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ASSESSMENT OF SPATIAL CONTINUITY OF EROSION-PRONE RIPARIAN AND VALLEY VEGETATION AREAS, CHEWUCH RIVER, WASHINGTON

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to

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and

WINTHROP RANGER DISTRICT, OKANOGAN NATIONAL FOREST

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Director

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KEY WORDS

landscape analysis, riparian vegetation, rivers, soil erosion, spatial continuity

INTRODUCTION

The Chewuch River basin (531 mi^2) is a major tributary to the Methow River in north central Washington (Fig. 1). A major issue in the Chewuch River basin involves the input and deposition of erosional materials in tributary streams and the main river channel (Chewuch River Watershed Analysis 1994). The objective of this assessment is to demonstrate a method that defines the spatial continuity of erosion-prone vegetative areas. Erosion-prone refers to vegetation having plant structures and functions with low potentials for preventing the erosion of soils. The vegetation areas of interest are those areas occurring close together and containing similar vegetative characteristics. The areas of high spatial continuity (e.g., where high values describing erosion-prone plant areas are close to other high values) may be at greatest risk to erosion.

The products of this assessment are as follows:

- descriptions of the spatial continuity of vegetative areas that are erosion prone, and that co-occur with soil areas having moderate and high erosion potentials;
- recommendations for applying the method that quantifies the spatial continuity of vegetative to the evaluation of other erosion-prone areas, and to the implementation of management actions (e.g., design of riparian reserves, and restoration sites within riparian and stream).

STUDY AREA

The vegetative areas of the riparian corridor and valley of the Chewuch River provide a unique opportunity for examining the spatial distribution of vegetation in this drainage. This area can be viewed as two, large superpositioned vegetative patterns that have plant communities and distributions commonly developing along abrupt gradients of moisture and landforms that arise between dry lowlands and wetter uplands. The primary limiting factor for downstream vegetative patterns is water. Upstream, water as a limiting factor decreases as steep landforms and periodic disturbances become more important in maintaining the plant distribution and diversity. The vegetative zones in the Chewuch River valley are dominated by steppe meadows and Ponderosa pine (*Pinus ponderosa*) in the lowlands, and Douglas fir (*Pseudotsuga menziesli*) and Subalpine fir (*Abies lasiocarpa*) in the uplands (Chewuch River Watershed Analysis 1994).

The geology, soils, natural disturbance regimes, ecological characteristics, and management history of the Chewuch River basin all contribute to the input and deposition of erosional materials to numerous sites located in the valley near the main Chewuch River channel and within several tributary streams (e.g., Eightmile, Boulder, and Twentymile creeks) (Chewuch River Watershed Analysis 1994). Excessive sediment deposits within channels can adversely impact fishery resources of the region (Wissmar et al. 1994, McIntosh et al. 1994). The main channel of the Chewuch River contains some of the most important spawning habitats for spring chinook salmon (*Oncorhynchus tshawytscha*) within the Methow River drainage.

The river valley and tributary watersheds of the Chewuch River basin contain landforms and ecological areas that experience relatively frequent natural and man-induced disturbances. These

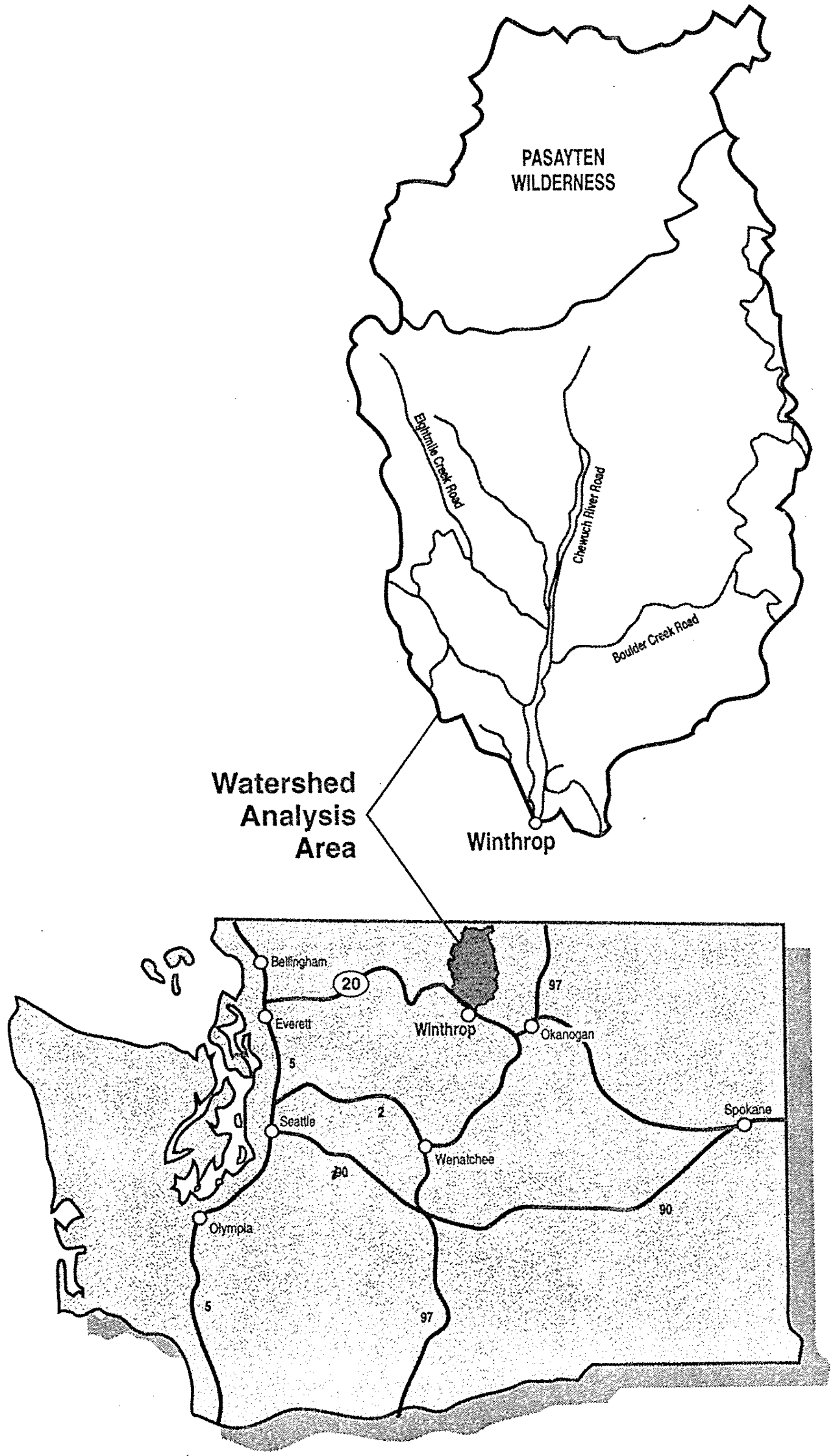

Figure 1. The Chewuch River is a tributary to the Methow River in north central Washingtion (Chewuch River Watershed Analysis (1994) .

areas include steep slopes, unstable soils, and geologic formations that coincide with plants associations that have low potentials for preventing soil erosion. Such areas can be sensitive to frequent natural disturbances (fires and floods) and land-use practices (timber harvest, roads, livestock grazing, recreation), which can induce erosion. Moreover, many of the forest stands (type, age, structure) that occur in these areas can be in early developmental or recovery stages that are very sensitive to repeated disturbances. These stands contain root and canopy structures that can be functionally ineffective in stabilizing soils, hillslopes, and streambanks. Other vegetative areas that may be erosion-prone when disturbed include open steppe-grass areas and mountain meadows. If these areas are subjected to cumulative disturbances, the result can be persistent erosion problems over long time periods.

METHODS

The spatial continuities of the vegetative areas were evaluated for eight river reaches of the Chewuch River valley. The length of a reach along the river was defined by the confluences of major tributary streams with the main river channel (Fig. 2). The reaches from downstream to upstream are Cub-Boulder, Boulder-Eightmile, Eightmile-Falls, Falls-Doe, Doe-Twentymile, Twentymile-Lake, Lake-Trench, and Trench-Windy. These reaches lie within a gradient of different vegetative zones that extend from the Cub Creek confluence with the main river upstream (~30 miles) to Windy Creek (Chewuch River Watershed Analysis 1994).

The spatial continuity of erosion-prone vegetative areas was assessed by determining the covariance, C(h), between paired vegetative areas (V_i, V_j) at different separation distances (h). The hypothesis is that high C(h) values for vegetative pairs (V_i, V_j) indicate the close proximity of erosion-prone areas. In other words, high C(h) values should indicate where the spatial continuity is high (e.g., high C(h) values describing erosion-prone plant areas should be close to other high values).

The determination of the spatial continuity the vegetative areas uses a covariance model that has been successfully applied to a variety of geological (Isaaks and Scrivastava 1989) and ecological (Rossi et al. 1992) systems. The covariance, C(h), is defined as follows:

$$C(h) = 1/N(h)\ \Sigma_{(i,j),l\ hij} = h\ (V_i \cdot V_j) - (m_{-h} \cdot m_{+h}) \quad (1)$$

where the vegetative data values are $V_i \cdot\cdot V_j$, and the summation is for only the N(h) pairs of data whose locations are separated by the distance (h). The value m_{-h} is the mean of all the data points whose locations are -(h) away from other data locations and is defined as follows:

$$m_{-h} = 1/N(h)\ \Sigma_{il\ hij} = h\ V_i \quad (2)$$

The value m+h is the mean of all the data points whose locations are +(h) away from other data locations and is defined:

$$m_{+h} = 1/N(h)\ \Sigma_{jl\ hij} = h\ V_j \quad (3)$$

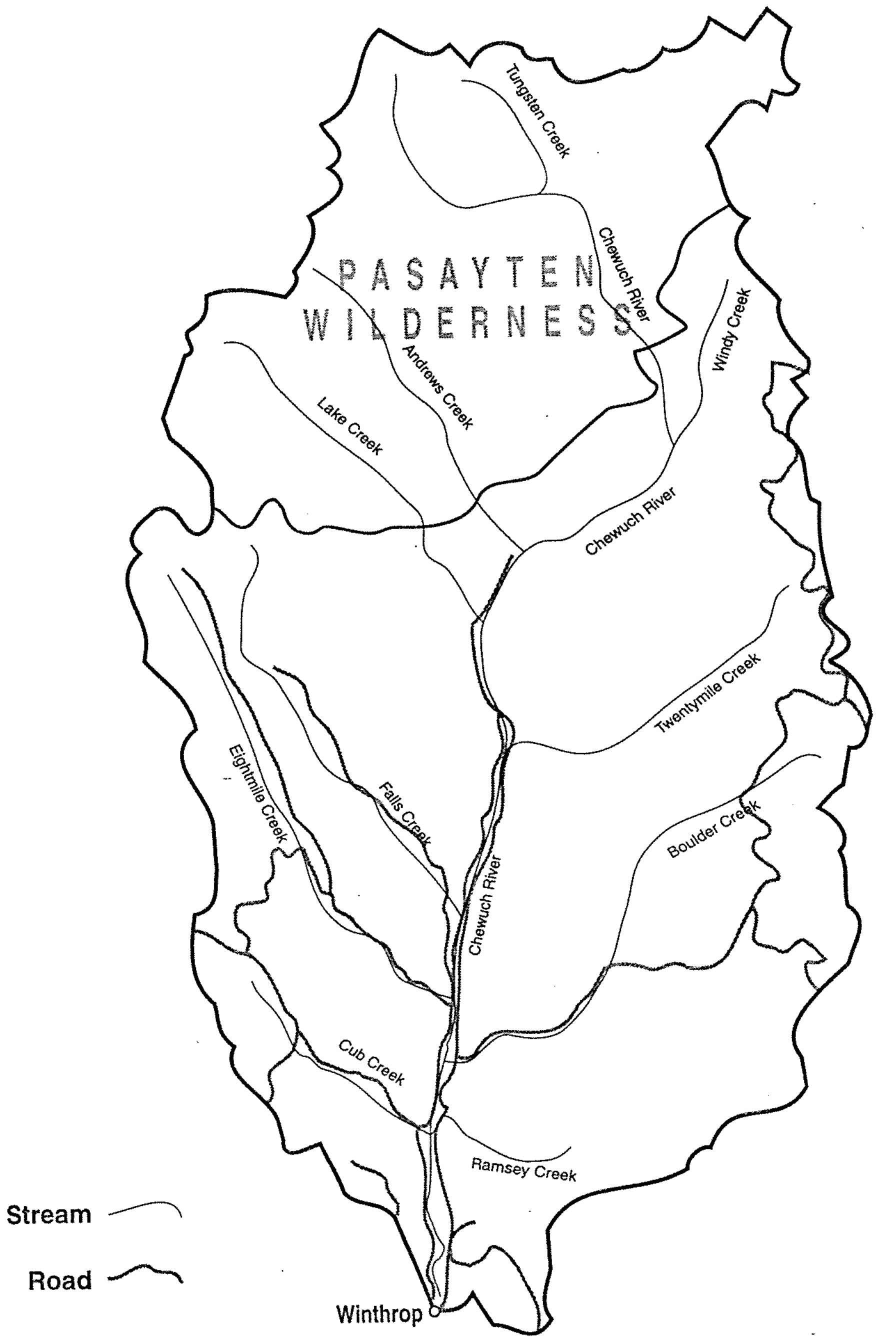

Figure 2. Locations of the major tributary watersheds.within the Chewuch River basin (Chewuch River Watershed Analysis 1994).

The covariance C(h) is a statistic that provides a quantitative summary of the spatial continuity between paired vegetation areas. The covariance (eq. 1) depends on the magnitude of the areas and the length of the separation distance (h). The relationships between C(h) and the separation distances (h) are used to assess the spatial continuity between paired vegetation areas (V_i, V_j) within the different reaches. The C(h) values that show the maximum change (e.g., slope) at the different separation distances are important indicators of erosion-prone vegetative areas.

The data for the stand structures, soil erosion potentials, and riparian reserve areas include files from the Supervisor's Office of the Okanogan National Forest for the Chewuch River Watershed Analysis (1994). The files are layers used in the geographical information systems (GIS). Stand structure layers are considered to be some of the most accurate GIS layers provided by Pacific Meridian satellite reflectance (Paul Nash, Tonasket Ranger District, Okanogan National Forest, Tonasket, Washington, pers. comm.). The forest stand structure layers used in this assessment include seedling, sapling, and pole forest stands with < 23 cm diameter dbh (PS); unforested grass-meadow areas (G); and shrubs (S). The layers for soil erosion potentials (moderate and high erosion) were derived by using soil texture characteristics and digital elevation model (DEM) information for slope and aspect (Ken Radeke, Okanogan National Forest, Okanogan, Washington, pers. comm.).

The vegetative areas PS, G, and S (represented by pixels) were sampled on moving window grids (Isaaks and Scrivastava 1989) that cover each side of the river channel (Fig. 3). The right and left sides of the river were assigned in the upstream direction. Each window represents a 10 x 10 pixel grid with each cell representing one pixel (length 38 m). The sampling scenario used overlapping windows of pixel grids to increase the sample size (Isaaks and Scrivastava 1989). The number of grids per reach ranged from 7 to 12 and also facilitated an adequate sample size within grids (N >30). Each count on the grid included a sample pair (V_i, V_j) and the distance (h) between the pair. A sample pair represents two separate areas with each area being defined by the number of pixels. The sampling procedure allowed a minimal magnitude on the distance (h) of 19 m (0.5 pixel). The tolerance on sampling directions, North-South (NS) and East-West (EW), within the windows (grids) for sample pairs also was 19 m (0.5 pixel). This criteria permitted the enumeration of adjoining pixels (patches of pixels).

The vegetative areas PS, G, and S were defined as erosion-prone according to limitations of canopy functions and rooting structures. The PS stands commonly exhibit canopies that are not

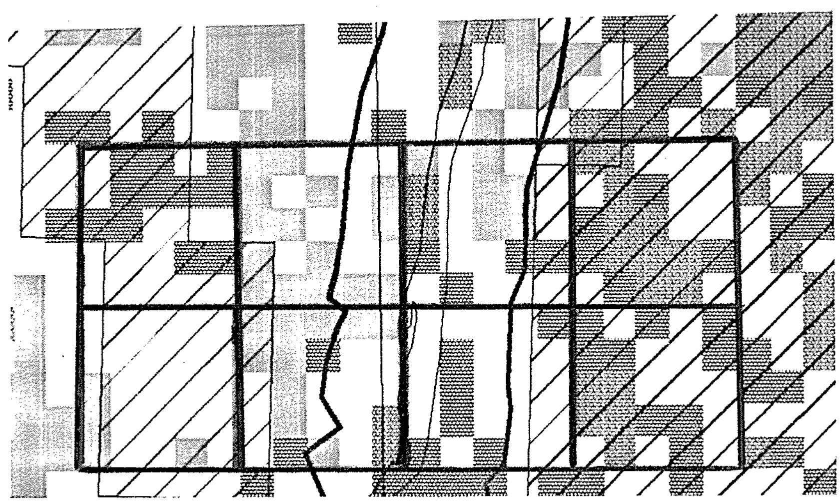

Figure 3. Example of grids for sampling erosion-prone vegetative areas along eight reaches of the Chewuch River. Shaded squares (pixels) represent erosion-prone vegetative areas (PS, G, S); cross-hatched areas represent potentially erodable soils; and irregular lines on each side of the river channel represent 90-m riparian reserve widths.

fully closed. Such "open-canopy forests" of the Pacific Northwest region are viewed as areas where stands have "recently" experienced disturbances (e.g., fires, timber harvest) that remove vegetation. These forest stands usually do not develop crown closures until after ~30 years (Wallin et al. 1994) in forests west of the Cascade Mts. and possibly longer time spans in eastern Washington and Oregon. Immature and poorly developed open-canopy forest stands are readily distinguished from mature closed canopy forest stands (Hansen et al. 1991). The immature and poorly developed stands can also have minimal rooting strengths (Sidel et al. 1985). The G and S areas of this steep-sloped drainage were also defined as erosion-prone because their aboveground biomass and root structures can be dysfunctional in stabilizing soils, hillslopes, and streambanks.

The potential for erosion in PS, G and S areas is related to aboveground plant structures (tree canopies, grasses, shrubs) that have low evapotranspiration rates. Low evapotranspiration in open areas can increase rates of snow melt, surface runoff, and waters input to soils. On steep slopes, where evapotranspiration could be minimal, excess water storage can occur belowground. The increased mass of water, along with the downward force of gravity, induces erosion and in some cases land failures. Erosion can be enhanced when PS, G and S areas having poor rooting strengths (e.g., root losses due to decomposition) (Hansen et al. 1991, Sidel et al. 1985), coinciding with unstable soils (Wissmar and Beer 1994), and experiencing cumulative disturbances like timber harvest, road construction, soils compaction, and livestock grazing.

RESULTS

Vegetative Areas (V_I and V_J) and Separation Distances (h)

Grid counts of the vegetative areas (V_i and V_j) indicated that the smallest areas commonly occur at the shorter separation distances. For example, in the Lake-Trench reach, the V_i areas that were 1444 m^2 in size were most frequent at the 19-m and 38-m separation distances (Fig. 4). The 1444 m^2 area was also observed at the separation distances of 76, 144 , 152, 190 and 228 m. The other areas (2888 m^2, 4332 m^2, and 5776 m^2) were less frequent at these separation distances (Fig. 4). Similar patterns were observed for the V_j areas. The Lake-Trench reach comprises a vegetative transition area between the Ponderosa pine and Douglas fir/Subalpine fir forests.

The combinations of the paired areas (V_i, V_j) varied within the different vegetative zones of the Chewuch River valley. Comparison of paired areas (V_i, V_j) at the 19-m separation distance within the Lake-Trench and Eightmile-Falls reaches show the differences in the number of different paired areas within the two reaches (Figs. 5 and 6). The Eightmile-Falls reach lies mostly within Ponderosa pine forests with some transition areas between steppe meadows to Ponderosa forests.

The Lake-Trench reach contained eight types of paired areas (Fig. 5, Table 1). The most frequent paired areas included two pairs (1444 m^2 and 1444 m^2 , 2888 m^2 and 1444 m^2) at frequency counts of 59 and 28, respectively. The areas of all the types of pairs (V_i, V_j) are defined in Table 1.

The Eightmile-Falls reach contained a larger number of paired areas (19 types) than the Lake-Trench reach (Fig. 6, Table 2). The three most frequent pairs (1444 m^2 and 1444 m^2 , 2888 m^2

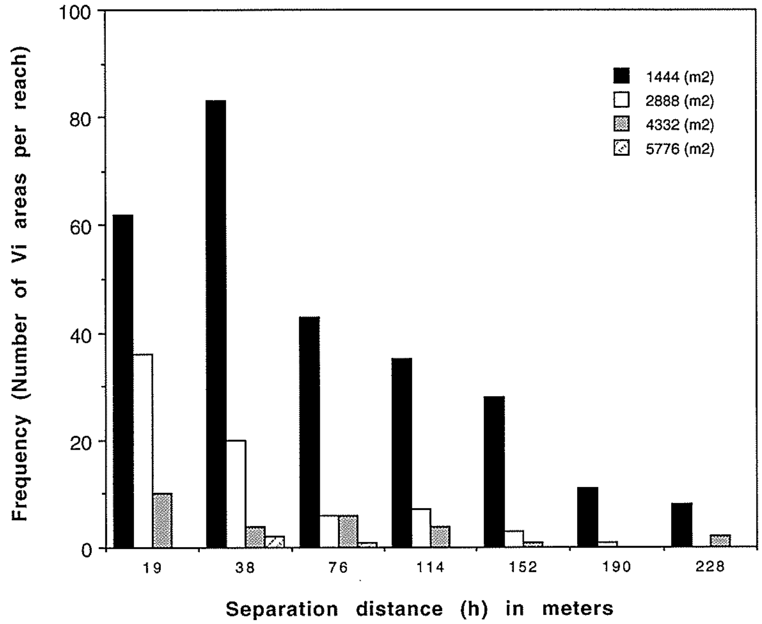

Figure 4. Frequency of the V_i areas at different separation distances (h) within the Lake-Trench reach of the Chewuch River.

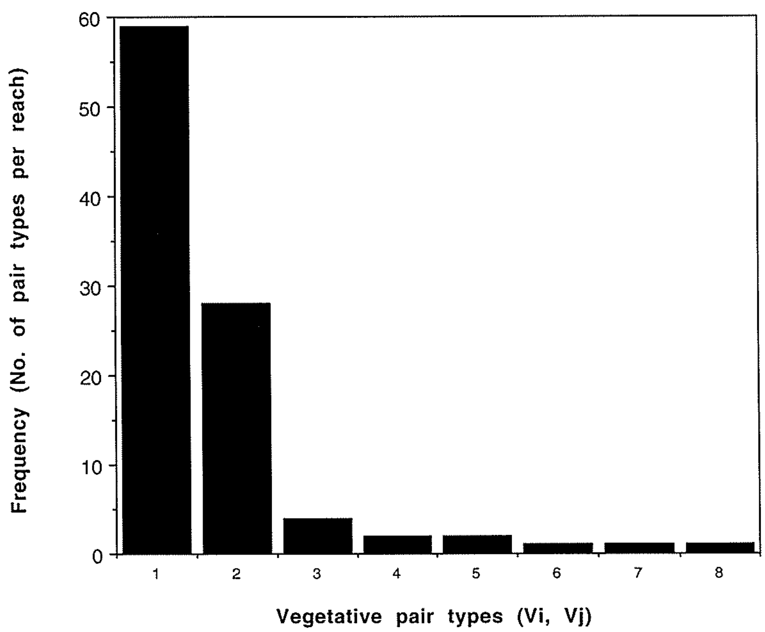

Figure 5. Frequency of the paired vegetative V_i, V_j types for the (h) 19 m separation distances that occurred within the Lake-Trench reach of the Chewuch River. See Table 1 for paired types which represent different combinations for the V_i and V_j vegetations areas (ha). The total V_i and V_j areas (ha) were estimated from the frequency counts and areas (m^2) for V_i and V_j within the reach. The total areas are expressed as hectares (ha) or 10,000 m^2.

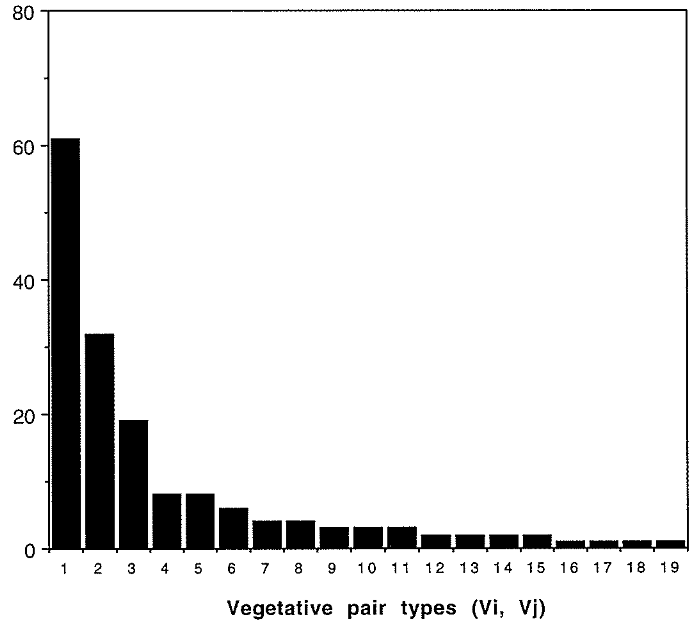

Figure 6. Frequency of the paired vegetative (V_i, V_j) types for the (h) 19 m separation distance that occurred within the Eightmile-Falls reach of the Chewuch River. See Table 2 for paired types which represent different combinations for the V_i and V_j vegetations areas (ha). See Figure 5 for definition of areas.

Table 1. The V_i and V_j vegetative areas for the (h) 19 m separation distances that occurred within the Lake-Trench reach of the Chewuch River. The total areas for the reach were estimated from the frequency counts for the respective V_i and V_j areas (m^2). The total areas are expressed as hectares (ha) or 10,000 m^2.

	V_i, V_j	Area (m^2)		Total area (ha)	
Frequency	pair type	V_i	V_j	V_i	V_j
59	1	1444	1444	8.52	8.52
28	2	2888	1444	8.09	4.05
4	3	4332	1444	1.73	0.58
2	4	2888	2888	0.58	0.58
2	5	1444	2888	0.29	0.58
1	6	4332	1444	0.43	0.14
1	7	2888	4332	0.29	0.43
1	8	1444	4332	0.14	0.43

Table 2. The Vi and Vj vegetative areas for the (h) 19 m separation distances that occurred within the Eightmile-Falls reach of the Chewuch River. See Table 1 for definition of areas.

Frequency	V_i, V_j pair type	Area (m^2)		Total area (ha)	
		V_i	Vj	V_i	Vj
61	1	1444	1444	8.81	8.81
32	2	2888	1444	9.24	4.62
19	3	1444	2888	2.74	5.49
8	4	1444	4332	1.16	3.47
8	5	2888	2888	2.31	2.31
6	6	5776	1444	4.62	0.87
4	7	2888	5776	1.16	2.31
4	8	4332	1444	1.73	0.58
3	9	1444	5776	0.43	1.73
3	10	1444	11552	0.43	3.47
3	11	4332	2888	1.30	0.87
2	12	1444	10108	0.29	2.02
2	13	2888	4332	0.58	0.07
2	14	5776	2888	1.16	0.58
2	15	10108	2888	2.02	0.58
1	16	1444	8664	0.14	0.87
1	17	7220	5776	0.72	0.58
1	18	10108	1444	1.01	0.14
1	19	14440	1444	1.44	0.14

and 1444 m^2, and 1444 m^2 and 2888 m^2) had frequency counts of 61, 32 and 19, respectively. The areas of all the types of pairs (V_i, V_j) are defined in Table 2.

A scatterplot for the Eightmile-Falls reach shows all the possible V_i and V_j areas located at separation distances of 19, 38, and 76 m (Fig. 7), which represent 163, 152, and 56 pairs, respectively. The V_i and V_j areas, number of pairs, and (h) 19-m distances are defined in Table 3. This scatterplot describes the parameters involved in the evaluation of the spatial continuity of vegetative areas in different reaches of the Chewuch River valley.

Spatial Continuity of Paired Vegetation Areas (V_i, V_j)

The C(h) describes the spatial continuity between paired vegetation areas (V_i, V_j) by providing quantitative measures of the covariances between the pair values. For example, the scatterplot of Eightmile-Falls reach (Fig. 7, Table 3) shows a larger number of plots at the (h) 19 distance. These plots contribute most to the covariance between pairs at this separation distance. The large sized areas, which plot the farthest from the origin, also make major contributions to large C(h) values. C(h) values for the V_i and V_j parameters, and separation distances of 19, 38, and 76 m in Figure 7 are listed in Table 3.

The spatial continuity of the vegetation areas within a reach is assessed by evaluating relationships between C(h) and the separation distances (h). Examples of the relationships between C(h) and (h) are shown for the Lake-Trench and Eightmile-Falls reaches (Fig. 8). The C(h) values indicate that the covariance between the paired areas becomes stronger as the distance between

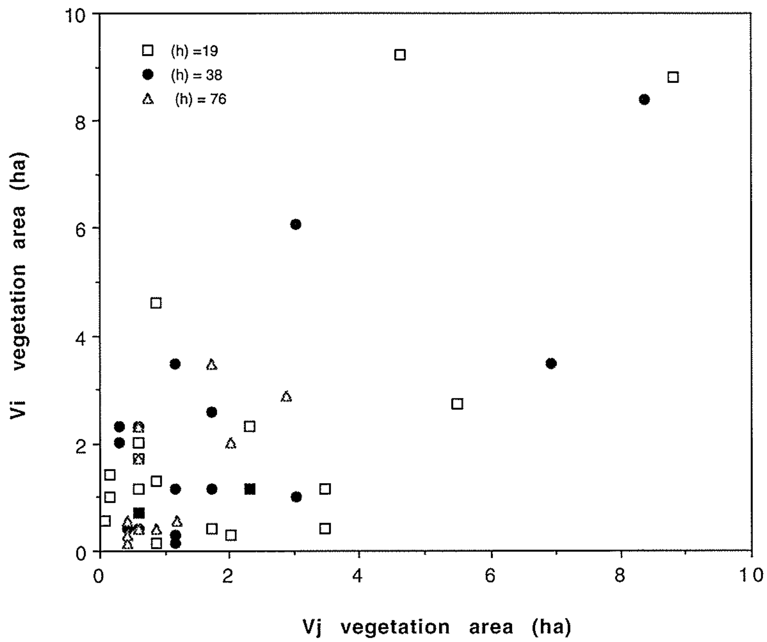

Figure 7. A scatterplot for the Eightmile-Falls Creek reach of all the possible pair values (total areas of V_i, V_j) whose locations are separated by 19, 38, and 76 m separation distances (h). See Figure 5 for definition of areas.

Table 3. The separation distances (h), number of vegetative pairs (V_i, V_j), ranges of total V_i and V_j areas (ha), and C(h) values for the Eightmile-Falls reach of the Chewuch River. The C(h) values for the 19, 38 and 76 m separation distances describe the spatial continuity of the erosion-prone vegetative areas. See Table 1 for definition of areas.

(h) (m)	No. pairs (V_i, V_j)	Range of total V_i areas (ha)	Range of total V_j areas (ha)	Covariance C(h)
19	163	0.29 to 9.24	0.14 to 8.81	349, 710
38	152	0.14 to 8.38	0.29 to 8.38	161,182
76	57	0.14 to 3.47	0.43 to 2.89	80,674

the paired locations decreases. The maximum C(h) values occur at the smallest (h) distance of 19 m. The higher C(h) values between the V_i, V_j pairs for Eightmile-Falls than Lake-Trench indicates the closer proximity of erosion-prone vegetative areas within the Eightmile-Falls reach. The vegetation areas of the Eightmile-Falls reach lie within the steppe meadows-Ponderosa transition areas and Ponderosa forests stands. The C(h) value for the (h) 19-m distance of the Eightmile-Falls reach was 349,710, two times greater than the C(h) value (179,218) for the Lake-Trench reach (Fig. 8).

The C(h) values that show the maximum change (e.g., slope) at the other separations distance are also important indicators of erosion-prone vegetative areas (Fig. 8). For the Eightmile-Falls reach (Fig. 8), these C(h) values occur at the separation distances of 38 and 76 m and show a steady

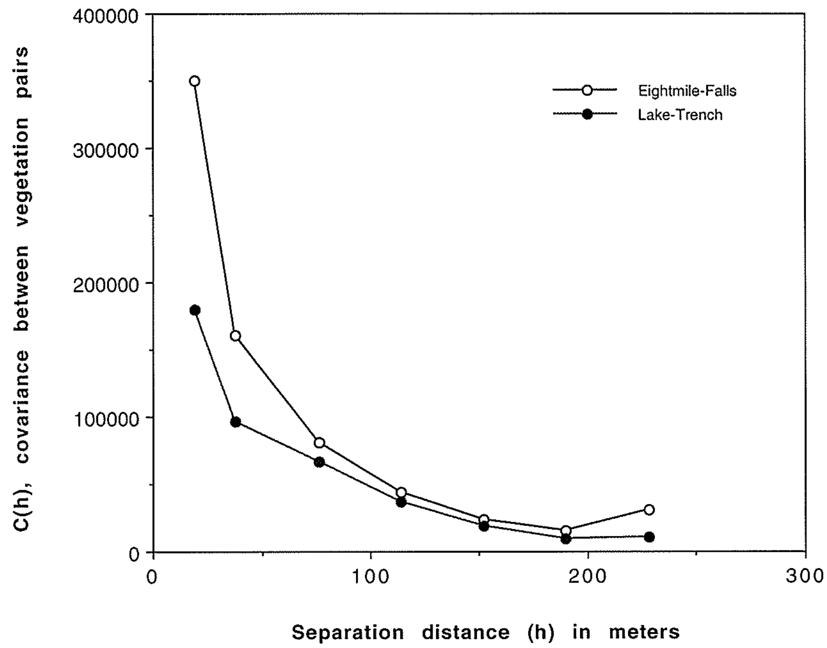

Figure 8. C(h) and (h) relationships for the Lake-Trench and Eightmile-Falls reaches of the Chewuch River. The C(h) values for separation distances (h).describe the spatial continuity of the erosion-prone vegetative areas.

decline in covariance as the distance between pairs increases. As C(h) decreases at separation distances >114 m, the lower C(h) values between the V_i, V_j pairs indicate minimal spatial continuity between erosion-prone vegetation areas a the wider separation distances.

An important result of assessing the C(h) and (h) relationships for the different reaches was that the relationships provided consistent information about the spatial distribution of vegetative patches relative to the channel. This finding was based on high correlations between C(h) values estimated from separate NS and EW directional grid counts within each reach. An example of the similarity of the C(h) and (h) relationships estimated for NS and EW directional counts is shown for the Lake-Trench reach (Fig. 9). The correlation between the C(h) values was r = 0.97. Because the correlations for the directional counts (NS and EW) were consistently high for all reaches, the relationships between C(h) and the separation distances (h) for the different reaches only represent the NS directional counts.

Spatial Continuity of Vegetative Areas Within the Eight River Reaches

The relationships between C(h) and (h) for the vegetative areas of the eight river reaches of the Chewuch River valley showed similar patterns. However, there were considerable differences in the magnitudes of the C(h) values among reaches. The higher C(h) values were observed within the three most downstream reaches, Cub-Boulder, Boulder-Eightmile, and Eightmile-Falls (Fig. 10). These three reaches showed C(h) of >300,000 at the 19-m (h) distance. The Cub-Boulder reach

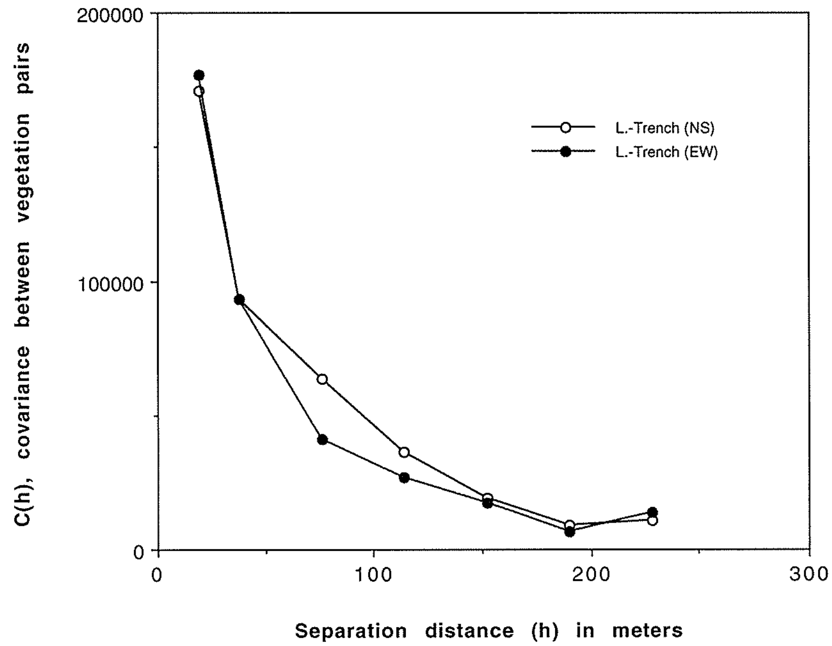

Figure 9. Comparisons of C(h) and (h) relationships estimated from NS and EW directional grid counts with the Lake-Trench reach of the Chewuch River. See Figure 8 for definition of C(h) values.

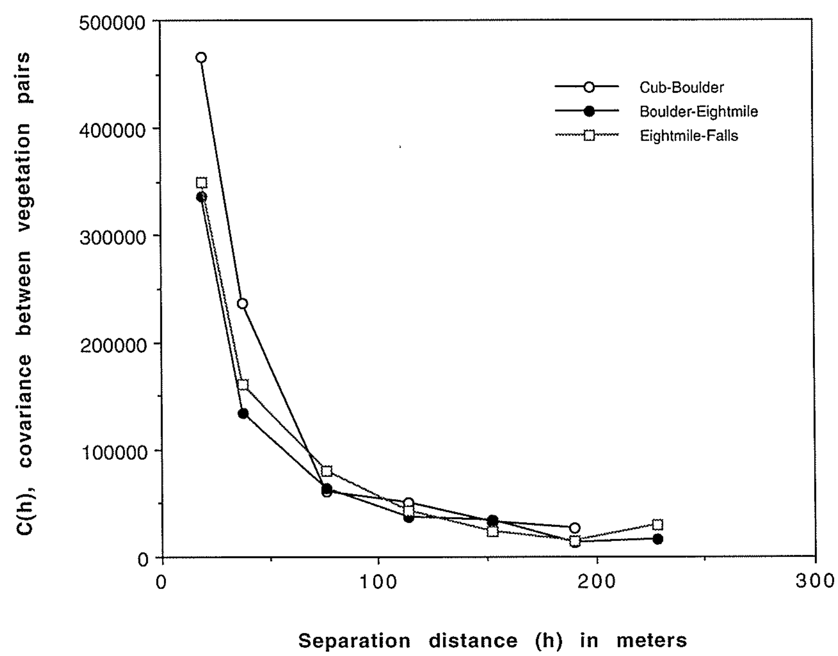

Figure 10. Comparisons of C(h) and (h) relationships for the Cub-Boulder, Boulder-Eightmile, and Eightmile-Falls reaches of the Chewuch River. See Figure 8 for definition of C(h) values.

had the highest C(h) values (466,349 and 236,710) at the separation distances of 19 and 38 m, respectively. Cub-Boulder, the most downstream reach, lies within vegetation zones dominated by steppe meadows and steppe meadows-Ponderosa forest transition areas. This reach contains grass areas on terraces with lesser amounts of shrubs on the floodplains. Small pole stands of Ponderosa forests were infrequent in this reach. The other two reaches, Boulder-Eightmile and Eightmile-Falls, also lie within steppe meadows-Ponderosa forest transition areas and Ponderosa forest stands. The Ponderosa forests of these reaches contained PS stands and dispersed shrub and grass areas.

The Boulder-Eightmile and Eightmile-Falls reaches contained the largest C(h) values for reaches dominated by Ponderosa forest stands (Fig. 10). As in the other reaches, the highest covariances occurred at the shorter separation distances. However, the C(h) values at the separation distance of 19 m in both reaches were highest on the right side (upstream direction) of the river. For the Eightmile-Falls reach (Fig. 11), the C(h) values show a closer proximity of erosion-prone vegetative areas on the right side, 440,433 compared to 258,998 on the left side. The C(h) values then dropped steadily from these maximum values on both sides of the river. The decrease in covariances was most abrupt on the right side at separation distances of 38 and 76 m, pointing to a decline in the spatial continuity of erosion prone areas. The C(h) values for both sides of the river(Fig. 11), as well as the NS and EW directional counts (Fig. 8), demonstrate how relationships between C(h) and (h) provide different perspectives for examining the spatial distribution of erosion-prone vegetative areas relative to the channel.

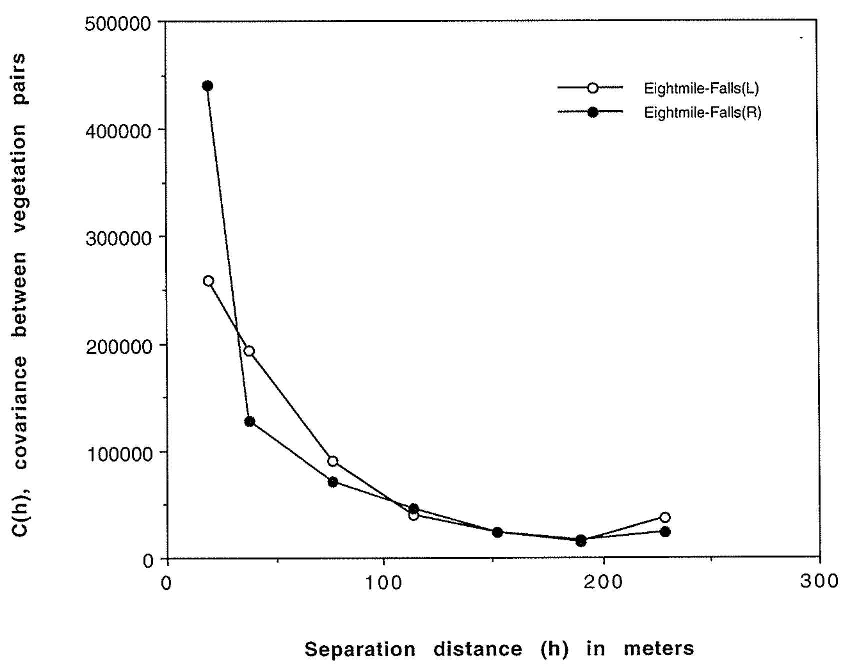

Figure 11. Comparisons of C(h) and (h) relationships for the left and right side of the river within the Eightmile-Falls reach of the Chewuch River. See Figure 8 for definition of C(h) values.

The reaches upstream from the Eightmile-Falls reach showed C(h) values <300,000 at (h) 19-m distance. Three reaches (Falls-Doe, Doe-Twentymile, and Twentymile to Lake) lie in the middle region of the Chewuch River valley within the Ponderosa forest zone (Fig. 12). The C(h) values ranged from 212,052 to 258,909 at the separation distance of 19 m with the lowest occurring upstream in the Twentymile-Lake reach. The relationships between C(h) and (h) showed that the Falls-Doe and Doe-Twentymile reaches had greater covariances for paired vegetative areas at separation distances of 19, 38, and 76 m than at the Twentymile-Lake reach.

The two remaining reaches (Lake-Trench and Trench-Windy) lie upstream of the Ponderosa forest zone (Fig. 13). These reaches showed major difference in the C(h) values at the (h) 19 and 38-m separation distances. The lowest C(h) values at these separation distances (179, 218 and 96,294, respectively) occurred in the Lake-Trench reach, which is characterized by narrow valley walls and steep channel gradients. This reach lies within a transition area between Ponderosa pine and the Douglas-fir/Subalpine fir forest. Higher C(h) values at the 19 and 38-m separation distances (287,265 and 134,950, respectively) occurred in the Trench-Windy reach. The Trench-Windy reach, the most upstream reach, contains well-developed floodplains surrounded by steep valley walls. This reach lies within the Douglas fir/Subalpine fir zone.

DISCUSSION

Erosion-Prone Vegetation Areas and Management Considerations For Chewuch River Reaches

The spatial continuities for erosion-prone vegetation and related characteristics of the eight river reaches of the Chewuch River valley are summarized in Table 4. The spatial continuity is by described C(h) values at a separation distance of 19 m. The other reach characteristics include (h) distances showing the highest C(h) values, the dominant types of vegetation within sampling grids, the presence of areas (~%) with potentially erodable soils (moderate and high potentials) within the sampling grids and within 90 m of the channel. The last column recommends modifications to 90-m riparian reserve widths for different reaches. These recommendations are based on the other reach characteristics. The summaries are for the left and right sides of the river channel.

This summary provides a framework for identifying management considerations relating to the spatial distribution of erosion-prone vegetative patches in the Chewuch River valley. The differences in C(h) for the reaches reflect changes in vegetative zones. The C(h) levels also suggest influences of precipitation patterns, landform and soil structures within the valley landscape. High C(h) and the close spacing of areas at the (h) 19-m distance for both sides of the river indicate where the most erosion-prone vegetative areas occur within the landscape. The highest C(h) values show the most erosion-prone areas occur within the two downstream reaches (Boulder-Cub and Cub-Eightmile) and within the two most upstream reaches (Lake-Trench and Trench-Windy). The erodable soils areas (~%) occurring within the sampling grids and within 90 m of the channel where also higher within these reaches. The co-occurrence of high C(h) values

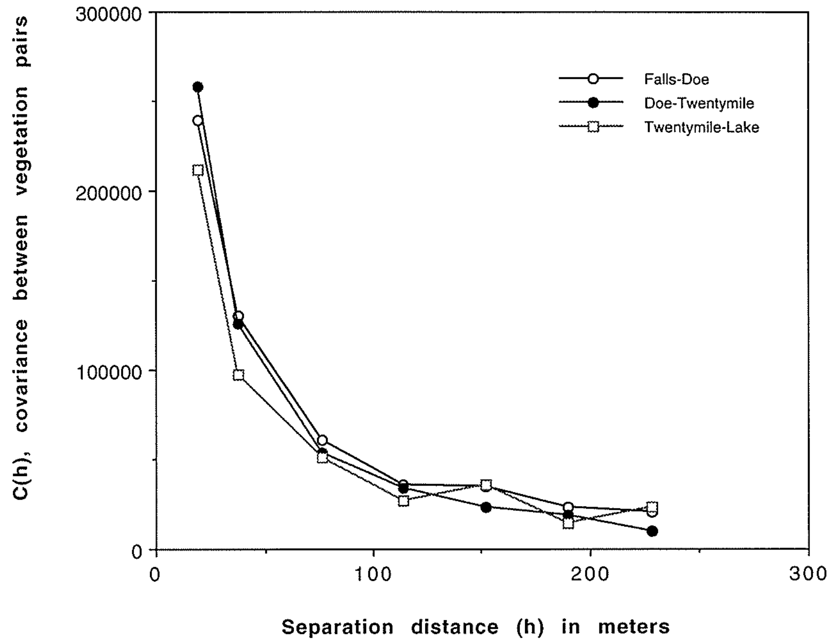

Figure 12. Comparisons of C(h) and (h) relationships for the Falls-Doe, Doe-Twentymile, and Twentymile-Lake reaches of the Chewuch River. See Figure 8 for definition of C(h) values.

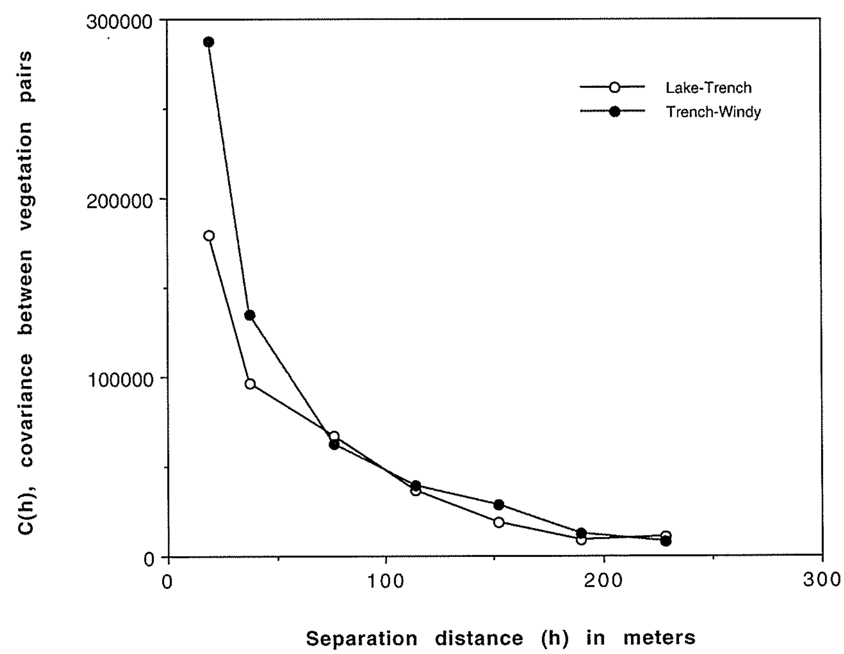

Figure 13. Comparisons of C(h) and (h) relationships for the Lake-Trench and Trench-Windy reaches of the Chewuch River. See Figure 8 for definition of C(h) values.

Table 4. Comparison of reach characteristics for eight river reaches within vegetative zones of the Chewuch River valley. The reach characteristics include C(h) for spatial continuity of erosion-prone vegetative areas at the (h) 19 m separation distance, (h) distance with high C(h), the dominant types of vegetation within sampling grids, and the presence areas with potentially erodable soils (moderate and and high potentials) within the sampling grids (See Methods for definition of grids). The percentages are preliminary estimates (~%). The last column presents potential modifications to 90 m riparian reserve widths. The reach characteristics are described for the left (L) and right (R) sides of the river channel.

Reach	Spatial continuity, C(h) at 19 m (h) distance		(h) distances with high C(h) (m)	Erosion-prone vegetation types within grids[a]		Potential erodable soils[b] (~%) within grids		Potential erodable soils[b] (~%) within 90 m		Modified riparian[b] widths (m)	
	L	R		L	R	L	R	L	R	L	R
Cub-Boulder[c]	564,078	368,620	19-38	G>PS>S	G & PS>S	10	30	5	20	90	>90
Boulder-Eightmile[d]	358,884	314,262	19-38	G>PS>S	PS>G>S	20	50	5	20	90	>90
Eightmile-Falls[d]	258,988	440,433	19-76	G>PS & S	PS & G>S	20	75	0	40	90	>90
Falls-Doe[e]	255,448	222,371	19-76	G>S>PS	PS & S>G	40	10	0	5	90	90
Doe-Twentymile[e]	269,229	247,545	19-76	G & S	PS > S	10	50	0	5	90	>90
Twentymile-Lake[e]	247,802	176,302	19-76	PS>G & S	PS>G & S	20	10	5	5	90	90
Lake-Trench[f]	166,893	191,544	19-114	PS	PS>S	90	100	75	90	>90	>90
Trench-Windy[g]	303,840	270,691	19-114	PS>S>G	PS>S	75	75	50	90	>90	>90

[a]PS (seedling, sapling, and pole forest stands < 23 cm diameter dbh), G (grass-meadows), and S (shrubs) defined by limitations of rooting structures and canopy functions (See Methods) and from GIS layers (Chewuch River Watershed Analysis 1994).
[b]Soil erosion potentials and riparian widths defined using GIS layers and the Chewuch River Watershed Analysis (1994).

Vegetative zones (Chewuch River Watershed Analysis 1994):
[c]SM>SM/PP =Steppe meadows, and transition areas between steppe meadows to Ponderosa pine forests.
[d]SM/PP>PP =Transition between steppe meadows to Ponderosa forests, and Ponderosa forests.
[e]PP = Ponderosa pine forests.
[f]PP/DF =Transition between the Ponderosa pine and Douglas-fir/Subalpine fir forests
[g]DF = Douglas Fir/Subalpine fir

with potentially erodable soils areas suggest major risk areas that may require specific management prescriptions. For example, within these reaches the riparian widths required to buffer the floodplain and river channels against natural and human-induced perturbations could exceed the 90–m riparian reserve width (e.g., the right side of the Cub-Boulder reach, Table 4). The modified riparian widths for these reaches should be viewed as preliminary recommendations. Additional recommendations may be possible upon detailed analyses of soil layers and stream survey data.

Of the reaches within the Ponderosa forest zone, the Doe-Twentymile reach appeared to be the reach in need of modified riparian widths. On the right side of the river channel, this reach shows high C(h) values at separation distances of 19, 38 and 76 m and the occurrence of erodable soils. The potentially erodable soil areas occur ~50% of the time within the sampling grid and ~5% within 90 m of the channel (Table 4).

The two most upstream reaches, Lake-Trench and Trench-Windy, appear to need modified riparian widths on both sides of the river. The left and right sides of the river channel exhibited high C(h) values at separation distances of 19, 38 and 76 m as well as erodable soil areas (Table 4). The erodable soil areas occur about 70% to 100% of the time within the grid and about 50% to 90% within 90 m of the channel. The recommended increases in riparian widths within the Doe-Twentymile, Lake-Trench, and Trench-Windy reaches appear necessary to protect the riparian areas and the river channels from timber harvest, secondary roads, and dispersed recreational activities within these reaches.

Habitat Restoration

The summaries for spatial continuity of erosion-prone vegetative areas, soil characteristics, and recommendations for variable riparian widths for reaches of the Chewuch River valley (Table 4) provide examples of the types of information needed to develop ecosystem management, restoration, and monitoring programs. The determination of co-occurring stands of erosion-prone vegetation and erodable soils within floodplain and valley areas is essential for successful restoration plans within riparian and channel habitats (Wissmar in press, MacDonald et al. 1991, Wissmar 1993). A preliminary assessment of erosion-prone vegetative and erodable soil areas near two proposed restoration projects within riparian and channel habitats (sites 9 and 10) of the Falls-Doe reach demonstrates the types of information that can be useful in planning. At the site scale, the locations of erosion-prone vegetative areas of pole stands, shrubs and grasses suggest where erosive conditions might occur (Table 5). The occurrence of pole stands and highly erodable soils on the right side of the river point to areas that may be very sensitive to disturbances. The right side of the river, if disturbed, could erode and deposit sediments in riparian and channel habitats. At the reach scale, high C(h) values indicate erosion-prone vegetative areas for separation distances of 19 to 76 m on both sides of the channel (Table 4), and points to the need for even broader spatial investigations. The reach scale information, along with the site data, provide examples of observations that can be essential to the development of restoration designs, implementation actions, and monitoring procedures. These observations suggest the need for further analysis prior to any restoration efforts.

Table 5. Erosion-prone vegetative patches and soil areas associated with two possible restoration sites (habitat complexes numbers 9 and 10) within the Falls-Doe reach. The pole stands, shrubs, and grasses represent areas where erosive conditions may occur. The potentially erodable soil areas (moderate and high) were outside the 90-m riparian reserve width. The percent areas on the left and right sides of the river were of the total area of two sampling grid areas (57.76 ha) containing the sites.

	Left bank		Right bank	
	(ha)	%	(ha)	%
Erosion-prone vegetation				
Pole stands	7.1	12.3	3.6	6.2
Shrubs	1.9	3.3	1.0	1.7
Grass	5.3	9.2	1.4	2.4
Potentially erodable soils				
Moderate	2.0	3.5		
High	4.2	7.3		

CONCLUSIONS

The findings of this assessment support the hypothesis that high covariances between vegetative pairs (V_i, V_j) indicate the close proximity of erosion-prone vegetative pairs. Important findings, such as the high correlations between C(h) values from directional grid counts (NS and EW), and differences in spatial continuity of vegetation on the right and left sides of river reaches, all demonstrate the efficacy of high covariance C(h) values in indicating the spatial continuity of erosion-prone vegetative areas within different valley reaches and at locations near the river channel.

RECOMMENDATIONS

The following recommendations focus on using information about spatial continuity of erosion-prone vegetation areas, and soil erosion potentials, to improve the management of riparian areas and channel habitats. These recommendations are based on the spatial landscape analysis of vegetative patches performed during this assessment. The recommendations call for applying the spatial continuity procedure to evaluations of: other erosion-prone vegetative areas, riparian reserve areas, and restoration plans for riparian and fish habitats. The overall goal of these recommendations is to foster ecosystem management approaches that reduce soil erosion and inputs of sediment to streams. The recommendations include:

- The application of the spatial continuity procedure within the major tributaries. This assessment will provide information useful in identifying the sizes of modified riparian widths and the magnitudes of erosion risk areas within the Chewuch River basin.
- The application of GIS layers that contain smaller pixel sizes in order to improve the spatial scales of the spatial continuity procedure. The capacity to improve the resolution of the data layers has significant ramifications for all the recommendations.

- The assessment of alternative sampling designs for improving the identification of the locations of vegetative patches (e.g., different stand structures), accumulations of large woody debris (LWD), and unstable soils areas relative to channel sites. These assessment would involve identifying sampling designs on transects located at specific angles relative to channel sites.
- The application of the spatial continuity procedure to larger sized forest stands (e.g., dbh) to identify the major landscape areas that have potentials for frequent tree blowdown and recruitment of LWD to streams. For example, high C(h) levels for large sized stands that co-occur with unstable soils, could indicate the most active blowdown zones. This application would include the assessment of major stand characteristics such as the relative rooting strengths of stands of Ponderosa, Douglas Fir /Subalpine fir forests.
- The assessment of landscape scale (e.g., reach) and mesoscale (e.g., habitat restoration sites) information required for developing restoration designs, implementation, and monitoring procedures. These assessments are especially needed to better define the proposed restoration sites (22 sites) identified within the riparian and river habitat complexes of the Chewuch River. Some of these habitat complexes could be important to the winter survival of juvenile salmon. Fish survival in the river channel during winter could be limited by low discharge levels (40 to 60 cfs), low water temperatures, and freezing conditions. Winter surveys are needed to assess the number and location of these habitats, and to monitor fish populations and movements between habitats. These assessments should include the mapping and monitoring of groundwater upwelling sites, and the monitoring of seasonal changes in water temperatures. Groundwater upwellings can be important to fish survival because they offer continuous supplies of water, and constant temperatures that prevent freezing.
- The spatial continuity procedure needs to be applied to silvicultural prescriptions. The use of the covariance analyses to identify the close proximity of erosion-prone vegetative pairs should be incorporated into prescriptions involving stand manipulations within riparian areas. These applications should consider silvicultural influences on the development patterns of different stand ages and structures, and the relationships of these applications to the spacing of vegetative patches and locations of unstable soil areas. These applications have significant ramifications for all the recommendations.

REFERENCES

Chewuch River Watershed Analysis. 1994. Okanogan National Forest, Winthrop Ranger District, U.S. Government Printing Office: 1994-689-114/00603, Region No. 10, 267 p.

Hansen, A.J., T.A. Spies, F.J. Swanson, and J. L. Ohmann. 1991. Conserving biodiversity in managed forests. BioScience 41:382-392.

Isaaks, E.H. and R.M. Scrivastava. 1989. An Introduction to Applied Geostatistics. Oxford University Press, NY. 561 p.

MacDonald, L., A. Smart, and R.C. Wissmar. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. EPA/910/9-91-001. Edwards Brothers Press, Ann Arbor, MI.

McIntosh, B.A., J.R. Sedell, J.E. Smith, R.C. Wissmar, S.E. Clarke, G.R. Reeves, and L.A. Brown. 1994. Historical changes in fish habitat for select river basins of eastern Oregon and Washington. Northw. Sci. (Special Issue) 69:36-53.

Rossi, E.R., D.J. Mulla, A.G. Journel, and E.H. Franz. 1992. Geostatistical tools for modeling and interpreting ecological spatial dependence. Ecol. Monogr. 62:277-314.

Sidel, R.C., A.J. Pearce, and C.L. O'Loughlin. 1985. Hillslope stability and land use. Wat. Res. Monogr. Ser. 11, Am. Geophys. Union. 140p.

Wallin, D. O., F. J. Swanson and B. Marks. 1994. Landscape pattern response to changes in pattern generation rules: Land-use legacies in forestry. Ecol. Applic. 4:569-580.

Wissmar, R.C. 1993. Long-term monitoring in stream ecosystems. Environ. Monit. Assess. 26:219-234.

Wissmar, R.C., J.E. Smith, B.A. McIntosh, H.W. Li, G.H. Reeves, and J.R. Sedell. 1994. A history of resource use and disturbance in riverine basins of eastern Washington and Oregon. Northw. Sci. (Special Issue) 69:1-35.

Wissmar, R.C. and W.N. Beer. 1994. Distribution of fish and stream habitats and influences of watershed conditions, Beckler River, Washington. Univ. Washington, School of Fisheries, Fish. Res. Inst. FRI-UW-9417. Seattle. 54 p.

Wissmar, R.C. In press. Historical framework for watershed restoration. Chapter 6. *In* J.E. Williams, M.P. Dombeck, W. Elmore, C.A. Wood (eds.), Watershed Restoration: Principles and Practices For Aquatic and Riparian Ecosystems. American Fisheries Society.