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Developing an Image-Based Riparian Inventory Using a Multistage Sample: Phase I Report

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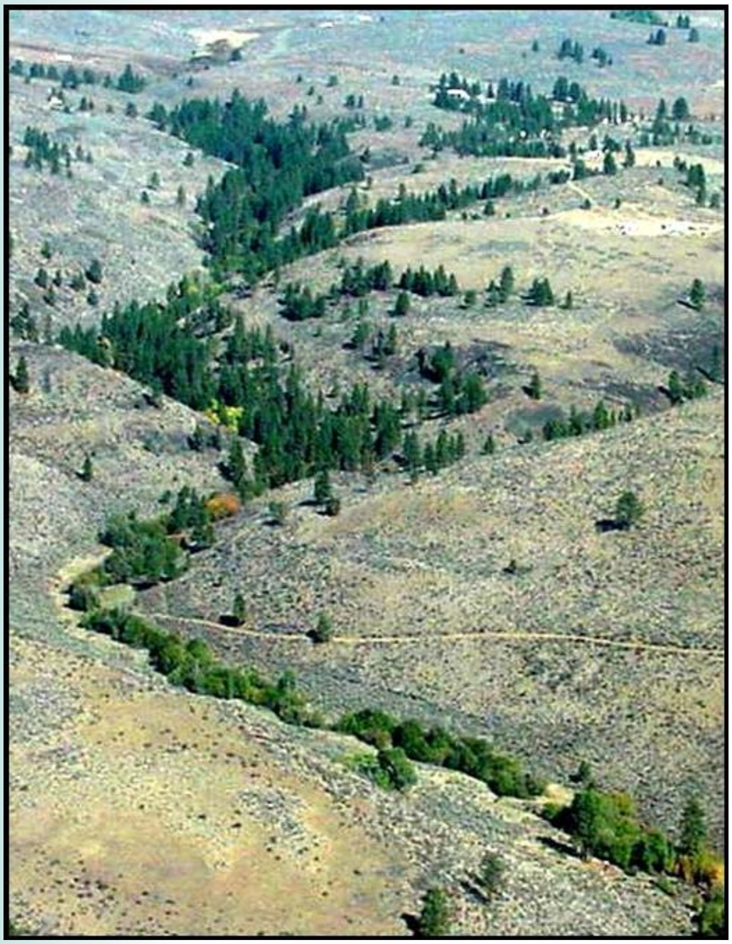

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Abstract

Riparian ecosystems are transitional areas between terrestrial and aquatic environments. In the western United States, riparian ecosystems comprise less than ten percent of the total landscape making riparian ecosystems difficult to sample adequately with standard sampling procedures (Prichard and others 1996). The objective of this project is to develop a method of inventorying sparsely distributed riparian areas using Wyoming as the study area. The method will be appropriate for inventorying large areas, focus on sample designs that are more cost effective than sample designs that depend on ground sampling, be based on imagery and other geospatial data, ensure that the general approach can be applied nationally, be adaptable to a hierarchy of scales, and be consistent with the direction provided in the Aquatic Ecological Unit Inventory Technical Guide (Hixson and others 2004). The methodology chosen for the project was nested area frame sampling (NAFS). NAFS uses imagery at different resolutions that continues to refine land cover estimates. Coarse resolution imagery (time-series of NDVI MODIS) was initially used to create five strata. Primary sampling units were chosen in each strata. The number of primary sampling units depended upon the variability in the remote sensing imagery. Using mid-resolution imagery (GeoCover, www.mdafederal.com/geocover), vegetation occurring in the primary sampling units was classified as riparian/non-riparian. Using these classifications, riparian estimates were calculated for the state of Wyoming and for the individual strata. The methodology used in this project was shown to be effective in sampling large areas on the scale of states. Even though the riparian estimates (3.4% with a standard error of 0.4%) produced by this project for Wyoming are biased because of the inclusion of all vegetation not just riparian, they compare favorably to riparian estimates from much larger projects, such as Wyoming GAP (2.6%).

Background

Riparian ecosystems exist in transitional areas between terrestrial and aquatic environments. They occur adjacent to water bodies and extend to the adjoining uplands. The upland areas differ from the riparian areas in soil composition, fauna and flora communities, and the occasional presence of water from flooding events.

Water passes through riparian ecosystems as it journeys from terrestrial to aquatic environments. Water transports particulates in the form of nutrients, pollutants, and sediments. Riparian ecosystems act as filters that reduce the amount of particulates entering aquatic environments. In this way, riparian ecosystems play significant roles in water quality, biodiversity, nutrient cycling, ecological productivity, and geomorphic processes.

In the western United States, riparian ecosystems comprise less than ten percent of the total landscape making riparian ecosystems difficult to sample adequately with standard sampling procedures (Prichard and others 1996). The USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) program is responsible for the inventory of the nation's forests. FIA samples forest land, which by definition is greater than ten percent tree cover, and greater than one acre in area extent, at approximately 5-km intervals. This sample design does not adequately sample sparse and widely distributed resources such as riparian ecosystems. Therefore, riparian ecosystems, particularly non-forested areas, are likely to be underestimated and poorly characterized.

Inventories of natural resources frequently use multistage sampling with field sampling as one of the stages. This methodology achieves highly accurate and detailed assessments, but the extensive use of field data makes it expensive and time-consuming. A methodology is needed that can provide much of the inventory data at a fraction of the cost.

The objective of this project is to develop a method of inventorying sparsely distributed riparian areas. The method will:

- Be appropriate for inventorying large areas.
- Focus on sample designs that are more cost effective than sample designs that depend on ground sampling.
- Be based on imagery and other geospatial data.
- Ensure that the approach can be applied nationally.
- Be adaptable to a hierarchy of scales.
- Be consistent with the guidelines in the Aquatic Ecological Unit Inventory (AEUI) Technical Guide (Hixson and others 2004).

To develop the methodology, riparian resources were assessed using remotely sensed imagery and other geospatial data. This technique provided important information on riparian resources without using costly field data collection. However, if more detailed information is needed, high-resolution imagery and/or field-based sampling can be nested within the structure of this broad-scale assessment methodology. It is important to note that the methodology does not produce wall-to-wall delineations of riparian areas at some fixed scale, but does produce tabular estimates of riparian area.

Study Area

The state of Wyoming served as the study area (figure 1). Wyoming's 25 million hectares contain three primary ecological zones: Rocky Mountain Forest, Short Grass Prairie, and the Wyoming Basin. Wyoming has an average elevation of over 2,000 meters; Gannett Peak (4,207 meters) is the highest point in the state, and areas in northeastern Wyoming are just over 900 meters (Green and Conner 1989). Wyoming has a dry, semiarid climate and is characterized as a steppe region, which includes lowlands and highlands (Bailey 1978).

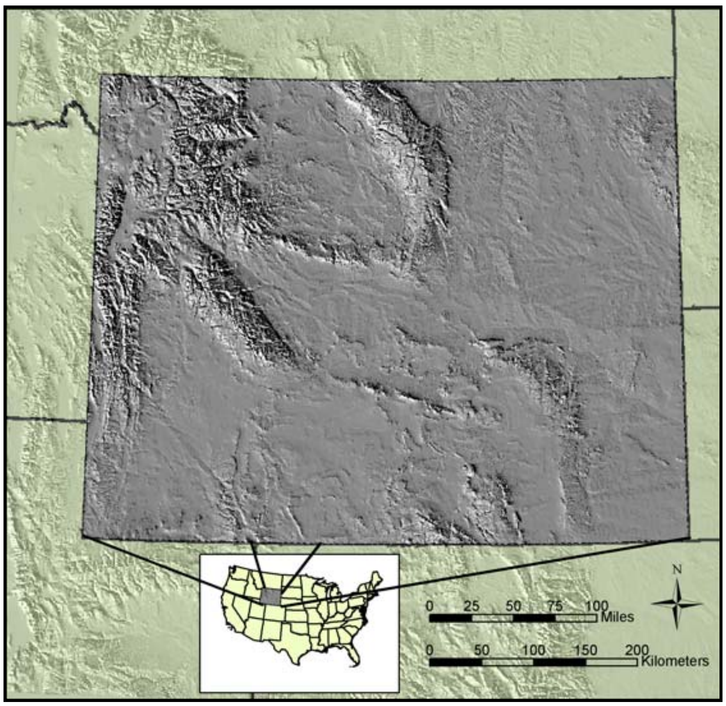


Figure 1— Shaded area relief of Wyoming. The entire state of Wyoming was the area used for the riparian resources assessment project.

Methodology

Remotely sensed imagery is available at a variety of resolutions. Coarser imagery (low-spatial resolution) is used for large geographic areas and detailed (high-spatial resolution) imagery is more practical for smaller areas. Coarse resolution imagery appropriate for state or regional studies are Moderate Resolution Imaging Spectral Radiometer (MODIS) (250-meter and 500-meter resolution) and Advanced Very High Resolution Radiometer (AVHRR) (1,000-meter resolution). Study areas of 200,000 to 2 million hectares are well suited to analysis with moderate resolution imagery, such as Landsat (30-meter resolution). High-resolution imagery, such as IKONOS or QuickBird (approximately 1-meter resolution) and aerial photography (typically less than 1-meter resolution), are feasible for small-scale projects.

The concepts and tools used to accomplish the goals of this project were derived from the nested area frame sampling (NAFS, figure 2) methodology developed by the Earth Satellite Corporation (Koeln and Kollasch 2000). NAFS is a multistage stratified area sampling procedure using several different resolutions of imagery. The NAFS approach is well suited for analysis of large regions and to situations where field work is impossible or too expensive. The NAFS approach is known to achieve high accuracy with low cost. The NAFS approach stratifies the area of interest using coarse resolution imagery, samples the strata using moderate resolution imagery, and refines the sampling using high-resolution imagery. For this particular project, the NAFS approach involved four steps (figure 3):

1. Creation of strata.
2. Identification of primary sampling units (PSUs).
3. Identification and classification of riparian areas within the PSUs.
4. Calculation of riparian estimates.

The flowchart in figure 3 illustrates these four steps.

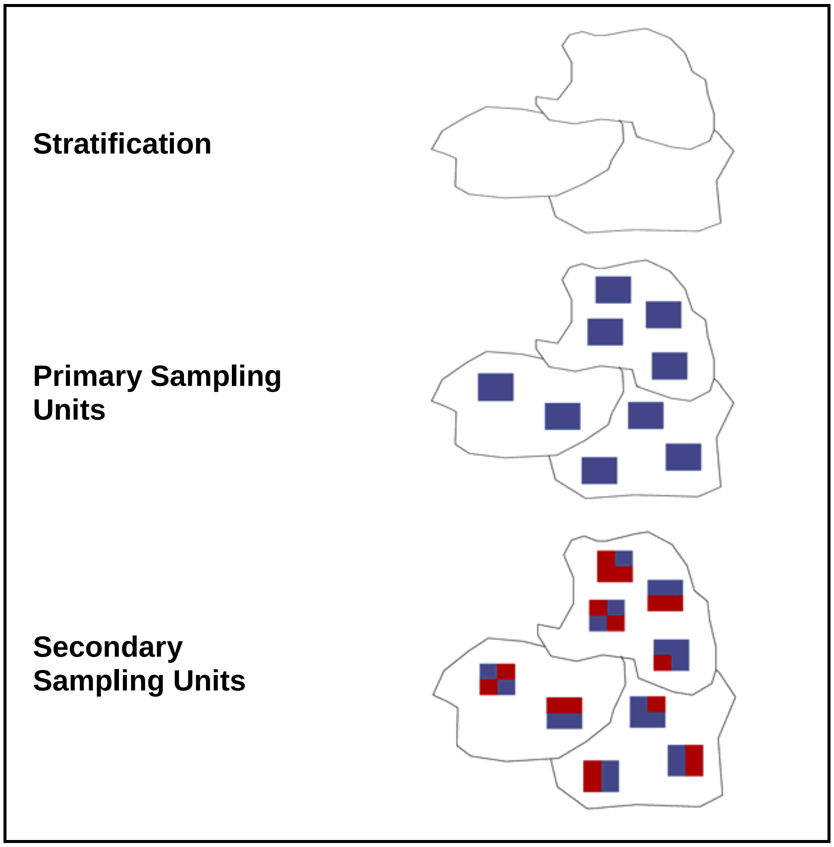


Figure 2—Nested Area Frame Sampling Schematic (Koeln and Kollasch 2000). First stage is to stratify the landscape using coarse-resolution imagery. Next, primary sampling units are chosen using mid-resolution imagery. Lastly, using high-resolution imagery, small secondary sampling units are chosen.

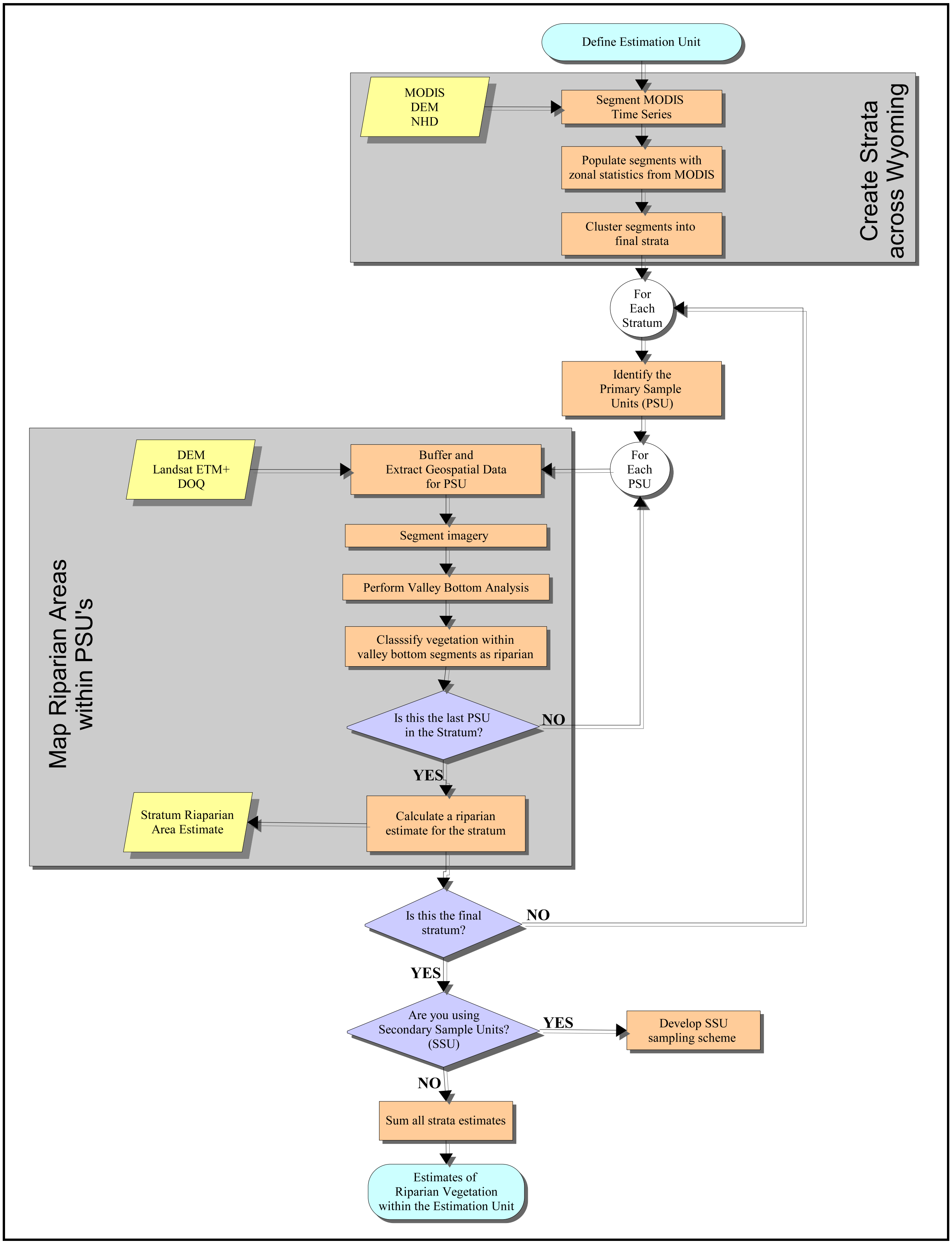


Figure 3—Flowchart of the process used to derive riparian area estimates for the state of Wyoming. The process is based upon the Nested Area Frame Sampling process.

Creation of Strata

The first step of the NAFS approach is to stratify the landscape using coarse resolution imagery. For this project, MODIS imagery (250-meter resolution) was chosen because it has a higher resolution than AVHRR imagery (1,000-meter resolution). Several MODIS products are available (see edcdaac.usgs.gov/modis/dataproducts.asp). For this project, the NDVI (Normalized Difference Vegetation Index) MODIS product was chosen. NDVI is a standard vegetation index that highlights densities of plant growth; the higher the NDVI value, the denser the plant growth. A time series of NDVI was created by combining 21 NDVI MODIS images; the acquisition dates for these images ranged between April and September for the years 2001 through 2004 (table 1). This NDVI time series helped to differentiate between conifer and deciduous trees, and between dry and moist vegetation.

The initial strata were created by combining the 21 NDVI images and using eCognition (Baatz and others 2003, www.definiens-imaging.com) to partition the combined 21 images into segments. Segments are spatially contiguous groups of pixels that have a distinct local variance structure when compared to neighboring segments. Using the 21 NDVI images, the mean NDVI value was calculated for each segment. Unsupervised classification techniques (ISODATA) (Lillesand and Kiefer 2000) were used to cluster the means into five strata.

An elevational gradient influenced the classification of the five strata. To control for this elevational gradient, the five strata were divided into 11 strata based upon elevation. The elevation data was obtained from the USGS 3 arc-second/90-meter resolution product. The elevation image was resampled using nearest neighbor resampling to 250-meter resolution, which was the resolution of the strata. The elevation breaks used were 1,850 meters and 2,500 meters.

The 11 strata were further evaluated by using Wyoming GAP Landcover data (www.sdvc.uwyo.edu/24k/landcov.html). For each stratum, the percent area of each Wyoming GAP Landcover class occurring in the associated stratum was calculated. Based upon these summaries, the 11 strata were condensed into five strata that were similar with respect to land cover composition (figure 4). A sixth stratum was created from the USGS National Hydrography Data Set (NHD, nhd.usgs.gov). The strata are:

Table 1—Dates of 16-day NDVI MODIS composites used for the development of strata for the Wyoming riparian area assessment.

7 April 01 – 22 Apr 01
9 May 01 – 24 May 01
10 Jun 01 – 25 Jun 01
12 Jul 01 – 27 Jul 01
13 Aug 01 – 28 Aug 01
14 Sep 01 – 29 Sep 01
7 Apr 02 – 22 Apr 02
9 May 02 – 24 May 02
10 Jun 02 – 25 Jun 02
12 Jul 02 – 27 Jul 02
13 Aug 02 – 28 Aug 02
14 Sep 02 – 29 Sep 02
7 Apr 03 – 22 Apr 03
9 May 03 – 24 May 03
10 Jun 03 – 25 Jun 03
12 Jul 03 – 27 Jul 03
13 Aug 03 – 28 Aug 03
14 Sep 03 – 29 Sep 03
6 Apr 04 – 21 Apr 04
8 May 04 – 23 May 04
9 Jun 04 – 24 Jun 04

Stratum 1: lowland rangelands and bare soils

Stratum 2: upland rangelands, forest lands

Stratum 3: irrigated agriculture, high-order riparian, ponderosa pine forests

Stratum 4: forest lands

Stratum 5: high alpine, sparse vegetation

Stratum 6: lakes and reservoirs

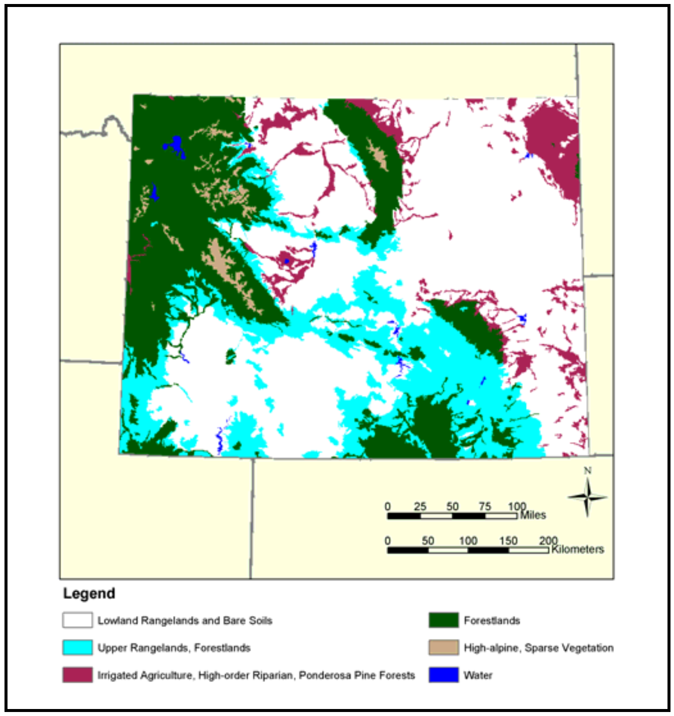


Figure 4—The state of Wyoming divided into six strata.

All analyses except for the final estimation include only the first five strata. Groups of pixels bearing the same stratum number define each of the five strata. Some of these groups consisted of only a single 250-meter pixel, which was too small an area to analyze. To eliminate these small groups, a minimum mapping unit size for the five strata was determined, and groups less than the minimum mapping unit size were assigned to an adjacent group of pixels belonging to a different stratum.

Using NHD to calculate stream density, Stratum 3 had the highest stream density (table 2). A systematic elimination of groups of pixels in Stratum 3 could significantly change the riparian composition of that stratum. Since Stratum 3 was the most sensitive to any changes, it was used to determine the minimum mapping unit. A loss of five percent of the area of Stratum 3 was determined to be acceptable. Five percent of the total area of Stratum 3 was comprised of groups of pixels less than or equal to 1,425 hectares. Thus, 1,425 hectares was selected as the minimum mapping unit for all strata, and groups of pixels that were less than 1,425 hectares in size were assigned to an adjacent stratum. The result of this process is a stratification layer where no contiguous area of any stratum is less than 1,425 hectares in size.

Table 2—National Hydrography Dataset (NHD) stream density by stratum for the state of Wyoming. Stratum 1 includes lowland rangelands and bare soils. Stratum 2 includes upland rangelands and forest lands. Stratum 3 includes irrigated agriculture, high-order riparian, and ponderosa pine forests. Stratum 4 includes forest lands and Stratum 5 includes high alpine and sparse vegetation.

Stratum	Stratum Area (hectares)	NHD Area per Stratum	Percent NHD per
1	12,870,477	1,070,345	8%
2	4,523,880	330,736	7%
3	1,555,484	212,499	14%
4	5,764,359	494,319	9%
5	462,330	27,114	6%

Identification of Primary Sampling Units

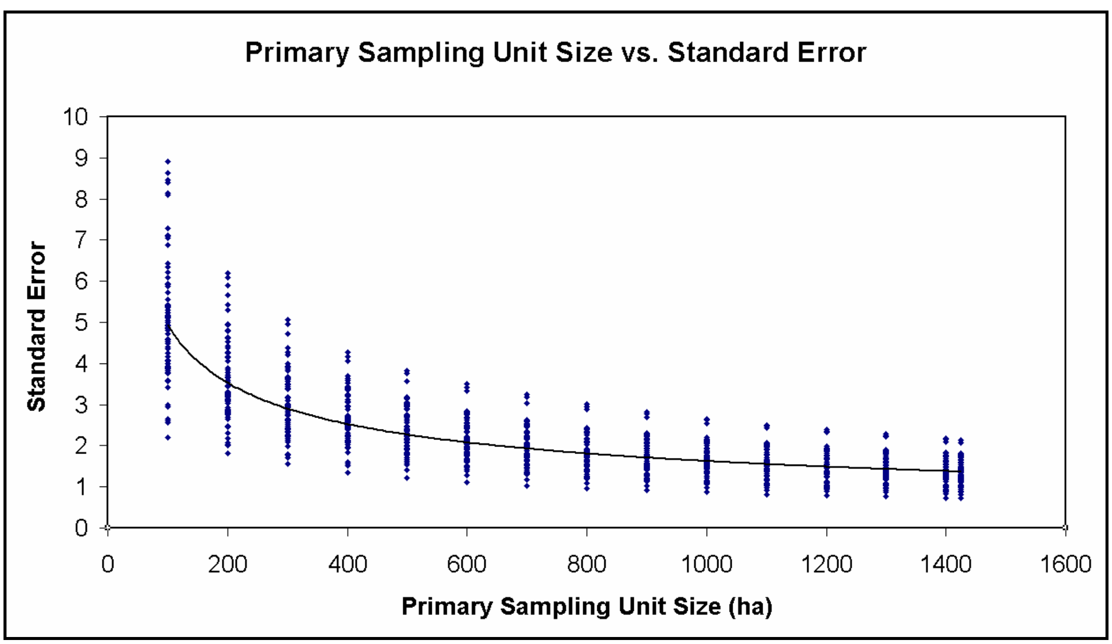
The moderate resolution imagery used for sampling of the strata with Primary Sampling Units (PSUs) was the GeoCover – Ortho product (www.mdafederal.com/geocover), hereafter referred to as GeoCover. GeoCover is a free, nation wide, 30-meter resolution dataset derived from three bands of Landsat7 data (bands 2, 4, and 7). GeoCover's classification of vegetation / not-vegetation was compared to that of native Landsat7. For this simple classification scheme, the comparison was favorable, so GeoCover was chosen for the moderate resolution sampling.

The first step in the identification of the PSUs was to select the size of the PSU. The PSU could not be larger than 1,425 hectares, which was the minimum mapping unit established through the merging process described above. The PSU should be sized to capture the variability with the minimum amount of area sampled. If most of the spectral variability with in a PSU is captured, most of the vegetation information contained within the PSU will be captured as well.

Within each stratum, five tests were conducted. Each test consisted of randomly selecting 15 areas of different sizes (100; 200; 300; 400; 500; 600; 700; 800; 900; 1,000; 1,100; 1,200; 1,300; 1,400; 1,425 hectares). Using GeoCover, spectral variances of these areas were calculated and charted. Figure 5 shows all the tests results for all the strata. Based upon these charts, a PSU size near the point of diminishing returns of 1,000 hectares captures most of the variability within the strata.

The number of PSUs for each stratum was chosen using similar methodology. Within each stratum, different numbers of PSUs of 1,000 hectares each were randomly selected. The numbers of PSUs used were 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200. Using GeoCover, spectral variances for each of these samples were compared and charted (figure 6).

Figure 5—Results of tests to determine the primary sampling unit size, which was selected at 1000 hectares.



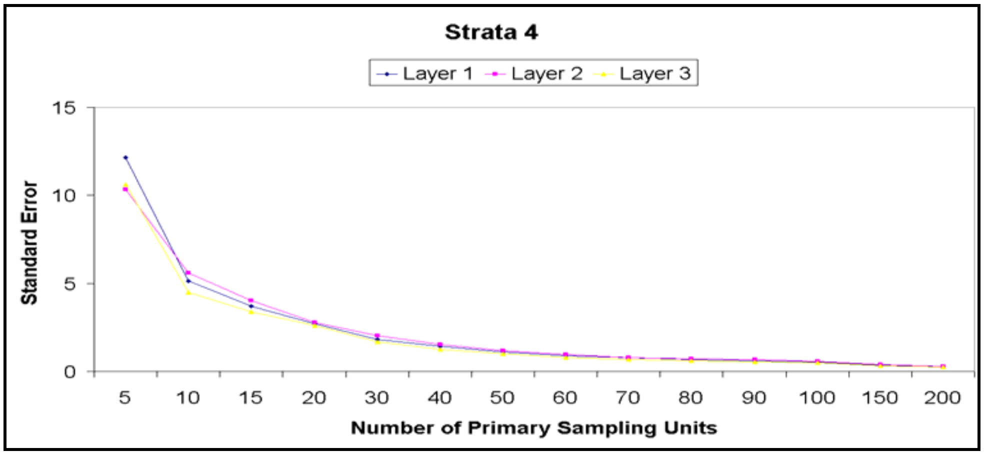


Figure 6—Example of a test to determine the number of primary sampling units in a stratum. For this particular stratum, 40 primary sampling units were chosen. The three layers refer to the three layers of the GeoCover product (Landsat bands 2, 4, 7; www.mdafederal.com/geocover).

The number of PSUs that captured sufficient variability was chosen for each stratum. The number of PSUs was different for each stratum. Stratum 1 had 100 samples; Stratum 2 had 150 samples; Stratum 3 had 90 samples; Stratum 4 had 40 samples, and Stratum 5 had 20 samples.

Identification and Classification of Riparian Areas

Within each stratum, the PSUs were randomly selected and a valley bottom analysis was performed on the PSUs. The valley bottom analysis entailed the creation of a Strahler-ordered stream network using 30-meter spatial resolution USGS National Elevation Dataset (NED, ned.usgs.gov) and the stream network generation commands in ArcInfo (Environmental Systems Research Institute 2002). The valley bottoms were created using a method developed by Goetz (2001). This method classifies areas as valley bottoms that are within a variable distance and differential elevation change orthogonal to the streams (table 3). The distance and elevation parameters used were recommended by Goetz (2001). In Idaho and Wyoming, Goetz (2001) measured distances and elevations of actual valley bottoms in the field. Relationships were formed between the distance and elevation values and stream order. Using this information, Goetz (2001) created models for valley bottoms using 30-meter spatial resolution digital elevation data. Gillham and others (2004) used these valley bottom parameters and models in Nevada with 10-meter spatial resolution elevation data with good success. Based on the literature and prior experience, the valley bottom parameters used for this project are believed to have modeled valley bottoms adequately. This project did not have a field component, however, so the accuracy of the valley bottom modeling was untested, and this test remains to be done in a follow up study.

The valley bottoms were also classified into nine classes based upon three valley bottom width criteria (< 30 meters, 30 – 90 meters, and > 90 meters) and three stream gradient criteria (< 3%, 3 – 6%, and > 6%) (Jensen and others 1997). The valley bottom width was

Table 3—Parameters used for the valley bottom delineations as recommended by Goetz (2001).

Strahler Stream Order	Elevation (meters)	Width (pixels)
1	1	1
2	3	2
3	4	3
4	5	5
5	6	10
6	8	15
7	8	15
8	8	15
9	8	15

measured perpendicular from the stream flow direction. The width was measured as the number of pixels. Diagonal distances were measured the same as vertical and horizontal distances. The stream gradient was the slope, calculated from the NED, of the stream network. Because this classification was performed on a pixel-by-pixel basis along the stream, the resulting slope-class segments contained some noise. To reduce the noise, the valley bottoms classifications were smoothed using focal analyses (figure 7).

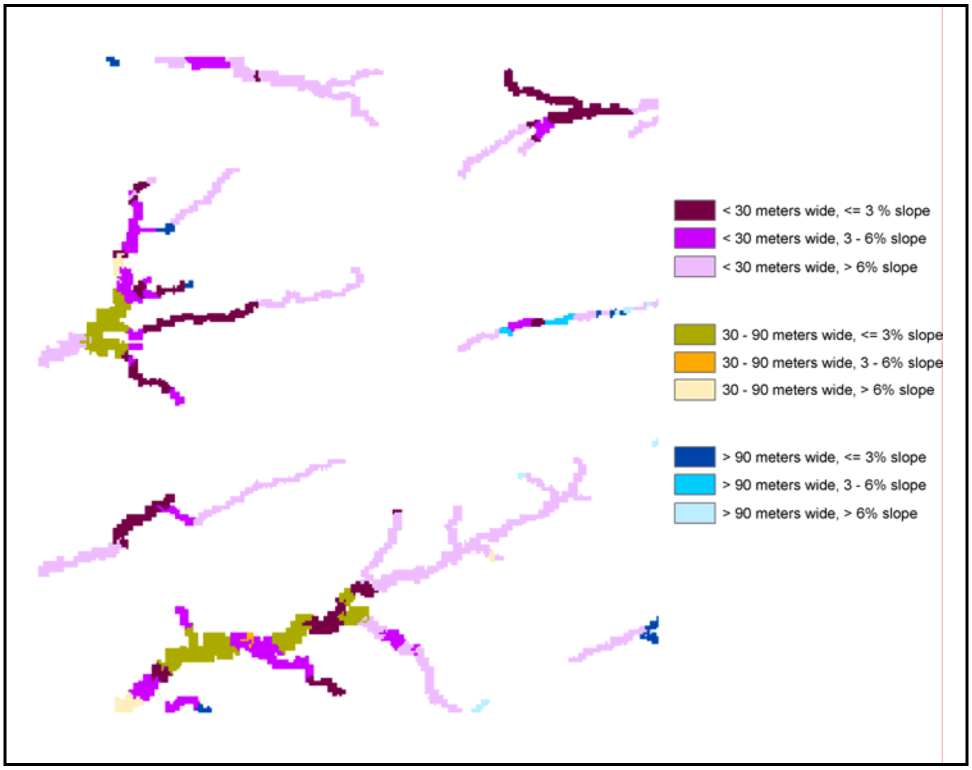


Figure 7—Example of a valley bottom classification.

One of the major assumptions of this methodology is that all vegetation occurring in the valley bottoms is riparian vegetation. However, since valley bottoms (particularly wide valleys), may include terraces and benches, riparian vegetation does not always extend fully across the entire width. Accordingly, the authors recognize that this assumption is not always correct because it is not possible to differentiate non-riparian vegetation from riparian vegetation. The riparian estimates derived from this methodology will nearly always overestimate the true amount of riparian area. A tertiary sample with higher resolution imagery or field data is needed to adjust the estimate.

Vegetation (from the imagery) was classified within the valley bottoms using See5 (Quinlan 1993, www.rulequest.com), a CART (Classification and Regression Trees) technique developed by Gillham and others (2004). This technique has been used on numerous projects at RSAC and is generally accepted as the best current method available.

The steps of the CART technique are:

- Mask the imagery for the PSUs in each stratum using valley bottom delineations. The imagery used for this project was the GeoCover image.
- Segment the masked imagery using eCognition. Each segment contains pixels with similar spectral properties.
- Calculate the mean pixel value within each segment to create a zonal mean image for the PSUs in each stratum.
- Select training segments. Training segments were comprised of manually selected riparian and non-riparian segments. Table 4 shows the number of segments chosen for each stratum.
- Extract the zonal mean data for the training segments.

Table 4—Image segments representing riparian/non-riparian vegetation were manually chosen for the development of See5 models. This table shows the number of segments chosen for model development and model testing. Stratum 1 includes lowland rangelands and bare soils. Stratum 2 includes upland rangelands and forest lands. Stratum 3 includes irrigated agriculture, high-order riparian, and ponderosa pine forests. Stratum 4 includes forest lands and Stratum 5 includes high alpine and sparse vegetation.

Number of Segments Used for See5 Model Development					
	Stratum 1	**Stratum 2**	**Stratum 3**	**Stratum 4**	**Stratum 5**
Riparian Segments	990	961	1796	2323	638
Non-riparian Segments	965	1613	1945	3320	630
Number of Segments Used for See5 Model Testing					
	Stratum 1	**Stratum 2**	**Stratum 3**	**Stratum 4**	**Stratum 5**
Riparian Segments	108	106	194	310	79
Non-riparian Segments	109	179	221	316	61
Total Segments	2172	2859	4156	6269	1408

- Use See5 to create models for the PSUs in each stratum with riparian/non-riparian as the dependent variable and the extracted zonal mean data as the independent variables.
- Apply the See5 models to the zonal mean imagery creating classified riparian/non-riparian PSUs in each stratum.

From the training segments, a randomly selected sample of ten percent of the training segments were withheld from model development and were used for accuracy assessment of the models, which was performed in See5. Table 4 shows the number of testing segments per stratum. The overall accuracy of the riparian classification was 98.9% (table 5). Stratum 5 had the lowest accuracy at 97.86%, and Stratum 1 had the highest accuracy at 100%. Note that these accuracies are relative to what is visible with 30-meter imagery, and samples with higher resolution imagery or field data are needed to assess their true accuracy.

Table 5—Accuracies of See5 models developed for Wyoming stratum classifications of riparian/non-riparian vegetation.

Stratum 1: Lowland Rangelands, Bare Soils			
	Riparian	**Non-riparian**	
Riparian	108	0	
Non-riparian	0	109	
		Overall Accuracy =	100.0%
Stratum 2: Upland Rangelands, Forestlands			
	Riparian	**Non-riparian**	
Riparian	106	0	
Non-riparian	2	177	
		Overall Accuracy =	99.3%
Stratum 3: Agriculture, Riparian, Pine Forests			
	Riparian	**Non-riparian**	
Riparian	193	1	
Non-riparian	2	219	
		Overall Accuracy =	99.3%
Stratum 4: Forestlands			
	Riparian	**Non-riparian**	
Riparian	306	4	
Non-riparian	7	309	
		Overall Accuracy =	98.2%
Stratum 5: High Alpine, Sparse Vegetation			
	Riparian	**Non-riparian**	
Riparian	78	1	
Non-riparian	2	59	
		Overall Accuracy =	97.9%
Wyoming			
	Riparian	**Non-riparian**	
Riparian	791	6	
Non-riparian	13	873	
		Overall Accuracy =	98.9%

Results - Calculation of Riparian Estimates

Table 6 shows the riparian estimates for the state of Wyoming and for the strata. These estimates were obtained from the riparian/non-riparian PSU classifications. The PSU riparian areas were summed for each stratum and for the state. Likewise, standard errors were calculated for the PSUs in each stratum and for the state. The sums and standard errors were divided by the total PSU area and multiplied by either the total stratum areas or the total state area to derive riparian estimates for the entire state and the strata.

Table 6—Wyoming riparian area estimates for the strata and for the state. Stratum 1 includes lowland rangelands and bare soils. Stratum 2 includes upland rangelands and forest lands. Stratum 3 includes irrigated agriculture, high-order riparian, and ponderosa pine forests. Stratum 4 includes forest lands and Stratum 5 includes high alpine and sparse vegetation.

	Total Riparian (hectares)	Percent of Riparian to Total Riparian	Standard Error	Percent of Standard Error to Riparian	Total Stratum Area (hectares)	Percent of Riparian in Stratum
Stratum 1	314,325	36%	44,730	14%	12,772,806	2%
Stratum 2	77,693	9%	8,259	11%	4,359,281	2%
Stratum 3	170,311	20%	11,465	7%	1,694,963	10%
Stratum 4	299,650	35%	39,149	13%	6,029,219	5%
Stratum 5	6,302	1%	1,175	19%	386,400	2%
Wyoming	868,281	100%	104,778	12%	25,242,669	3%

Wyoming has a total of 868,281 (104,778 standard error) hectares of riparian, which comprises three percent of the total area of Wyoming. The stratum with the most riparian area is Stratum 1 with 314,325 (44,730 standard error) hectares, but Stratum 1 also is the largest stratum with a total of 12.8 million hectares. Stratum 1 included the lowland rangelands and bare soils. The next stratum with the most riparian area is Stratum 4 with 299,650 (39,149 standard error) hectares, which comprises five percent of the total area of Stratum 4. Stratum 4 included the forested areas of Wyoming. The stratum with the highest density of riparian area is Stratum 3 with 170,311 (11,465 standard error) hectares of riparian, which comprises ten percent of the area of Stratum 3. Stratum 3 included the high-order streams and associated riparian areas. The stratum with the lowest riparian area with 6,302 (1,175 standard error) hectares was Stratum 5. This stratum included the high alpine areas.

To gain an understanding of the types of lifeforms that occur in riparian areas, riparian estimates were grouped by National Land Cover Data (NLCD, landcover.usgs.gov) classes. The NLCD was recoded into three classes: tree (NLCD codes: 41, 42, 43, and 91), shrub (NLCD codes: 51, 71, 81, 82, 83, 84, 85, and 92), and other (NLCD codes: 11, 12, 21, 22, 23, 31, 32, 33, and 61) (see landcover.usgs.gov/classes.asp). Wyoming is comprised of 85% shrub /herbaceous, 12% tree, and 3% sparsely vegetated. The amount of riparian area and the standard errors for these three classes were calculated for the state and for each stratum (table 7).

Table 7—Riparian estimates grouped by NLCD lifeform for Wyoming and all strata.

Riparian Vegetation Type	Hectares	Percent Lifeform Area to Total Area	Standard Error	Percent Standard Error to Lifeform Area
Wyoming				
Tree Lifeform	164,996	19%	28,566	17%
Shrub/Herbaceous Lifeform	691,906	80%	98,904	14%
Sparsely Vegetated	11,227	1%	4,765	42%
Stratum 1: Lowland Rangelands, Bare Soils				
Tree Lifeform	23,103	7%	9,485	41%
Shrub/Herbaceous Lifeform	289,210	92%	38,622	13%
Sparsely Vegetated	2,012	1%	820	41%
Stratum 2: Upland Rangelands, Forest Lands				
Tree Lifeform	8,372	11%	1,846	22%
Shrub/Herbaceous Lifeform	69,024	89%	7,464	11%
Sparsely Vegetated	237	0%	79	33%
Stratum 3: Irrigated Agriculture, High-order Riparian, Ponderosa Pine Forests				
Tree Lifeform	22,992	14%	2,881	13%
Shrub/Herbaceous Lifeform	142,126	83%	11,547	8%
Sparsely Vegetated	5,094	3%	2,307	45%
Stratum 4: Forest Lands				
Tree Lifeform	109,818	37%	14,141	13%
Shrub/Herbaceous Lifeform	186,173	62%	40,119	22%
Sparsely Vegetated	3,666	1%	1,485	41%
Stratum 5: High Alpine, Sparse Vegetation				
Tree Lifeform	711	11%	214	30%
Shrub/Herbaceous Lifeform	5,373	85%	1,152	21%
Sparsely Vegetated	218	3%	75	34%

Riparian area estimates were also calculated for the valley bottom classes for the state and strata (table 8). For strata 1-4 and the state, the majority of riparian area occurs in either wide to intermediate width (> 30 meters) and flat (< 3% slope) valleys or intermediate width (30 – 90 meters) and steep valleys (> 6% slope). Wide and flat valleys should have large amounts of riparian areas, but the high amount of riparian area in intermediate width and steep valleys is unexpected. Steep valleys should also be narrow and not have large riparian areas. In this case, the steep wide valleys can probably be explained by the spatial resolution of the data used for the project, which was 30 meters. A 30-meter valley bottom is actually only one pixel wide. For a valley bottom to be less than 30-meters wide, there must actually be no valley bottom and just the stream. This will only occur in the extremely narrow valleys. The valley bottom classification scheme was perhaps defined too narrowly for the spatial resolution used for this project.

Stratum 4 has the most riparian area in the intermediate width (30 – 90 meters) and steep (> 6% slope) valleys. Most of the riparian area in Stratum 5 also occurs in the intermediate width (30 – 90 meters) or narrow (< 30 meters) and steep (> 6% slope) valleys. Since both of these strata occur in mountainous regions, these results are to be expected. For the other strata and the state, the most riparian area occurs in the wide (> 90 meters) and flat (< 3% slope) valley bottoms.

Table 8—Wyoming riparian estimates grouped by valley bottom classes. Riparian estimates are in hectares followed by the standard errors in parentheses. The rows are organized by valley bottom widths (< 30 meters, 30 - 90 meters, and > 90 meters). The columns are organized by stream gradients (< 3%, 3 – 6%, and > 6%).

Wyoming			
	0% - 3%	**3% - 6%**	**> 6%**
> 90 m	297,211 (70,895)	54,148 (17,245)	29,153 (8,387)
30 m – 90 m	169,519 (35,897)	76,676 (12,190)	183,704 (26,557)
< 30 m	3,813 (1,363)	5,564 (1,523)	46,381 (8,407)
Stratum 1: Lowland Rangelands, Bare Soils			
	0% - 3%	**3% - 6%**	**> 6%**
> 90 m	136,716 (29,055)	33,570 (12,327)	12,340 (3,262)
30 m – 90 m	57,167 (11,127)	22,606 (3,592)	45,229 (8,984)
< 100'	1,382 (482)	1,762 (591)	3,460 (1,244)
Stratum 2: Upland Rangelands, Forest Lands			
	0% - 3%	**3% - 6%**	**> 6%**
> 90 m	18,163 (4,242)	4,944 (1,193)	3,408 (910)
30 m – 90 m	13,592 (2,174)	8,538 (1,388)	21,007 (2,849)
< 100'	238 (101)	630 (159)	8,571 (1,760)
Stratum 3: Agriculture, High-order Riparian, Ponderosa Pine Forests			
	0% - 3%	**3% - 6%**	**> 6%**
> 90 m	68497 (10,123)	7,309 (1,325)	3,672 (1,315)
30 m – 90 m	49,530 (6,238)	14,155 (1,605)	18,505 (2,056)
< 100'	1,080 (236)	1,425 (209)	6,051 (880)
Stratum 4: Forest Lands			
	0% - 3%	**3% - 6%**	**> 6%**
> 90 m	73,757(27,417)	8,177 (2,252)	9,571 (2,803)
30 m – 90 m	48,833 (16,221)	31,194 (5,522)	94,998 (11,872)
< 100'	1,095 (531)	1,747 (564)	26,962 (4,280)
Stratum 5: High Alpine, Sparse Vegetation			
	0% - 3%	**3% - 6%**	**> 6%**
> 90 m	77 (57)	148 (148)	163 (97)
30 m – 90 m	397 (136)	183 (83)	3,965 (795)
< 100'	18 (12)	0 (0)	1,337 (243)

The valley bottom classes were grouped into the three NLCD derived lifeform classes: tree, shrub/herbaceous, and sparsely vegetated. For the tree lifeform, the majority of the riparian area for the state and all strata except for Stratum 1 occurs in the narrow and intermediate width (< 90 meters) and steep (> 6% slope) valley bottoms (table 9). For Stratum 1, the most riparian area in the tree lifeform occurred in the wide (> 90 meters) and flat (< 3% slope) valley bottoms. For the shrub/herbaceous lifeform, the majority of the riparian area for the state and all strata also occurs in flat (< 3% slope) and wide (> 90 meters) valley bottoms.

Table 9—Wyoming riparian estimates grouped by valley bottom classes and lifeform for the strata and the state. Riparian estimates are in hectares followed by the standard errors in parentheses. The rows are organized by valley bottom widths (< 30 meters, 30 - 90 meters, and > 90 meters). The columns are organized by stream gradients (< 3%, 3 – 6%, and > 6%).

Tree

	0% - 3%	3% - 6%	> 6%
Wyoming			
> 90 m	25,366 (10,084)	12,224 (6,017)	11,290 (3,257)
30 – 90 m	28,636 (6,897)	26,322 (6,944)	28,121 (9,278)
< 30 m	6,203 (2,114)	9,268 (2,492)	50,448 (19,491)
Stratum 1: Lowland Rangelands, Bare Soils			
> 90 m	11,858 (5,296)	4,854 (3,733)	1,017 (432)
30 – 90 m	1,052 (446)	1,118 (467)	2,865 (1,463)
< 30 m	95 (95)	126 (121)	106 (65)
Stratum 2: Upland Rangelands, Forest Lands			
> 90 m	995 (807)	476 (182)	470 (77)
30 – 90 m	1,304 (272)	1,044 (117)	914 (726)
< 30 m	477 (9)	710 (10)	8,365 (489)
Stratum 3: Agriculture, Riparian, Pine Forests			
> 90 m	5,822 (1,257)	1,126 (313)	619 (224)
30 – 90 m	2,077 (416)	2,596 (554)	6,805 (1,201)
< 30 m	151 (71)	370 (94)	3,147 (686)
Stratum 4: Forest Lands			
> 90 m	6,685 (2,699)	5,767 (1,789)	9,173 (2,517)
30 – 90 m	24,147 (5,714)	21,559 (5,803)	17,127 (5,739)
< 30 m	5,481 (1,939)	8,061 (2,268)	38,649 (18,186)
Stratum 5: High Alpine, Sparse Vegetation			
> 90 m	7 (6)	1 (4)	10 (31)
30 – 90 m	56 (48)	5 (3)	410 (663)
< 30 m	0 (0)	0 (0)	181 (293)

Shrub

	0% - 3%	3% - 6%	> 6%
Wyoming			
> 90 m	213,076 (479,981)	57,469 (177,747)	42,517 (112,428)
30 – 90 m	147,993 (259,399)	61,817 (103,511)	78,456 (170,997)
< 30 m	8,828 (18,376)	12,161 (22,038)	16,564 (44,657)
Stratum 1: Lowland Rangelands, Bare Soils			
> 90 m	123,241 (25,181)	28,716 (9,266)	11,289 (2,991)
30 – 90 m	55,848 (11,020)	21,488 (3,340)	42,286 (8,443)
< 30 m	1,285 (424)	1,635 (547)	3,342 (1,216)
Stratum 2: Upland Rangelands, Forest Lands			
> 90 m	7,557 (3,611)	6,506 (1,077)	7,612 (849)
30 – 90 m	12,732 (1,960)	8,751 (1,357)	6,347 (2,598)
< 30 m	2,276 (101)	3,301 (155)	3,060 (1,181)
Stratum 3: Agriculture, Riparian, Pine Forests			
> 90 m	58,902 (9,297)	5,911 (1,186)	3,044 (1,172)
30 – 90 m	45,574 (5,992)	11,139 (1,469)	11,413 (1,371)
< 30 m	868 (192)	1,014 (172)	2,862 (390)
Stratum 4: Forest Lands			
> 90 m	23,321 (15,105)	16,191 (9,485)	20,421 (9,577)
30 – 90 m	33,536 (10,738)	20,293 (6,200)	15,033 (6,053)
< 30 m	4,390 (1,744)	6,211 (2,063)	6,211 (2,063)
Stratum 5: High Alpine, Sparse Vegetation			
> 90 m	55 (48)	146 (146)	152 (98)
30 – 90 m	303 (98)	146 (77)	3,377 (773)
< 30 m	10 (10)	0 (0)	1,088 (232)

Sparsley Vegetated

	0% - 3%	3% - 6%	> 6%
Wyoming			
> 90 m	4,961 (2,748)	494 (401)	343 (226)
30 – 90 m	2,572 (1,185)	803 (509)	795 (512)
< 30 m	128 (98)	109 (100)	264 (173)
Stratum 1: Lowland Rangelands, Bare Soils			
> 90 m	1,618 (7,548)	0 (0)	34 (256)
30 – 90 m	267 (1,100)	0 (0)	78 (456)
< 30 m	3 (29)	0 (0)	11 (115)
Stratum 2: Upland Rangelands, Forest Lands			
> 90 m	50 (591)	38 (266)	28 (182)
30 – 90 m	29 (307)	9 (26)	7 (190)
< 30 m	0 (0)	0 (0)	0 (0)
Stratum 3: Agriculture, Riparian, Pine Forests			
> 90 m	2,781 (14,009)	218 (1,910)	8 (54)
30 – 90 m	1,592 (6,225)	216 (1,210)	146 (547)
< 30 m	61 (277)	28 (209)	37 (225)
Stratum 4: Forest Lands			
> 90 m	496 (2,890)	236 (1,116)	272 (1,137)
30 – 90 m	659 (2,423)	577 (2,385)	453 (2,214)
< 30 m	64 (418)	81 (494)	163 (694)
Stratum 5: High Alpine, Sparse Vegetation			
> 90 m	16 (52)	1 (6)	0 (0)
30 – 90 m	24 (49)	2 (8)	111 (195)
< 30 m	0 (0)	0 (0)	6

Conclusions

The objective of this project was to generate and demonstrate a methodology to improve the sampling of sparse, linear, and widely distributed riparian environments. The methodology used in this project was effective in sampling large areas on the scale of states. The methodology used remote sensing imagery and other geospatial data that are available nationally, and can easily be scaled to other image resolutions or area sizes. Even though the riparian estimates (3.4% with a standard error of 0.4%) produced by this project for Wyoming are biased because of the inclusion of all vegetation not just riparian, they compare favorably to riparian estimates from much larger projects, such as Wyoming GAP (2.6%).

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