PB2000-107422

METHODS FOR MULTI-SPATIAL SCALE CHARACTERIZATION OF RIPARIAN CORRIDORS

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ABSTRACT: This paper describes the application of aerial photography and GIS technology to develop flexible and transferable methods for multi-spatial scale characterization and analysis of riparian corridors. Relationships between structural attributes of riparian corridors and indicators of stream ecological condition are not well established. As part of a research project focused on assessing riparian-stream systems in agricultural landscapes of Oregon's Willamette Valley, GIS land cover/land use databases were created from 1997 aerial photography and digital orthophotography for 23 predominantly agricultural watersheds, including detailed land cover/land use coverages within 150 m of perennial and intermittent streams. GIS functions were used to partition the stream networks at various lateral-longitudinal scales to quantify land cover/land use and to generate functionally relevant metrics of riparian vegetation, such as its composition, width, and continuity. The methods developed provide considerable flexibility for generating metrics characterizing attributes of riparian corridors and for exploring relationships among these metrics and indicators of stream ecological condition.

KEY TERMS: Willamette Valley; agricultural landscapes; riparian corridor; watershed; aerial photography; GIS

INTRODUCTION

Riparian plant communities are widely considered critical for maintaining stream ecological condition (Gregory *et al.* 1991). Aquatic functions of riparian vegetation include: 1) providing stream shading, 2) contributing large woody debris and fine organic matter, 3) regulating the flux of upland-derived sediments, nutrients, and other chemicals, and 4) stabilizing stream banks (Brinson *et al.* 1981, Malanson 1993). The principal structural attributes of riparian corridors affecting the above functions include the composition, width, and continuity of natural vegetation adjacent to and along the stream network (Malanson, 1993, Forman 1997). The relationships between riparian structural attributes and stream ecological condition are not well established. Because these relationships are likely to be scale-dependent, effective methods are necessary for addressing the effects of spatial scale on the strength of associations between riparian and watershed structural attributes and biotic, chemical, and physical indicators of stream condition.

As part of the U.S. Environmental Protection Agency's Pacific Northwest Research Program (Baker *et al.* 1995), research is being conducted to determine the effect of riparian areas on the ecological condition of small, perennial streams in agricultural landscapes of the Willamette Valley (Moser *et al.* 1997). The overall objective of this research is to quantify relationships between remotely-sensed riparian and watershed structural attributes at varying spatial scales and field-based indicators of stream ecological condition. Stream ecological condition indicators were derived from field measurements of biotic assemblages, water chemistry, and physical habitat in a single stream reach at the base of each study watershed. A stream reach was defined as 40 times its mean wetted width during summer, low flow conditions; and, for our study, stream reaches ranged from 150 to 320 m in length. Currently, statistical relationships between reach-level indicators of stream ecological condition and riparian and watershed attributes upstream of the sampling reach are being investigated (see Wigington *et al.* this volume). This paper extends the methods reported by Schuft *et al.* (1999) from a sampling strategy to a full multi-scale characterization of riparian areas along the entire stream network; and, provides specific applications of these methods beyond the objective of the current research.

METHODS

The study was conducted on 23 watersheds (about 15 to 87 km^2) distributed throughout Oregon's Willamette Valley (Figure 1A). The Willamette Valley is predominantly an agricultural landscape of approximately 13,165 km^2 lying between the Coast Range on the west and the Cascade Range on the east; and, represents one of the largest concentrations of

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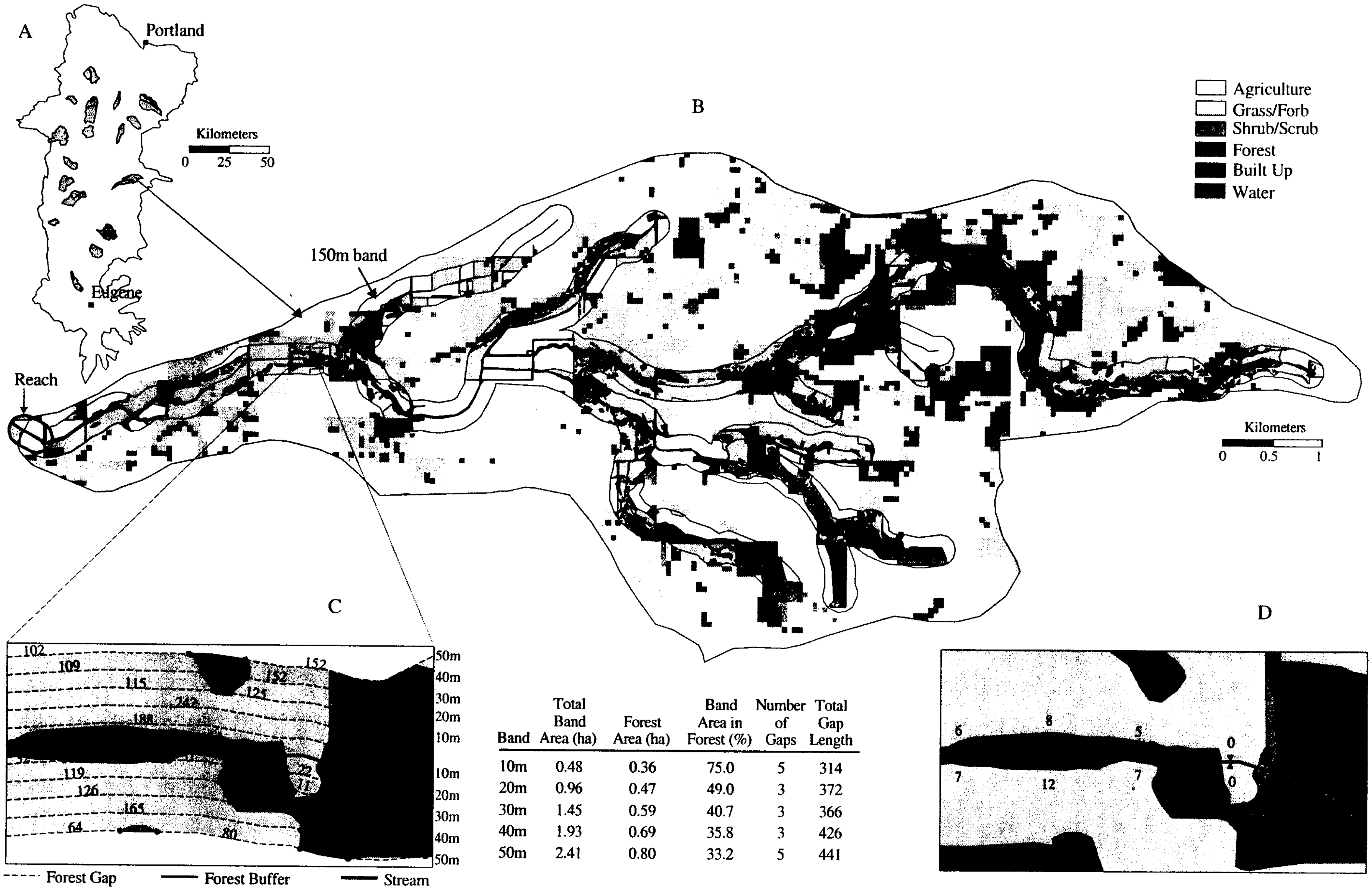

Band	Total Band Area (ha)	Forest Area (ha)	Band Area in Forest (%)	Number of Gaps	Total Gap Length
10m	0.48	0.36	75.0	5	314
20m	0.96	0.47	49.0	3	372
30m	1.45	0.59	40.7	3	366
40m	1.93	0.69	35.8	3	426
50m	2.41	0.80	33.2	5	441

Figure 1. Location of the 23 study watersheds within the Willamette Valley (A); distrubution of six LCLU classes in the Bear Branch watershed and within the 150 m band on both sides of the stream network (B); segment of Bear Branch demonstrating the use of 10 m incremental banding for calculating percent LCLU (e.g., forest) and the number and length (m) of gaps between forest patches as a function of distance from the stream (C); and, the same segment of Bear Branch demonstrating the use of arcs perpendicular to the stream for estimating the width (m) of riparian vegetation, such as forest (D).

diversified agriculture in the Pacific Northwest, with substantial areas in grass seed cropping systems. Because the focus of the study is to determine the influence of riparian areas on the ecological condition of small, perennial streams in agricultural landscapes, the selection of the study streams and associated riparian systems was restricted to streams draining watersheds lying within the Valley's Prairie Terraces and Foothill ecoregions (Pater *et al.* 1998) Additional selection criteria included watersheds having a large proportion of their area in agriculture and having no urban development.

Color-infrared aerial photography (1:31,680) of the study watersheds was flown in mid July 1997. Digital orthophotos with a minimum resolvable unit of about one meter were created from the aerial photos. The watershed for each of the sampled stream reaches was determined from 1:24,000 USGS topographic maps and subsequently delineated on the digital orthophotos. Perennial and intermittent streams were delineated directly on the digital orthophotos to create a geographic information system (GIS) coverage for each stream network. A detailed classification system, modified after Anderson *et al.* (1976), was used to interpret and characterize land cover/land use (LCLU) of the riparian corridor, defined in this study as a 150 m banded area adjacent to and along each side of the stream network (Figure 1B). The riparian corridor classification system incorporated 49 LCLU classes, including: 1) forest (pastured and non-pastured coniferous, deciduous, and mixed forest, each with three canopy closure types, for a total of 18 subclasses), 2) clear-cut, 3) tree plantation, 4) pastured and non-pastured shrub/scrub, 5) pastured and non-pastured grass/forb, 6) agriculture (13 subclasses); 7) built-up (five subclasses), 8) barren, 9) water (three subclasses), and 10) other. The riparian corridor polygon coverage was digitized with a minimum mapping unit of 0.1 ha. It was produced with the intention of being able to capture narrow patches of riparian vegetation along the stream network. Watershed LCLU was characterized using a more generalized classification system which incorporated 18 LCLU classes, including: 1) forest, 2) clear-cut, 3) shrub/scrub, 4) grass/forb, 5) agriculture (9 subclasses), 6) built-up (two subclasses), 7) barren, 8) water, and 9) other. The watershed coverage (Figure 1B) was created using a grid composed of 0.25 ha square polygons in which the dominant LULC class was assigned to each polygon.

Prior to the interpretation of riparian LCLU, extensive field reconnaissance was conducted during the summer of 1997 to record agriculture land use adjacent to and along both sides of the stream networks in the 23 watersheds. During the photo-interpretation process, additional field reconnaissance was conducted to classify problematic polygons. Upon completion of the GIS coverages, ground-truthing was conducted in each watershed to estimate the classification accuracy of the photo-interpreted LCLU within the riparian corridor. Based on 1,889 ground observations, the overall classification accuracy was 84.1%. At the highest level in the classification hierarchy, user's accuracy was over 90% for forest, agriculture, built-up, barren, and water; and over 80% for shrub/scrub and grass/forb.

We are developing approaches and methods for multi-spatial scale characterization of riparian structural attributes across and along the corridor's lateral and longitudinal dimensions (i.e., potential areas of influence). Data from this multi-spatial scale approach are being used to investigate empirical relationships between metrics characterizing riparian structural attributes and indicators of stream ecological condition (see Wigington *et al.* this volume). GIS functions and programs are being used to band and partition the riparian corridor into various lateral-longitudinal combinations. The lateral dimension captures the cross-sectional structure of the riparian corridor, while the longitudinal dimension captures the linear structure along the riparian corridor. As shown in Figure 1C, the composition of riparian LCLU is being characterized using GIS clipping functions to incrementally band the riparian corridor. In this example, the proportional area of forest as a function of distance from the stream was calculated in 10-m incremental bands out to 50 m for both sides of a short segment of Bear Branch. Figure 1C also illustrates the use of banding to address the continuity of natural riparian vegetation (e.g., forest, shrub/scrub, and grass/forb), where the number and length of gaps between forest patches were calculated as a function of distance from the stream. As shown in Figure 1D, the width of the riparian buffer is being estimated from arcs aligned perpendicular to both sides of the stream at 50-m intervals. In this example, the width of the forest cover immediately adjacent to the stream was measured to the outer edge of contiguous forest cover.

Investigations of the effects of riparian structural attributes on stream ecological condition can be enhanced with the development of methods for partitioning the riparian corridor along its longitudinal dimension. We used GIS clipping functions to partition the 150-m laterally banded riparian corridor into several longitudinal sections (i.e., the reach, and absolute distances along the perennial and intermittent streams of 500, 1,000, 2,500, 5,000, 7,500, 10,000 m above the reach, as well as the entire network above the reach). This approach allows for the characterization of riparian structural attributes at multiple lateral and longitudinal scales along the riparian corridor, such as LCLU composition within a 10-m lateral distance from the stream over a 10,000-m longitudinal distance above the stream reach. Figure 2 illustrates this approach for riparian LCLU composition, where the proportional area of three selected LCLU classes are plotted as a function of distance from the stream at four different longitudinal scales of Bear Branch, including the 150-m stream reach, and absolute distances along the primary channel and tributaries of 1,000 m, 10,000 m, and entire network above the reach. Width and gap measurements of defined riparian buffers can also be calculated for multiple lateral and longitudinal scales.

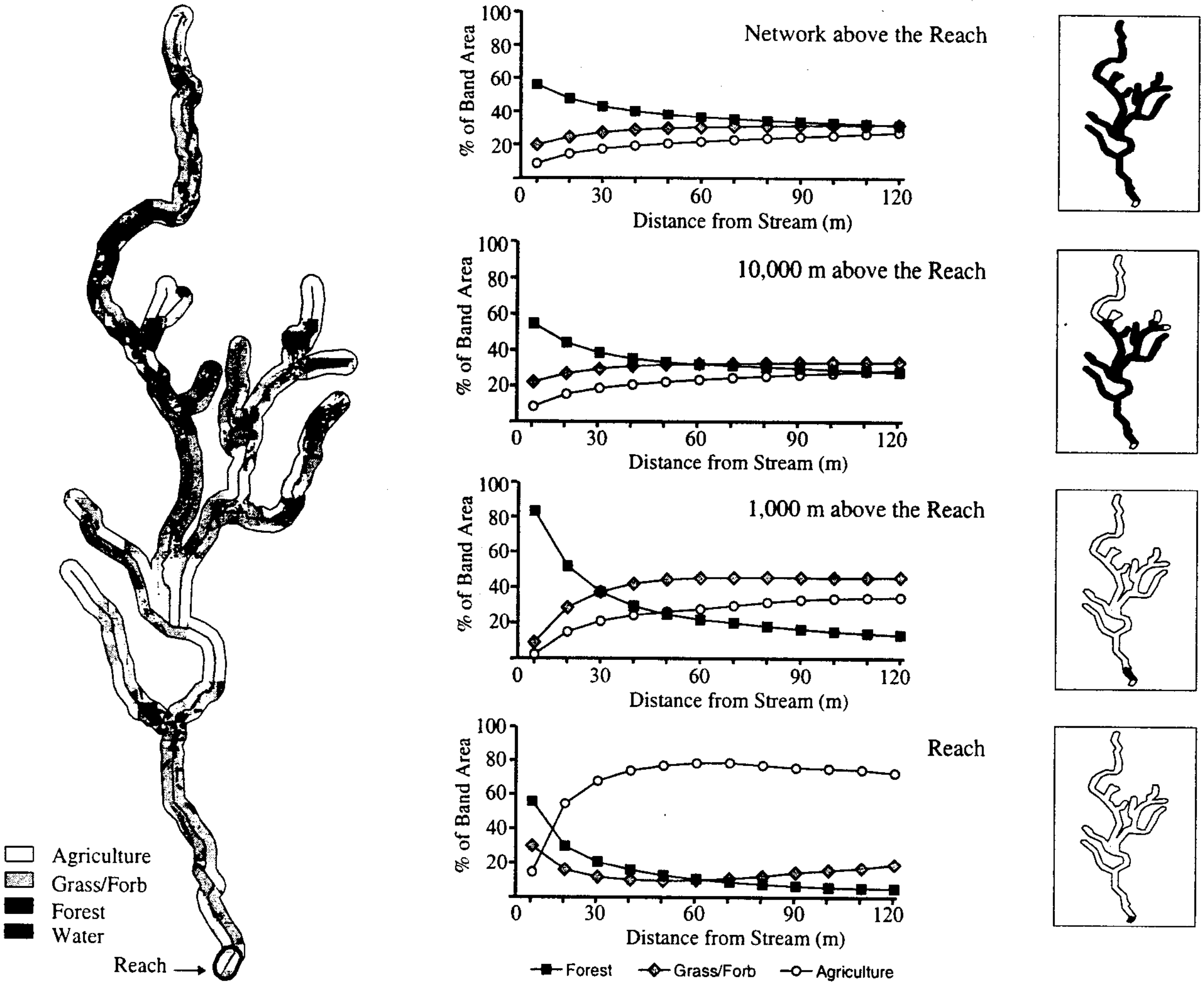

Figure 2. Comparison of Bear Branch LCLU as a function of distance from the stream over four longitudinal scales of the stream network.

RESULTS AND DISCUSSION

An important consideration in designing a study to predict stream ecological condition through the use of spatially explicit LCLU data is the ability to explore the effect of spatial scale on the strength of associations between a suite of explanatory landscape variables and various response variables derived from stream measurements of biotic assemblages, water chemistry, and physical habitat. Researchers conducting watershed-scale studies have used LCLU maps or GIS data to demonstrate scale-dependent relationships between land cover composition and/or pattern to indicators of stream condition (Barton, 1988, Lammert and Allan 1999, Roth *et al.* 1996, Steedman 1988). The methods for characterizing riparian corridors that are discussed in this paper build upon the work of others, particularly Roth *et al.* (1996) and Schuft *et al.* (1999).

Compositional metrics, such as the proportion of an individual LCLU class or a combination of LCLU classes relative to a unit area, are easy to generate and are often used to demonstrate statistical relationships with stream condition indicators (Lammert and Allan 1999, Osborne and Wiley 1988, Roth *et al.* 1996, Steedman 1988). These metrics are also useful in the initial, more descriptive phases of LCLU data analyses, where comparisons among study areas and between different landscape units within the same study area can reveal overall trends and lead to questions about the distribution of LCLU within the watershed and along the stream network. For example, Table 1 lists the percent composition of selected LCLU classes for five of our 23 watersheds at two different spatial scales, watershed and riparian corridor. A considerable range in percent areal cover for forest, grass/forb, and agriculture at both the watershed and riparian corridor spatial scales can be seen. Because of their potential contributions to riparian buffer functions, it is interesting to note the greater proportion of area in forest, shrub/scrub, and/or grass/forb at the riparian corridor scale compared to the watershed scale. With the exception of Butte Creek, the proportional area in agriculture was less at the riparian corridor scale than at the watershed scale.

Table 1. Areal cover of selected LCLU classes for five of the 23 Willamette Valley watersheds and their associated riparian corridors at the 30-m lateral and network longitudinal scale (including the stream reach).

	Percent of Watershed Area					Percent of Riparian Corridor Area				
Watershed Name	Forest	Shrub/ Scrub	Grass/ Forb	Ag	Built	Forest	Shrub/ Scrub	Grass/ Forb	Ag	Built
Howell Prairie Creek	3.7	0.6	3.6	89.0	2.9	23.3	12.9	20.6	38.0	1.1
Spoon Creek	4.6	0.4	12.3	81.6	0.7	7.4	2.6	17.5	70.2	1.9
Case Creek	9.8	1.8	12.5	71.1	3.8	45.5	20.2	16.3	4.7	1.0
Bear Branch	16.4	2.8	28.5	50.5	1.6	42.4	10.4	26.7	17.0	1.3
Butte Creek	46.8	2.6	12.5	28.9	0.7	45.6	6.2	15.3	29.5	1.4

Because of the spatial heterogeneity within landscapes (see Figure 1), an analysis of LCLU data for an entire watershed or for an entire riparian corridor (as in Table 1) may fail to discover finer spatial scale relationships between riparian structural attributes and stream ecological condition. The investigation of the composition of LCLU classes at varying lateral and longitudinal scales can provide important insights on the distribution and pattern of LCLU along a stream network. Figure 2 shows there are clear distinctions in the distribution of the three LCLU classes plotted for Bear Branch as the scale increases in both a lateral and longitudinal direction. Although forest declined and agriculture increased as a function of distance from the stream at the four longitudinal scales shown, the rate of change in both LCLU classes was much more pronounced at the reach scale and 1,000 m above the reach scale than at the two larger scales. Grass/forb increased as a function of distance from the stream at longitudinal scales above the stream reach. Thus, characterization of riparian LCLU only adjacent to an in-stream sampling reach may give a misleading picture of the entire riparian corridor. The incremental banding of riparian corridors is an effective approach allowing for the visualization of spatial variability among riparian attributes; and, for conducting explicit examinations of the affects of riparian LCLU over a range of lateral-longitudinal combinations on stream ecological condition.

The width and continuity of riparian vegetation along stream networks are important structural attributes affecting stream ecological condition (Barton *et al.* 1985, Castille *et al.* 1994, Forman 1997, Weller *et al.* 1998). However, metrics addressing these attributes are more difficult to quantify than compositional metrics and require additional definition and linkages to riparian functions of interest. Width and gap calculations were made using the methods illustrated in Figures 1C and 1D and frequency distributions of riparian vegetation for the Bear Branch network were plotted for two buffer types. Figure 3 shows distinct differences in width and gap lengths between the two buffer types. The forest buffer was narrower with a greater number of long gaps than the forest-shrub/scrub-grass/forb buffer, illustrating that width and continuity of a riparian buffer are dependent upon its compositional components. About 17% of the network streambank had a forest buffer width of more than 30 m, compared to about 44% for the forest-shrub/scrub-grass/forb buffer (Figure 3A). From inspection of the y-intercept in Figure 3A, a forest buffer was absent on about 37% of the streambank, compared to about 8% for the forest-shrub/scrub-grass/forb buffer. Continuity metrics provide information addressing the number and length of gaps between riparian vegetation patches along the stream network. For example, the forest and forest-shrub/scrub-grass/forb buffers had a total of 296 gaps (ranging from 1 to 887 m in length) and 63 gaps (ranging from 1 to 600 m in length), respectively. About 50% of the gaps for the forest buffer were greater than 30 m, while 15% of the gaps for the forest-shrub/scrub-grass/forb buffer were greater than 30 m (Figure 3B). Additional gap metrics can be generated from this basic information, such as mean gap length and variation and the number of gaps per unit length of streambank or lateral band.

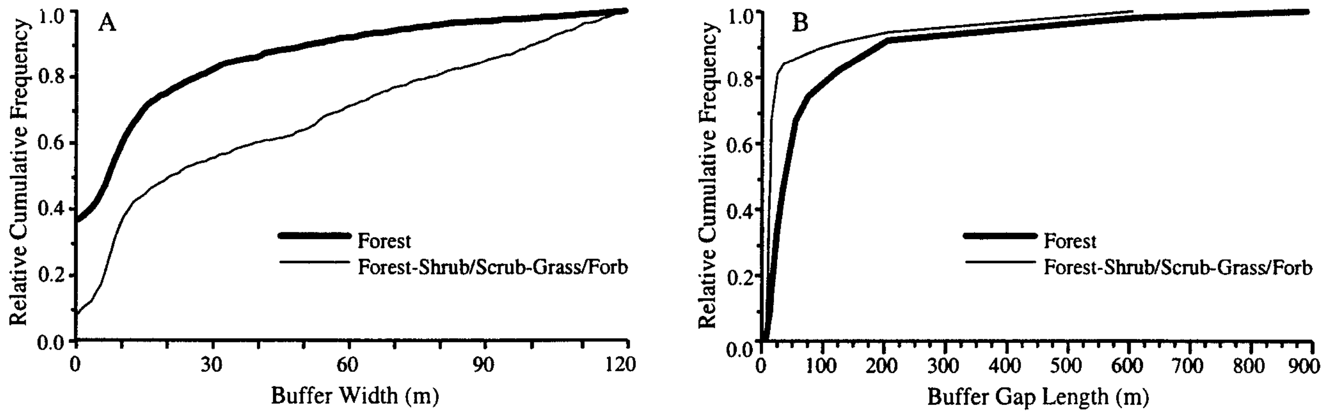

Figure 3. Relative cumulative frequency distributions of width (A) and gap length (B) for two riparian buffer types for the Bear Branch network. Width was measured at 50-m intervals as shown in Figure 1D. The number and length of gaps between buffer vegetation on the network streambank was determined as shown in Figure 1C.

The methods described provide considerable flexibility and are broadly applicable for multi-scale characterization and analysis of riparian and watershed GIS LCLU coverages. Partitioning the stream network into longitudinal segments provides a method for investigating the influence of riparian structural attributes, such as LCLU composition and width and gap metrics, on temperature or water quality data obtained from a series of in-stream reaches along a longitudinal gradient. Because the contribution of forest vegetation in moderating stream temperature and providing large woody debris diminishes with distance from the stream, the incremental banding approach provides the ability to generate data that "drive" riparian process models of shading or woody debris input at the entire stream network scale. Mapping and graphically displaying the riparian LCLU data at various lateral-longitudinal combinations provides the ability to identify sites for field studies, such as process-level investigations of nutrient and sediment regulation. Finally, GIS LCLU coverages created from aerial photography or high resolution, multi-spectral satellite imagery provide continuous data along a stream network and offer alternatives to field-based inventory in conducting riparian assessments.

ACKNOWLEDGMENTS

We thank Lynne McAllister and Stephanie Gwin for their help in conducting initial field reconnaissance of agricultural land use, and Denis White and Peter Lattin for critical reviews of the document. The research described in this document has been funded by the U.S. Environmental Protection Agency, Western Ecology Division in Corvallis, Oregon through Contract 68-C6-0005 to Dynamac Corporation. It has been subjected to the Agency's peer and administrative review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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WED-00-044

TECHNICAL REPORT DATA

(Please read instructions on the reverse before completing)

1. REPORT NO. EPA/600/A-00/021	2.	3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE Methods for multi-spatial scale characterization of riparian corridors.

5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) Thomas J. Moser[1], Dale R. Lindeman[1], P.J. Wigington[2],Michael J. Schuft[3],John Van Sickle[2]

8. PERFORMING ORGANIZATION REPORT NO.

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Salem, OR 97310

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

US EPA ENVIRONMENTAL RESEARCH LABORATORY
200 SW 35th Street
Corvallis, OR 97333

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA/600/02

15. SUPPLEMENTARY NOTES:

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Willamette Valley, agricultural landscapes, riparian corridor, watershed, aerial photography, GIS		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES: 6
	20. SECURITY CLASS *(This page)*	22. PRICE

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