp*	Rubiaceae				x
GALWRI	*Galium wrightii*	Rubiaceae			x	
GERCAE	*Geranium atropurpureum*	Geraniaceae		x		
GER SP	*Geranium sp*	Geraniaceae			x	
GRISQN	*Grindelia nana*	Asteraceae	x			
GUTSAR	*Gutierrezia sarothrae*	Asteraceae		x	x	
HELMUL	*Helimerus multiflora*	Asteraceae		x		
LINEM SP	*Hesperolinon sp*	Linaceae			x	
HEITVIL	*Heterotheca villosa*	Asteraceae	x		x	x
HYMFIL	*Hymenopappus filifolius*	Asteraceae			x	
IPOAGR	*Ipomopsis aggregata*	Polemoniaceae	x	x	x	x
JUNBAL	*Juncus baliticus*	Juncaceae	x		x	x
JUNSP	*Juncus sp*	Juncaceae	x		x	x
JUNMON	*Juniperus monosperma*	Cupressaceae			x	
JUNOST	*Juniperus osteosperma*	Cupressaceae				x
JUNSCO	*Juniperus scopulorum*	Cupressaceae			x	
JUN SPP	*Juniperus sp*	Cupressaceae		x		
LACSER	*Lactuca serriola*	Asteraceae		x		
LAPOCC	*Lappula occidentalis*	Boraginaceae		x		
MACGRI	*Machaeranthera gracilis*	Asteraceae				x
MAHREP	*Mahonia repens*	Berberidaceae			x	
MEDLUP	*Medicago lupulina*	Fabaceae			x	
MEDSAT	*Medicago sativa*	Fabaceae		x		
MELILOTUS	*Melilotus sp*	Fabaceae	x		x	x
MENARV	*Mentha arvensis*	Lamiaceae			x	
MENMUL	*Mentzelia multiflora*	Loasaceae		x		
MIMFRE	*Mimulus fremontii*	Scrophulariaceae		x		
MIM SPP	*Mimulus sp*	Scrophulariaceae		x		
MIRLIN	*Mirabilis linearis*	Nyctaginaceae		x		
MIRMUL	*Mirabilis multiflora*	Nyctaginaceae		x		
MIROXY	*Mirabilis oxybaphoides*	Nyctaginaceae		x		
MULASP	*Muhlenbergia asperifolia*	Poaceae	x		x	x
MUHMIN	*Muhlenbergia filiformis*	Poaceae			x	
MUHPOR	*Muhlenbergia porteri*	Poaceae		x		
MUHLENB SP	*Muhlenbergia sp*	Poaceae			x	
ROR SPP	*Nasturtium sp*	Brassicaceae		x		
OENBIE	*Oenothera biennis*	Onagraceae	x	x		
OENPAL	*Oenothera pallida*	Onagraceae			x	x
OENETH SPP	*Oenothera sp*	Onagraceae	x	x	x	
OPUNTIA CHOLLA	*Opuntia cholla*	Cactaceae			x	
OPUNTIA SP	*Opuntia sp*	Cactaceae			x	x
OXAVIO	*Oxalis violacea*	Oxalidaceae		x		

PANBUL	*Panicum bulbosum*	Poaceae		**x**		
PARQUI	*Parthenocissus quinquefolia*	Vitaceae		**x**		
PENLIN	*Penstemon lentus*	Scrophulariaceae				**x**
PENSTEMON	*Penstemon sp*	Scrophulariaceae	**x**	**x**	**x**	**x**
PHAARU	*Phalaris arundinacea*	Poaceae		**x**		
PHIMIC	*Philadelphus argenteus*	Hydrangeaceae		**x**	**x**	
PHRAUS	*Phragmites australis*	Poaceae				**x**
PHYHED	*Physalis hederifolia*	Solanaceae		**x**		
PINEDU	*Pinus edulis*	Pinaceae			**x**	
PINPON	*Pinus ponderosa*	Pinaceae		**x**		
PIPMIC	*Piptatherum micranthum*	Poaceae		**x**		
PLALAN	*Plantago lanceolata*	Plantaginaceae			**x**	
PLAMAJ	*Plantago major*	Plantaginaceae			**x**	
POA COMB	*Poa combo (pratensis/compressa)*	Poaceae		**x**		**x**
POAFEN	*Poa fendleriana*	Poaceae	**x**		**x**	
POAPAL	*Poa palustris*	Poaceae		**x**	**x**	
POA SP	*Poa sp*	Poaceae		**x**	**x**	**x**
POLPER	*Polygonum persicaria*	Polygonaceae		**x**		
POPACU	*Populus acuminata*	Salicaceae			**x**	
POPFRE	*Populus fremontii*	Salicaceae	**x**		**x**	**x**
POPULUS SP	*Populus sp*	Salicaceae			**x**	
POTAMOGETON SP	*Potamogeton sp*	Potamogetonaceae			**x**	
POT SPP	*Potentilla sp*	Rosaceae		**x**		
PRUNELLA SP	*Prunella sp*	Lamiaceae			**x**	
PRUVUL	*Prunella vulgaris*	Lamiaceae		**x**		
PSEMEN	*Pseudotsuga menziesii*	Pinaceae			**x**	
PTETRI	*Ptelea trifoliata*	Rutaceae		**x**		
QUEGAM	*Quercus gambelii*	Fagaceae		**x**	**x**	**x**
QUEGRI	*Quercus grisea*	Fagaceae		**x**		
RANAQU	*Ranunculus aquatilis*	Ranunculaceae			**x**	
RANCYM	*Ranunculus cymbalaria*	Ranunculaceae			**x**	
RANMAC	*Ranunculus macounii*	Ranunculaceae		**x**		
RHUTRI	*Rhus aromatica*	Anacardiaceae		**x**	**x**	**x**
RIBS SPP	*Ribes sp*	Grossulariaceae		**x**		
UNKN RIB-col	*Ribes unknown-collected*	Grossulariaceae		**x**		
ROSWOO	*Rosa woodsii*	Rosaceae		**x**	**x**	**x**
RUBIDE	*Rubus ideaus*	Rosaceae		**x**		
RUDLAC	*Rudbeckia lacinata*	Asteraceae			**x**	
RUMCRI	*Rumex crispus*	Polygonaceae		**x**	**x**	
SALEXI	*Salix exigua*	Salicaceae	**x**		**x**	**x**
SALGOO	*Salix gooddingii*	Salicaceae				**x**
SALLAE	*Salix laevigata*	Salicaceae			**x**	
SALTRA	*Salsola tragus*	Asteraceae				**x**
SAXRHO	*Saxifraga rhomboidea*	Saxifragaceae		**x**		
SCHPUN	*Schoenoplectus pungens*	Cyperaceae	**x**			**x**
SCHOENOPLECTUS SP	*Schoenoplectus sp*	Cyperaceae			**x**	
SCIRPUS SP	*Scirpus sp*	Cyperaceae			**x**	
SENSPA	*Senecio riddellii*	Asteraceae	**x**			

SOLJAM	*Solanum jamesii*	Solanaceae		x		
SONASP	*Sonchus asper*	Asteraceae		x		
SPHAERALCEA	*Sphaeralcea sp*	Malvaceae		x	x	x
SPOCRY	*Sporobolus cryptandrus*	Poaceae	x	x	x	x
SPOR SP	*Sporobolus sp*	Poaceae			x	
SYMORE	*Symphoricarpos oreophilus*	Caprifoliaceae			x	
TAMRAM	*Tamarix ramosissima*	Tamaricaceae				x
TAROFF	*Taraxacum officinale*	Asteraceae			x	
TARAX SP	*Taraxacum sp*	Asteraceae		x	x	
THAFEN	*Thalictrum fendleri*	Ranunculaceae		x	x	
THAARV	*Thlaspi arvense*	Brassicaceae		x		
TOXRYD	*Toxicodendron rydbergii*	Anacardiaceae		x		
	Tragopogon lamottei	Asteraceae			x	
TRAG SPP	*Tragopogon sp*	Asteraceae		x		
TRIREP	*Trifolium repens*	Fabaceae			x	
TRIGLOC	*Triglochin sp*	Juncaginaceae			x	
TYPLAT	*Typha latifolia*	Typhaceae		x		
UNKN heart	*Unknown heart-shaped*			x		
URTDIO	*Urtica dioica*	Urticaceae		x		
VERTHA	*Verbascum thapsus*	Scrophulariaceae		x		
VERANA	*Veronica anagallis-aquatica*	Scrophulariaceae			x	
VERONICA	*Veronica sp*	Scrophulariaceae			x	
VICAME	*Vicia americana*	Fabaceae		x		
VIOLA SP	*Viola sp*	Violaceae		x	x	
XANSTR	*Xanthium strumarium*	Asteraceae	x		x	
ANNUAL SETARIA					x	
UNKN BIGMUL					x	
LITTLE BLUE STEM			x			
LOBEY COTYLEDON						x
LOBEY SPROUT						x
RED STEMMED COTY						x
SHRUBBY ASTER ROSETTE						x
SPHAERALCEA			x			
UKNWN LITTLE PENSTEMON					x	
UKNWN LITTLE SEED GRASS					x	
UNKN BRASSICACEA						x
UNKN COTYLEDON						x
UNKN COTYLEDON 2						x
UNKN COTYLEDON 3						x
UNKN COTYLEDON 4						x

UNKN COTYLEDON 5						**x**
UNKN DALEA SP						**x**
UNKN GLICK-LIKE COL			**x**			
UNKN GRASS						**x**
UNKN POINTY COTYL						**x**
UNKN ROSETTE						**x**
UNKWN ANN GRASS					**x**	
UNKWN ASTER BLUE			**x**			
UNKWN ASTER HAIRY LEAF			**x**			
UNKWN BASAL ROSETTE LINEAR					**x**	
UNKWN COMPOSIT ROSETT DIVIDED			**x**			
UNKWN COMPOSIT STELLATE			**x**			
UNKWN COMPOUND PINNATE COL			**x**			
UNKWN CRENULATE PUBESCENT ROSETTE					**x**	
UNKWN EUTHORBIA			**x**			
UNKWN GLABROUS CIRSIUM					**x**	
UNKWN GLANDLAR HAIRY LEAF					**x**	
UNKWN GLANDULAR MAT GROUND COVER					**x**	
UNKWN GRASS			**x**			
UNKWN GRAY BASAL					**x**	
UNKWN GRAY BASAL ROSETTE					**x**	
UNKWN LEATHERY BASAL ROSETTE					**x**	
UNKWN LITTLE SHEATH GRASS					**x**	
UNKWN PLAIN SPATULATE ROSETTE					**x**	
UNKWN ROSETTE GREEN					**x**	

UNDER/PURPLE TOP						
UNKWN ROSETTE LOBED					x	
UNKWN ROSETTE SPATULATE					x	
UNKWN SCHP/ELGANS			x			
UNKWN SENCIO PURPLE SERRATE					x	
UNKWN SENECIO					x	
UNKWN SENECIO LOBED					x	
UNKWN SENECIO PURPLE					x	
UNKWN SENECIO SP					x	
UNKWN SENECIO SP PURPLE					x	
UNKWN SILVER LEAF ROSETTE					x	
UNKWN SPIRAL BURR ANNUAL					x	
UNKWN SPORABOLIS BIG			x			
UNKWN SUCC GRVOVY					x	
UNKWN SUCCLENT COL			x			
UNKWN TOOTHED COMPOSITE					x	
UNKWN WHITE MIDRIB ROSETTE					x	
UNKWN YELLOW LEAF COMPOSITE					x	
UNNWN SPAT ROSETTE					x	
UPLAND GRAY MAT FORMING SHRUB					x	