K.M. Burnett, 2001, Relationships Among Juvenile Anadromous Salmonids, Their Freshwater Habitat, and Landscape Characteristics Over Multiple Years and Spatial Scales in the Elk River, Oregon, PhD dissertation, Oregon State University, Corvallis, Oregon.

CHAPTER 4

Comparing Riparian and Catchment-wide Influences of Landscape Characteristics on Channel Unit Features in Tributaries of the Elk River, Oregon

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ABSTRACT

Utility of multi-scale analyses for understanding relationships between landscape characteristics and stream habitat was demonstrated for a mountainous area where forestry is the primary land use. Riparian areas could be differentiated from upslope areas for a subset of landscape characteristics when riparian areas were approximated by a fixed-width buffer then described with digital topography and forest cover from satellite imagery. Percent area in forests of medium to very large diameter trees and road density were inversely related at all spatial scales, but the proportion of variation explained increased as scale increased. Mean maximum depth and volume of pools were each directly related to catchment area which explained more variation than landscape characteristics summarized at any spatial scale. Mean density of wood in pools was inversely related to catchment area. At each spatial scale except the catchment, more among-valley segment variation in wood density was explained by an inverse relationship to percent area of sedimentary rock types and a direct relationship to percent area in forest of medium to very large diameter trees than by any other regression model of landscape characteristics or catchment area. The sub-catchment-scale model explained the greatest proportion of variation in wood density. These findings suggested that although spatial scales were similar in processes affecting wood density, finer spatial scales (i.e., corridor and sub-network scales) omitted source areas for key wood delivery processes, and coarser spatial scales (i.e., network and catchment) included source areas for processes less tightly coupled to wood dynamics in surveyed channels. Little spatial autocorrelation was suggested in regression residuals. Multi-scale analysis can identify areas and processes most closely linked to stream habitat condition and can help design effective strategies to protect and restore stream habitats.

INTRODUCTION

Habitats for stream-dwelling species are perhaps best studied by placing them in the context of their catchment (Hynes, 1975; Frissell et al. 1986; Naiman et al. 1992). A catchment contains a mosaic of patches and interconnected networks (Pickett and White 1985; Swanson et al. 1997; Jones et al. 2000). Patches and network features have characteristics such as size, shape, type (e.g., paved roads, old growth forest, or bedrock outcrops) and location (e.g., ridge top or riparian). These landscape characteristics control the routing of energy and materials to streams and ultimately shape aquatic habitat (Swanson et al. 1998; Jones et al. 2000). The direct, local effects on streams of features in the riparian area are relatively well established (Osborne and Koviac 1993; Naiman et al. 2000). Perhaps less well understood are relationships between streams and riparian characteristics accumulated upstream along a channel network (e.g., Weller et al. 1998; Jones et al. 1999) or riparian and upslope characteristics accumulated throughout a catchment (e.g., Jones and Grant 1996; Thomas and Megahan 1998; Jones and Grant 2001).

In urbanized and agricultural systems, riparian and catchment characteristics have been compared for contributing to or moderating non-point source impacts on stream ecosystems. Conclusions in these multi-scale studies, drawn from empirically-derived statistical models, differed depending upon the response variable, location, and spatial extent examined. Certain responses were best explained by landscape characteristics summarized for the local riparian area [e.g., ecosystem processes (Bunn et al. 1999)]. Others were best explained by landscape characteristics summarized for the entire catchment [e.g., total fish and macro-invertebrate species richness (Harding et al. 1998)]. For water quality, landscape characteristics had more explanatory power in some studies when summarized for the riparian network (Hunsaker and Levine 1995; Johnson et al. 1997) but in others when summarized over the catchment (Omernik et al. 1981; Hunsaker and Levine 1995). Even when the same response variables (i.e., biological integrity and habitat quality) were examined in the same river basin, judgements differed about the influences of riparian and catchment conditions (Roth et al. 1996; Lammert and Allan 1999). Given such variability, it may be ill-advised to extrapolate under-standing derived from multi-scale studies in urbanized and agricultural systems to forested landscapes with greater topographic relief.

Riparian and catchment-wide landscape characteristics have seldom been compared for their relationships to streams in mountainous areas where silviculture was the dominant land use. Abundances of Pacific salmon and trout (*Oncorhynchus spp.*) or conditions of their freshwater habitat have been related to land cover characteristics reflecting timber harvest (e.g., road density or percent area logged). Relationships were found with such characteristics summarized at different spatial scales, including the local riparian area (Bilby and Ward 1991), the entire riparian network (Botkin et al. 1995; Lunetta et al. 1997), and the catchment (e.g., Reeves et al. 1993; Dose and Roper 1994; Dunham and Rieman 1999; Thompson and Lee 2000). Although these studies offered valuable insights, none directly compared relationships between stream habitat and landscape characteristics at multiple spatial scales. We are aware of only two response variables, macroinvertebrate biological integrity (Hawkins et al. 2000) and abundance of adult coho salmon (*Oncorhynchus kisutch*) (Pess et al. in review), for which relationships to riparian and catchment characteristics were compared in streams draining forested, montane regions. Analogous multi-scale assessments for stream habitat can identify riparian and upslope areas that contribute to habitat protection and restoration in forestry-dominated landscapes.

The goal of this study was to compare landscape characteristics at multiple spatial scales for their relationship to channel-unit habitat features in a basin where the main land use was forestry. Channel unit features targeted were those that helped distinguish between levels of valley-segment use by juvenile ocean-type chinook salmon (i.e., mean maximum depth of pools, mean density of large wood in pools, and mean volume of pools) (Chapter 3). Higher values of these channel unit features were observed in more highly used valley segments. These channel unit features are commonly considered relevant to freshwater habitat quality for salmonids (e.g., McIntosh et al 2000; Bilby and Bisson 1998). Specific objectives were to: 1) examine differences in landscapes characteristics among five spatial scales that varied in extent from the local riparian area to the entire catchment for valley segments in tributaries of the upper Elk River basin; 2) compare the proportion of among-valley segment variation in channel unit features that was explained by catchment area and by landscape characteristics summarized within each spatial scale; 3) determine which variables explained the greatest proportion of variation in channel unit features by selecting from among catchment area and landscape characteristics at all five spatial scales; and 4) assess residuals from these among-scale regressions for spatial autocorrelation.

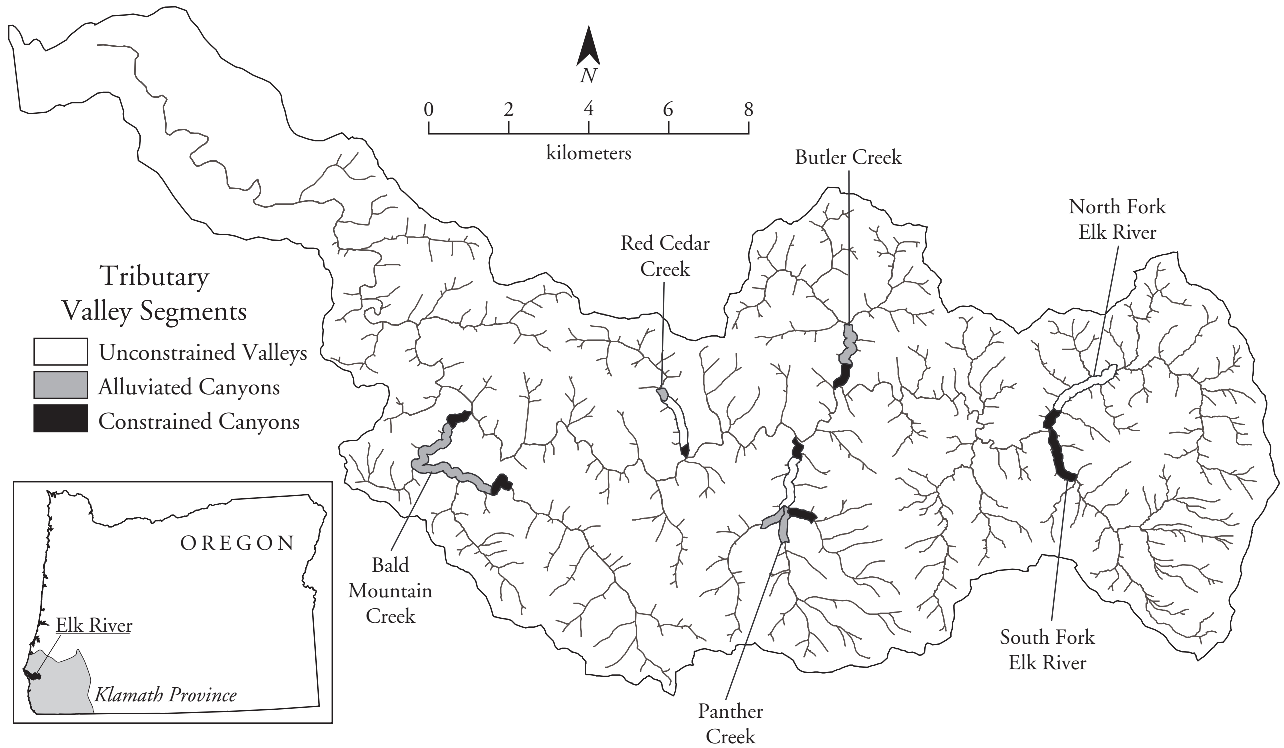
STUDY AREA

Elk River is located in southwestern Oregon, USA (Fig. 4.1). The mainstem flows primarily east to west, entering the Pacific Ocean just south of Cape Blanco (42°5' N latitude and 124°3' W longitude). The Elk River basin (236 km^2) is in the Klamath Mountains physiographic province (Franklin and Dyrness 1988) and is similar to other Klamath Mountain coastal basins in climate, land form, vegetation, land use, and salmonid community. The study area was confined to tributaries in the upper basin (i.e., above and inclusive of Anvil Creek).

The climate is temperate maritime with restricted diurnal and seasonal temperature fluctuations (USDA 1998). Ninety percent of the annual precipitation arrives between September and May, principally as rainfall. Peak stream flows are flashy following three- to five-day winter rainstorms rather than associated with spring snow melt, and base flows occur between July and October. Elevation ranges from sea-level to approximately 1200 m at the easternmost drainage divide. Recent tectonic uplift produced a highly dissected terrain that is underlain by the complex geologic formations of the Klamath Mountains. Stream densities in these rock types range from 3-6 km/km^2 (FEMAT 1993).

Much of the study area is in mixed conifer and broadleaf forests that include tree species of Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), Port Orford cedar (*Chamaecyparis lawsoniana*), tanoak (*Lithocarpus densiflorus*), Pacific madrone (*Arbutus menziesii*) and California bay laurel (*Umbellularia californica*). Typical additions in riparian areas are western red cedar (*Thuja plicata*), big leaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra*). Forests span early to late successional/old growth seral stages

Figure 4.1. Location and map of the Elk River, Oregon with valley segments identified for anadromous fish-bearing sections of its tributaries surveyed in 1988.



due to a disturbance regime driven by infrequent, intense wild fires and wind storms and by timber harvest (USDA 1998). The last major fire in the Elk River basin burned approximately 1.3 km^2 of the Butler Creek drainage in 1961. The next year a windstorm blew down approximately 2.8 km^2 of forest throughout the basin. Other than these events, timber harvest has been the dominant disturbance mechanism since fire suppression began in the 1930s (USDA 1998).

Ninety percent of the study area is owned by the federal government with the majority of this managed by the US Forest Service. The remainder is in private ownership. Much of the northern and eastern drainage is in the Grassy Knob Wilderness Area, Grassy Knob Roadless Area, and Copper Mountain Roadless Area. Despite this designated federal protection, portions of two tributaries, Bald Mountain Creek and Butler Creek, do not meet beneficial uses for salmonids based on habitat and temperature concerns and have been on the federal Clean Water Act (1972) Section 303(d) list since 1994/1996.

The upper mainstem of Elk River and its tributaries provide spawning and rearing habitat for native ocean-type chinook salmon (*Oncorhynchus tshawytscha*), coho salmon, coastal cutthroat trout (*O. clarki*), and winter-run steelhead (*O. mykiss*). The basin is highlighted in both state and federal strategies for protecting and restoring salmonids (USDA and USDI 1994; State of Oregon 1997).

METHODS

All GIS manipulations of digital coverages were conducted with ARC/INFO[1] (Version 7.1, ESRI, Inc., Redlands, CA). All statistical analyses were performed with SAS/STAT statistical software (Version 6.12, 1997, SAS Institute Inc., Cary, NC).

Digital Stream Layer and Valley Segment Identification

The UTM projection, Zone 10, Datum NAD 27 was used for digital coverages. A 1:24,000, centerlined, routed, vector-based, digital stream coverage, representing all perennially flowing streams within the Elk River basin, was obtained from the Siskiyou National Forest. Surveyed tributaries were either 3rd or 4th order channels (Strahler 1957) on this stream coverage.

Valley segments encompass sections of tributaries accessible by anadromous salmonids. Accessibility was determined in the field based on the absence of physical features considered to be barriers to adult fish migrating upstream. The type and boundaries of each valley segment were refined from Frissell (1992) through field reconnaissance. Valley segments were classified as one of three types (adapted from Frissell 1992) (Table 4.1 and Fig. 4.1). Unconstrained valleys (UV) contain stream channels that are relatively low gradient (mean ± SD; 2.0 ± 0.3%) and unconfined (i.e., valley width >2 x active channel width). Any confinement of the channel is imposed by terraces. Constrained canyons (CC) contain stream channels that are relatively high gradient (mean ± SD; 3.3 ± 1.5%) and confined by valley walls (i.e., valley width - channel width). Alluviated canyons (AC) contain stream channels that are intermediate in gradient (mean ± SD; tributaries 2.3 ± 0.7%) and confinement to those in the former two valley segment types.

[1]The use of trade or firm names is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 4.1. Characteristics of tributary valley segments in the Elk River, Oregon (1988). Numbers identifying valley segments increase in the upstream direction. Definitions of unconstrained valleys (UV), constrained canyons (CC), and alluviated canyons (AC) were adapted from Frissell (1992).

Valley segment	Valley segment type	Length (m)	Drainage area (ha)	Mean (SD) % gradient	Mean (SD) maximum depth of pools (m)	Mean (SD) volume of pools (m^3)	Mean (SD) density of wood in pools (no./100 m)
Bald Mountain Creek 1	CC	826	2,715	3.1 (3.8)	1.32 (0.58)	97.3 (97.2)	6 (10)
Bald Mountain Creek 2	AC	4,251	2,679	2.4 (2.7)	0.89 (0.32)	54.5 (50.9)	8 (16)
Bald Mountain Creek 3	CC	965	1,511	2.3 (2.6)	0.94 (0.35)	44.8 (36.7)	9 (22)
Butler Creek 1	CC	763	1,752	3.3 (4.3)	0.78 (0.41)	56.3 (72.8)	4 (8)
Butler Creek 2	AC	1,588	1,724	1.2 (1.8)	0.83 (0.29)	61.6 (46.9)	1 (2)
North Fork Elk River 1	CC	648	2,456	3.3 (4.9)	1.35 (0.38)	73.0 (36.1)	7 (11)
North Fork Elk River 2	UV	2,511	2,303	1.6 (2.9)	1.08 (0.32)	81.6 (70.3)	13 (16)
Panther Creek 1	CC	727	2,347	0.6 (0.8)	0.89 (0.47)	85.5 (73.1)	5 (15)
Panther Creek 2	UV	1,697	2,275	2.3 (2.0)	0.90 (0.34)	71.8 (51.3)	1 (5)
Panther Creek 3	AC	1,165	929	1.9 (1.9)	0.69 (0.32)	34.2 (30.2)	9 (17)
W. Fork Panther Creek	AC	806	575	2.8 (2.7)	0.51 (0.16)	8.7 (4.0)	12 (23)
Red Cedar Creek 1	CC	344	743	4.7 (3.3)	0.63 (0.13)	13.1 (12.8)	11 (19)
Red Cedar Creek 2	UV	1,418	737	2.1 (1.9)	0.81 (0.55)	19.7 (10.5)	13 (20)
Red Cedar Creek 3	AC	419	565	3.3 (3.4)	0.80 (0.20)	13.1 (6.0)	17 (26)
South Fork Elk River 1	CC	1,544	1,988	5.6 (6.2)	1.17 (0.44)	63.4 (35.2)	9 (14)

Landscape Characterization

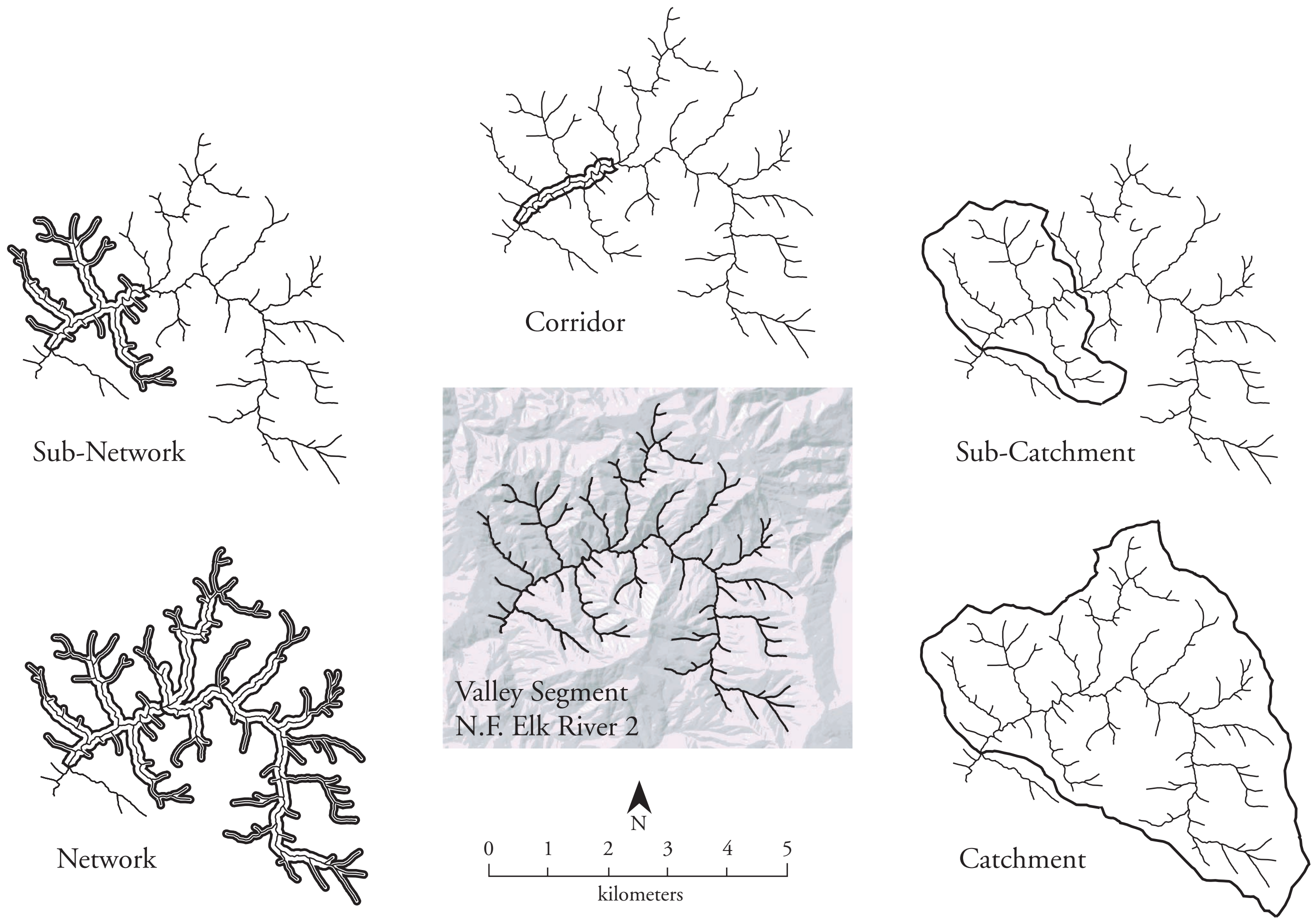
The approach for landscape characterization was to: 1) delineate analytical units for each valley segment, 2) overlay analytical units onto digital coverages of lithology, land form, and land cover, then calculate the percent area of each analytical unit occupied by each landscape characteristic, and 3) compare landscape characteristics among the five spatial scales.

Analytical units. Five analytical units, one for each spatial scale, were delineated for each valley segment. Spatial scales differed in the areas included upslope and upstream of valley segments (Fig. 4.2) and presumably in vegetative, geomorphic, and fluvial processes that may affect channel unit features. Analytical units were developed for three riparian buffer scales (i.e., corridor, sub-network, and network) and two upslope scales (i.e., sub-catchment and catchment). All buffers were based on the Riparian Reserve widths for perennial stream classes (i.e., 100 m on either side of fish-bearing channels and 50 m on either side of non-fish bearing channels) in the Northwest Forest Plan (USDA and USDI 1994). Sub-catchment and catchment boundaries were screen digitized from contour lines generated using US Geological Survey (USGS) 30 m digital elevation models (DEMs).

Corridor scale analytical units extended the length of each valley segment and included the area within a 100 m wide buffer on each side of the stream (mean ± SD, 22 ± 19 ha) (Fig. 4.2). Channel-adjacent processes (e.g., tree mortality in riparian stands and streamside landsliding) were assumed to dominate at the corridor scale. Sub-network scale analytical units encompassed those at the corridor scale plus the area within a buffer around all perennially flowing tributaries that drained directly into the valley segment from adjacent hill slopes (53 ± 82 ha) (Fig. 4.2). Debris flow processes were assumed to be added to channel-adjacent processes at the sub-network scale. Network scale analytical units included those at the sub-network scale plus the area within a buffer around all perennially flowing streams that were upstream of the valley segment (367 ± 211 ha) (Fig. 4.2). Fluvial transport processes were assumed to be added at the network scale. Sub-catchment scale analytical units contained the entire area draining into the valley segment from adjacent hill slopes, which included unmapped stream channels capable of transporting debris flows (190 ± 299 ha) (Fig. 4.2). Non-channelized hillslope processes (e.g., surface erosion, landsliding) were assumed to be added at the sub-catchment scale. Catchment scale analytical units encompassed those at the sub-catchment scale plus the entire area upstream of the valley segment (1562 ± 820 ha) (Fig. 4.2). Fluvial transport processes were assumed to be added at the catchment scale.

Digital coverages of landscape characteristics. Classes for the lithology, land form, and land cover data layers are described in Table 4.2. The lithology coverage was generalized from the digital 1:500,000 scale Quaternary geologic map of Oregon (Walker and MacLeod 1991) by the Forest Ecosystem Management and Assessment Team (FEMAT 1993). The land form layer of percent slope was generated for the basin from USGS 30 m DEMs. Slope classes were similar to those in Lunetta et al. (1997). Road density (km/km2) was calculated from a vector coverage of roads on all ownerships within the Elk River basin. The Siskiyou National Forest developed this coverage by augmenting the 1:24,000, 7.5 minute USGS quadrangle Digital Line Graph (DLG) with roads interpreted from Resource Orthophoto Quadrangles.

Figure 4.2. Analytical units used to summarize landscape characteristics at five spatial scales illustrated for the valley segment North Fork Elk River 2.



The forest cover layer was clipped from a coverage for western Oregon. It was developed by a regression modeling approach with spectral data from 1988 Landsat Thematic Mapper (TM) imagery and elevation data from USGS 30 m DEMs (Cohen et al. 2001). In areas such as the Elk River basin where forestry-related activities are the primary disturbance mechanism, age and stem diameter of forest cover reflects time since timber harvest. The greater the percent area in forests of older and larger trees the lower the percent area assumed to be affected by recent logging. With few exceptions (e.g., Botkin et al. 1995), studies relating stream and landscape characteristics in forested regions used harvest level or percent area logged (e.g., Reeves et al. 1993; Dose and Roper 1994) instead of high resolution forest cover data as was available for the Elk River basin.

Differences among spatial scales in landscape characteristics. We were interested in whether or not the five spatial scales differed with respect to landscape characteristics. Consequently, among-scale differences in variances and medians were assessed for each landscape characteristic. Among-scale differences in variances were analyzed using Levene's test of homogeneity of variance (Snedecor and Cochran 1980) on the absolute value of residuals from one-way ANOVA with scale as the independent variable. Among-scale differences in medians were evaluated using one-way ANOVA on the ranked data because parametric assumptions could not be met. Whenever an ANOVA F-test was significant (α=0.05), post-hoc pairwise comparisons were conducted with the Ryan-Einot-Gabriel-Welsch multiple range test (REGWQ) with the overall Type I error rate of α=0.05. Although extreme values were observed when landscape characteristics were screened for outliers, all data points were considered valid and were included in analyses.

We recognize that analytical units were not independent; analytical units at coarser scales subsumed those at finer scales (e.g., the sub-catchment scale completely encompassed the sub-network scale). Spatial dependence inherent in the design of analytical units likely reduced the actual degrees of freedom below the nominal value and inflated the probability of a type I error (Hurlbert 1984; Legendre 1993). All significance values from ANOVA and post-hoc comparisons should be evaluated with this in mind but were presented to indicate the relative strength of differences.

Regression of Channel Unit Features With Catchment Area and Landscape Characteristics

Channel unit features. Channel unit data were collected for 20 km of stream in fifteen valley segments from Elk River tributaries between July 25 and August 5, 1988. Information was obtained to derive channel unit features [i.e., mean volume of pools (m^3), mean density of wood in pools (no. pieces/100 m), and mean maximum depth of pools (m)]. These channel unit features were chosen because each helped discriminate between valley segments in Elk River tributaries for level of use by juvenile ocean-type chinook salmon (Chapter 3).

Each channel unit was classified by type [i.e., pool, fastwater

Table 4.2. Description of landscape characteristics for the Elk River, Oregon. All variables except road density were expressed as percent area of analytical units at each spatial scale.

Independent variable	Description
Lithology:	
Sedimentary rock types	Cretaceous - Rocky Point Formation sandstones and siltstones and Humbug Mountain formation conglomerates
Metasedimentary rock types[1]	Jurassic - Galice Formation shales and Colebrook Formation schists
Igneous rock types[1]	Granite and diorite
Landform:	
Slope class < 30%	
Slope class 31-60%[1]	
Slope class > 60%	
Land Cover:	
Road density	(kilometers of road per square kilometer)
Open area and semi-closed canopy forest	<70% tree cover
Broadleaf	>70% deciduous tree and shrub cover
Mixed broadleaf/conifer and conifer forest of:	>70% of deciduous and conifer tree cover
small diameter trees[1]	<25 cm diameter at breast height (dbh)
medium diameter trees	26-50 cm dbh
large diameter trees	51-75 cm dbh
very large diameter trees	>75 cm dbh
medium to very large diameter trees	>25 cm dbh

[1]Classes with relatively low explanatory power that were not used in regression analyses.

(Hawkins et al. 1993), or side channel (<10% flow)]. The length, mean wetted width, and mean depth of each channel unit was estimated using the method of Hankin and Reeves (1988). Channel units were at least as long as the estimated mean active channel width (10^0 -10^1 m). Dimensions were measured for approximately 15% of all channel units. A calibration ratio was derived from the subset of channel units with paired measured and estimated values. Separate calibration ratios were developed for each person estimating channel unit dimensions. All estimated dimensions were multiplied by the appropriate calibration ratio, and only calibrated estimates were analyzed. Number of wood pieces (≥3 m long and ≥0.3 m diameter) were counted in each channel unit. Maximum depth of each pool was measured if ≤1 m and was estimated otherwise. Channel unit data were geo-referenced to the digital stream network through Dynamic Segmentation in ARC/INFO (Byrne 1996) then were summarized for each valley segment to obtain channel unit features for subsequent regression analyses.

Developing regression models. Three sets of regression models were developed to explain variation in channel unit features. First, we regressed each channel unit feature with catchment area only. Next, we attempted to develop five within-scale linear regression models for each channel unit feature by selecting from landscape characteristics at each of five spatial scales. Finally, we attempted to develop a single 'best' among-scale linear regression model for each channel unit feature by selecting from among catchment area and landscape characteristics at all spatial scales. Independent variables for within- and among-scale regression models were selected with stepwise ($P \leq 0.11$ to enter and $P \leq 0.05$ to stay in the model) and adjusted R^2 procedures. We recognize that variable selection procedures cannot guarantee the best fitting or most relevant model unless all possible combinations are explored (James and McCulloch 1990). Thus, our criteria to determine the 'best' among-scale model was that it explained more of the variation in the dependent variable than other models we examined. Relatively few tributary valley segments (n=15) were available for analyses, thus we retained models with no more than two independent variables. This was a slightly more conservative criterion than the 5:1 cases to independent variables ratio of Johnston et al. (1990). The proportion of variation explained in linear regression was reported as r^2 and calculated as the coefficient of determination for one-variable models and as R^2 and calculated as the adjusted coefficient of determination for two-variable models.

Box plots and normal probability plots of regression residuals were inspected for constant variance and outliers prior to final model selection. Models were disregarded if parametric assumptions were not met following variable transformation. Reported within-scale models explained the largest proportion of variation in channel unit features and contained independent variables that were not also significantly ($P > 0.05$) correlated with catchment area. This allowed the unique contribution of landscape characteristics to be assessed. For comparison, channel unit features were regressed with the same independent variables for each reported model but summarized at the other four spatial scales.

Because valley segments were not selected with a probability sampling design and were contiguous within a tributary, we assessed regression residuals from each among-scale analysis for non-random errors that might reflect spatial autocorrelation. For all possible pairs of valley segments, stream distance and the absolute difference between regression residuals were calculated. These values were regressed to determine the proportion of the variation in the absolute difference between regression residuals explained by the stream distance between valley segments.

RESULTS

Landscape Characterization

Among-scale variances differed significantly (df = 5,84; $P \leq 0.05$) for all but three landscape characteristics, the percent area in: 1) igneous intrusive rock types, 2) slopes ≤30%, and 3) open and semi-closed canopy forest. The smallest variance was always at either the network or catchment scales for all other landscape characteristics except the percent area in forests of small diameter trees.

Medians differed significantly among the spatial scales for five of 14 landscape characteristics (Fig. 4.3). These were the percent area in

(Text continues at bottom of page 57)

Figure 4.3. Distribution of landscape characteristics among analytical units at each of the five spatial scales in tributaries of the Elk River, Oregon. Landscape characteristics were: (a) resistant sedimentary rock types; (b) metasedimentary rock types; (c) igneous intrusive rock types; (d) slope class <30%; (e) slope class 31-60%; (f) slope class >60%; (g) open area and semi-closed canopy forest; (h) broadleaf forest; mixed broadleaf/conifer and conifer forest of (i) small diameter trees, (j) medium diameter trees, (k) large diameter trees, (l) very large diameter trees, (m) medium to very large diameter trees; and (n) road density. Spatial scales were the corridor (Co), sub-network (SN), sub-catchment (SC), network (N), and catchment (C). Boxes designate the 25th and 75th percentiles, the solid line indicates the median and the dotted line the mean, and 5th and 95th percentiles are shown by disconnected points. Scales with significant ($P<0.05$) pairwise differences betwwen medians have the same label.

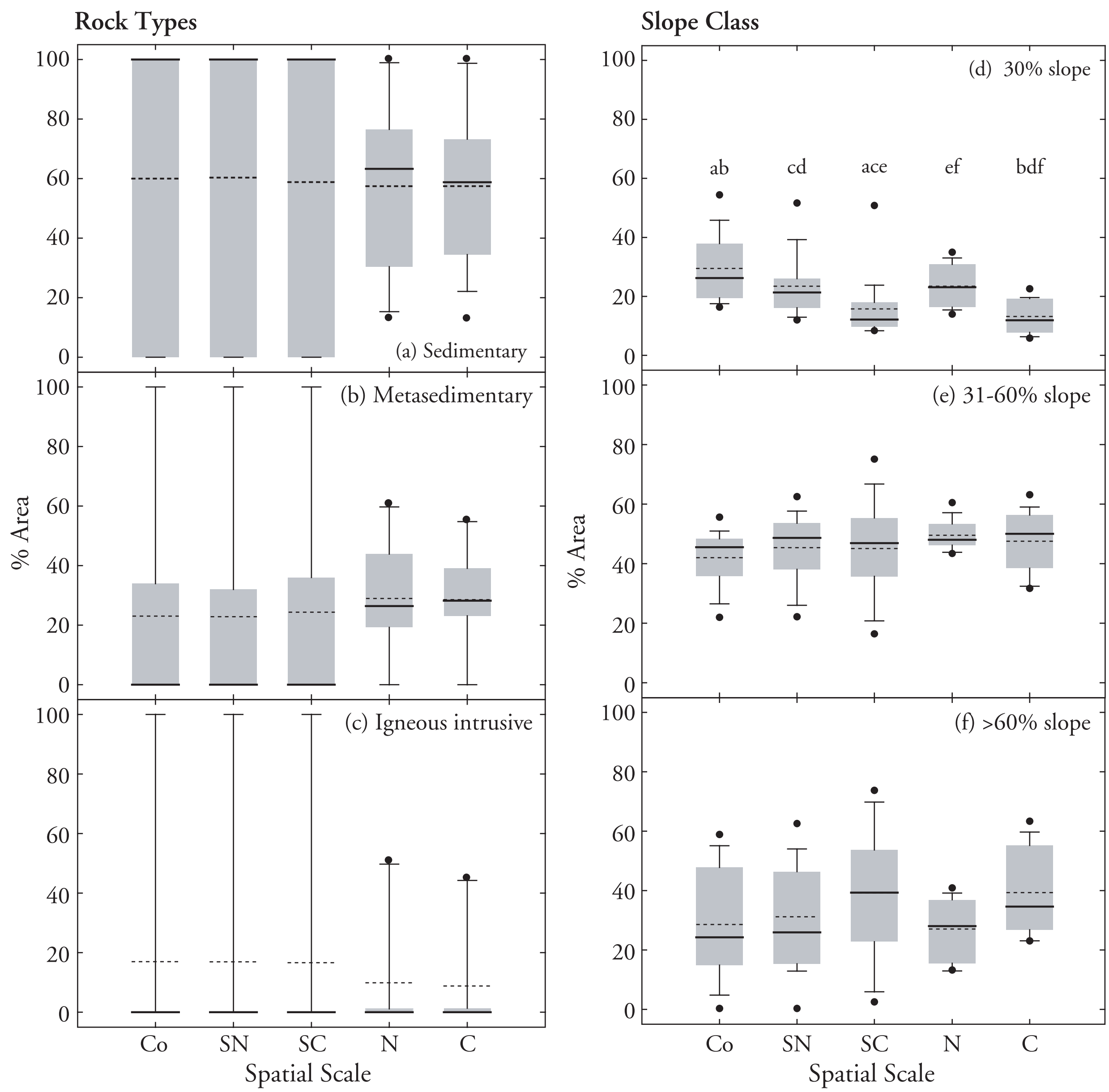


Figure 4.3 (continued, g-n)

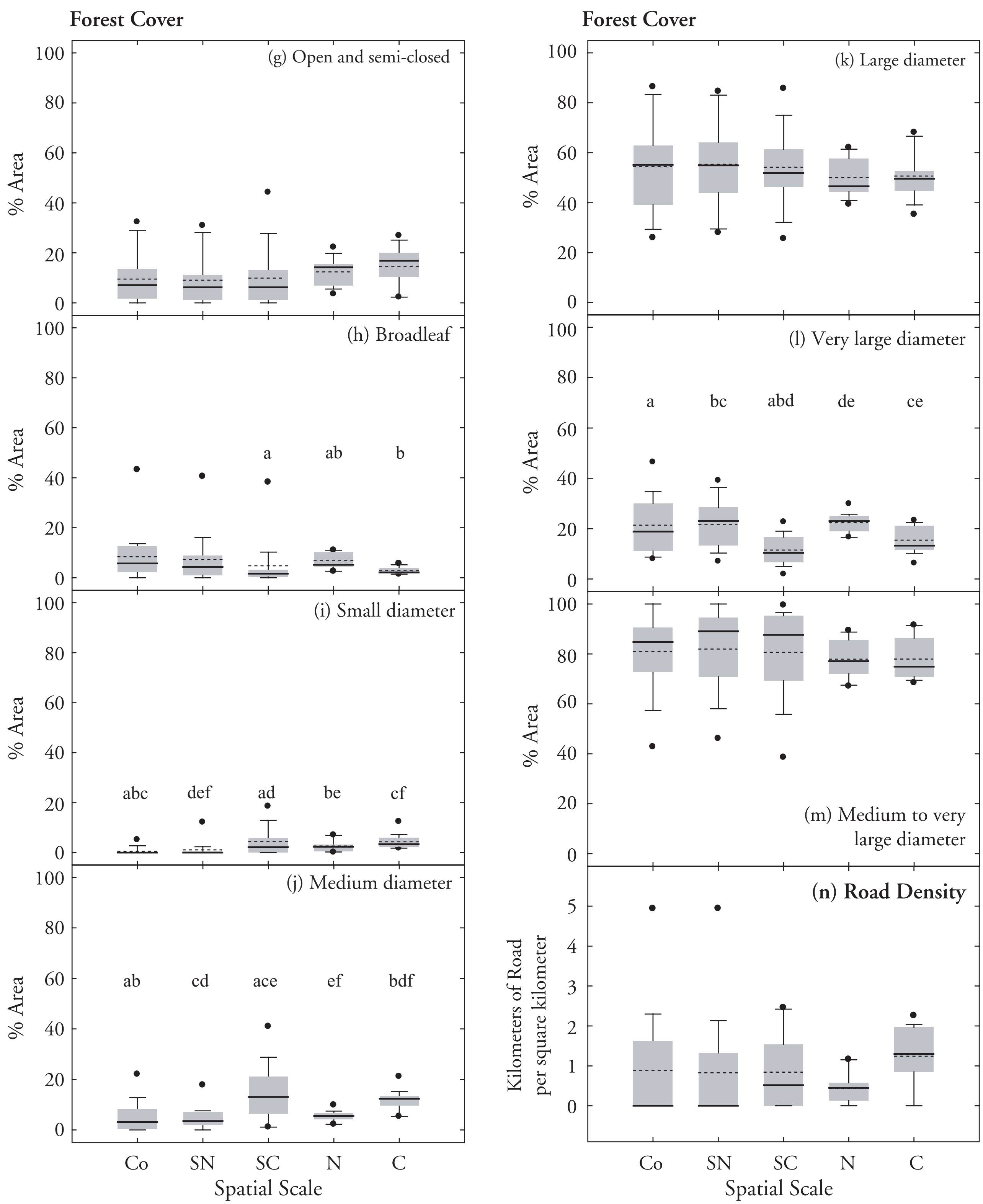


Table 4.3. Results from linear regression to explain among-valley segment variation in channel unit features in tributaries of the Elk River, Oregon. Independent variables were catchment area and landscape characteristics summarized at five spatial scales. Direction and significance of relationships between independent variables and dependent variables are indicated by +/- (Prob> ⌈t⌉). Models with all slope parameters significant at α=0.05 are indicated by *. Bonferroni correction for each model results in significance at α=0.05/5=0.01 for five spatial scales.

Model (df =14)	Corridor	Sub-network	Network	Sub=catchment	Catchment
Mean maximum depth of pools vs.					
Drainage area of the catchment					+(0.001)
r^2 (Prob>F)					0.57 (0.001)*
Mean volume of pools vs.					
Drainage area of the catchment					+(0.0001)
r^2 (Prob>F)					0.87 (0.0001)*
Mean density of large wood in pools vs.					
Drainage area of the catchment					-(0.02)
r^2 (Prob>F)					0.35 (0.02)*
Mean density of large wood in pools vs.					
% Sedimentary rock types	-(0.04)	-(0.01)	-(0.004)	-(0.04)	-(0.16)
% Forests of medium-very large diameter trees	+(0.05)	+(0.01)	+(0.003)	+(0.01)	+(0.02)
R^2 (Prob>F)	0.34 (0.03)*	0.48 (0.008)*	0.58 (0.002)*	0.41 (0.02)	0.34 (0.03)
Mean density of large wood in pools vs.					
% Sedimentary rock types	-(0.08)	-(0.08)	-(0.05)	-(0.02)	-(0.18)
Road density (km/km2)	-(0.05)	-(0.04)	-(0.06)	-(0.01)	-(0.06)
R^2 (Prob>F)	0.35 (0.03)	0.36 (0.03)	0.34 (0.03)	0.40 (0.02)*	0.22 (0.09)

slopes #30% ($F_{4,70}$ = 10.0; P = 0.0001) (Fig. 4.3d), broadleaf cover ($F_{4,70}$ = 3.6; P = 0.01) (Fig. 4.3h), forests of small diameter trees ($F_{4,70}$ = 12.1; P = 0.0001) (Fig. 4.3i), forests of medium diameter trees ($F_{4,70}$ = 8.5; P = 0.0001) (Fig. 4.3j), and forests of very large diameter trees ($F_{4,70}$ = 6.4; P = 0.0002) (Fig. 4.3k). Pairwise comparisons for these landscape characteristics never differed significantly (P>0.05) between the corridor and sub-network scales or between the sub-catchment and catchment scales (Fig. 4.3). For variables subsequently used in regression analyses, significant pairwise comparisons were always between the upslope scales and the riparian buffer scales (i.e., corridor, sub-network, or network scales) (Fig. 4.3). As an example, for the percent area in slopes ≤30% (Fig. 4.3d), the medians of the sub-catchment (12.2%) and the catchment (11.9%) scales, although not significantly different from each other, were significantly different (P≤0.05) from those of the corridor (26.2%), sub-network (21.3%), and network (23.1%) scales. No significant differences were observed among the riparian buffer scales for this variable.

Regression of Channel Unit Features With Catchment Area and Landscape Characteristics

The mean maximum depth of pools and the mean volume of pools were positively related to catchment area (Table 4.3). Catchment area explained more of the valley segment-scale variation in the mean maximum depth of pools and in the mean volume of pools than any landscape characteristic summarized at any spatial scale (Table 4.3). Furthermore, no landscape characteristic was significantly (P>0.05) related to either variable when considered in among-scale multiple linear regression with catchment area. Stream distance between each pair of valley segments explained only a small proportion of the variation in the absolute differences between residuals resulting from regression of catchment area with either the mean maximum depth of pools (r^2 = 0.04; df = 104; P = 0.06) (Fig. 4.4a) or mean volume of pools (r^2 = 0.01; df = 104; P = 0.36) (Fig. 4.4b).

Landscape characteristics that were most highly correlated with the mean maximum depth of pools and the mean volume of pools explained less than half the variation explained by catchment area and were themselves significantly related to catchment area. For example, the mean maximum depth of pools was positively related to the percent area in broadleaf forest at the corridor scale (r^2 = 0.29; df =14; P = 0.04), and the latter was positively related to catchment area (r^2 = 0.31; df =14; P = 0.03).

Although the mean density of wood in pools was negatively related to catchment area, an equal or greater proportion of the variation was explained by landscape characteristics at four of the five spatial scales (Table 4.3). The mean density of wood in pools was most significantly related to the percent area of sedimentary rock types and to the percent area in forests of medium to very large diameter trees when these were summarized at each spatial scale except the catchment. With landscape characteristics summarized at the network scale, almost as much of the variation was explained by a multiple linear regression model containing the percent area in sedimentary rock types and road density (km/km2) instead of the forest cover variable (Table 4.3). At this scale, as the density of roads increased, the percent area in forests of medium to very large diameter trees decreased (r^2 = 0.69, df = 14; P = 0.0001) (Fig. 4.5). These two land cover variables were negatively related also at each of the other four spatial scales (r^2 = 0.35 (corridor scale), r^2 = 0.46 (sub-

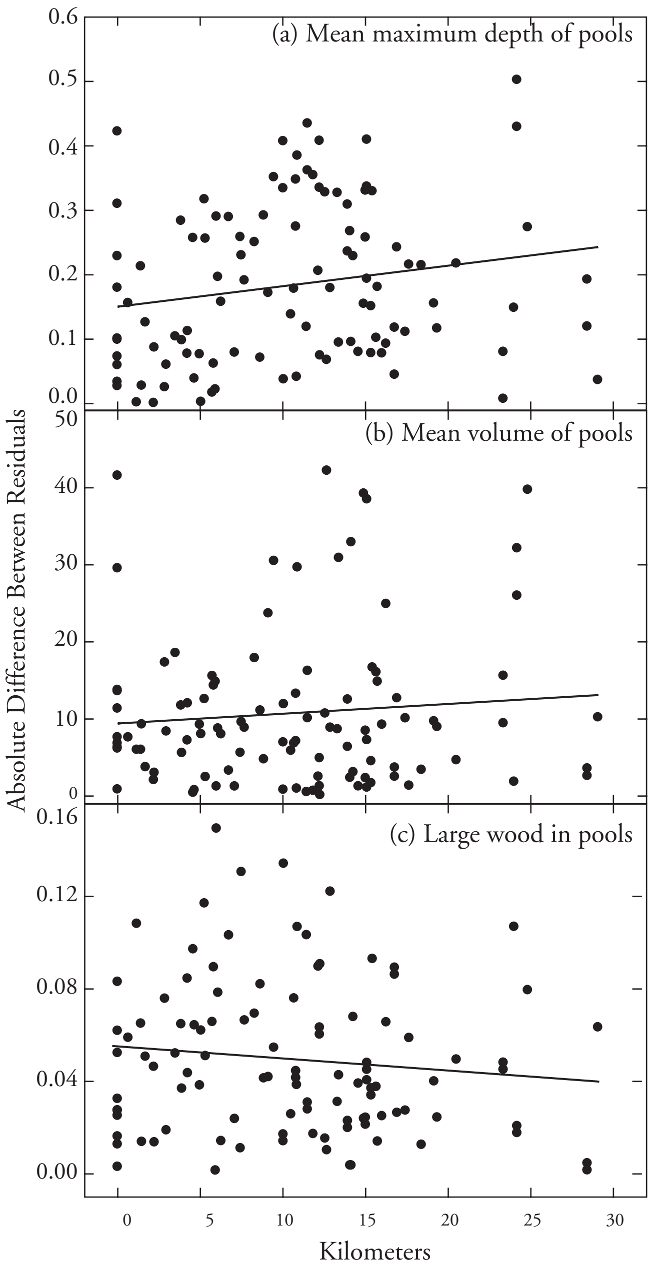


Figure 4.4. Results of linear regressions for stream distance between each pair of valley segments and the absolute difference between residuals from among-scale regressions of channel unit features with landscape characteristics for tributaries of the Elk River, Oregon. Residuals were from regression of mean maximum depth of pools with catchment area (a); mean volume of pools with catchment area (b); and mean density of large wood in pools with percent area in sedimentary rock types at the sub-catchment scale and percent area in mixed and conifer forest of medium to very large diameter trees at the sub-catchment scale (c).

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network scale), $r^2 = 0.37$ (sub-catchment scale), and $r^2 = 0.85$ (catchment scale); df = 14; P≤0.02).

Both within- and among-scale variable selection resulted in the same 'best' regression model for the mean density of wood in pools. The percent area of sedimentary rock types and percent area in forests of medium to very large diameter trees explained the greatest proportion of the variation in wood density at the sub-catchment scale (Table 4.3). Stream distance between each pair of valley segments explained little of the variation in the absolute difference between residuals ($r^2 = 0.01$; df = 104; P = 0.26) (Fig. 4.4c).

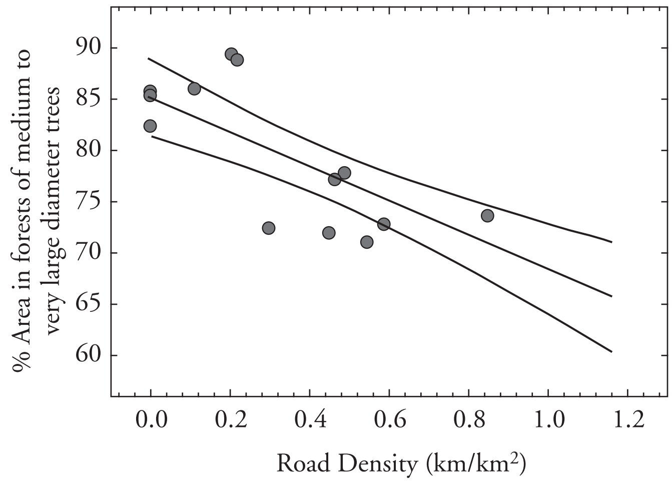

Figure 4.5. Results of linear regression between the percent area in forests of medium to very large diameter trees and road density at the sub-network scale for tributaries of the Elk River, Oregon The linear regression line and 95% mean confidence curves are shown (y = 85.7 - 16.7 x; $r^2 = 0.69$; P = 0.0001).

DISCUSSION

Landscape Characterization

Variances differed significantly among spatial scales for the majority of landscape characteristics. The smallest variance for landscape characteristics was generally observed at either the network or catchment scale. Because the spatial resolution of landscape coverages was typically smaller than the area of analytical units, variance declined as the area of analytical units increased. This agreed with observations that variability in landscape characteristics decreases as grain or patch size increases (Forman and Godron 1986; Syms and Jones 1999).

Medians differed significantly among spatial scales for a third of the examined landscape characteristics. For landscape characteristics subsequently used in regression analyses, differences in medians were between the sub-catchment or catchment scales and one or more of the riparian buffer scales (i.e., corridor, sub-network, and network). Thus, upslope and riparian areas were distinguished when the latter was approximated with a fixed-width buffer then described by digital topography and forest cover classes from satellite imagery. Depending upon the attribute, this approach appears useful for characterizing riparian areas over broad spatial extents in forested systems. Alternatively, the actual riparian zone can be delineated in the field with vegetation, soils, and geomorphic data or estimated from aerial photography. Both are time intensive processes that limit the spatial extent reasonably addressed. If analytical units had been spatially discrete (i.e., analytical units at coarser scales had not subsumed those at finer scales), among-scale differences may have been observed for more of the landscape characteristics. Most studies in agricultural systems that examined upslope and riparian areas over a broad region used a fixed-width buffer. Some of these found landscape characteristics in upslope and riparian areas were similar (e.g., Richards and Host 1994; Wang et. al. 1997), but others did not (e.g., Lammert and Allan 1999).

Regression of Channel Unit Features With Catchment Area and Landscape Characteristics

Among-scale regression models explained a significant proportion of the variation in the three channel unit features (i.e., mean maximum depth of pools, mean volume of pools, and mean density of large wood in pools). Residuals from these regressions suggested little evidence of spatial autocorrelation, so we did not attempt to remove or account for spatial structure in regression models (Cliff and Ord 1973; Legendre 1993). However, relatively small sample size may have hampered our ability to identify spatial autocorrelation. We are aware of no ideal technique to assess spatial dependence for stream networks when using relatively few coarse-grained analytical units that differ in size and spacing. Consequently, we adapted an approach that assesses the degree of relationship for geographic distances between all pairs of locations and corresponding differences between values of variables at those locations (Legendre and Fortin 1989). Geographic distances are usually calculated with x-y coordinates (e.g., Hinch et al. 1994), but we chose stream distance to better reflect potential connectivity between valley segments.

Catchment area explained more among-valley segment variation in the mean maximum depth of pools and the mean volume of pools than landscape characteristics at any of the five spatial scales. Catchment area is related to stream power through its direct influence on stream discharge. Streams with higher discharge generally have greater stream power, an index of the ability to transport materials (e.g., sediment and wood), and tend to be deeper and wider than those with lower discharge (Gordon et al. 1992). Accordingly, the mean maximum depth and volume of pools in Elk River tributaries increased as catchment area increased. Pool attributes have been negatively related to level of timber harvest (e.g., Bilby and Ward 1991; Wood-Smith and Buffington 1996). However, the forestry-related land cover variables we examined explained a smaller proportion of the variation in mean maximum depth and volume of pools than catchment area. For streams in the Midwestern US, catchment area had greater explanatory power than land cover variables for parameters describing channel cross sectional diameter (Richards et al. 1996).

The mean density of wood in pools was also negatively related to catchment area which is consistent with the increased ability of larger streams to transport wood. A similar relationship was found in other forestry-dominated systems (Bilby and Ward 1991; Montgomery et al. 1995), but not in an agricultural system (Richards et al. 1996). As the intensity and duration of human-caused disturbance increases along the continuum from silivcultural to agricultural to urban landscapes, the presence of wood in the channel may be determined more by wood availability than by fluvial transport processes. Wood density and an indicator of stream discharge, bank-full stream width, were related in areas with few human impacts (e.g., Bilby and Ward 1989). The utility of this relationship was recognized for determining if wood density at another site was similar to that expected for a 'natural' stream of the same size. Additionally, regression parameters or proportion of variation explained by the relationship may be useful benchmarks for assessing if wood dynamics at broader spatial scales are operating naturally [i.e, within natural variability (Landres et al. 1999)]. Deviations from such benchmarks may indicate that anthropogenic disturbances have disrupted wood dynamics and constrained variability of inchannel wood over an entire catchment or region.

Landscape characteristics generally explained as much or more of the variation in the density of large wood in pools than catchment area. The mean density of wood in pools was positively related to the percent area in forests of medium to very large diameter trees at all except the catchment scale. Age or stem diameter of forest cover reflects time since timber harvest in areas such as the Elk River basin where forestry-related activities currently dominate the disturbance regime. The greater the percent area in forests of medium to very large diameter trees, the lesser the percent area assumed to have been affected by recent timber harvest. Thus, our regression results using forest cover data corroborate findings wherein frequency of large wood in streams was negatively related to forest management (Bilby and Ward 1991; Reeves et. al. 1993; Montgomery et al. 1995; Wood-Smith and Buffington 1996; Lee et al. 1997). Because land cover variables had more explanatory power for the mean density of wood in pools than for the mean maximum depth and volume of pools, large wood metrics may be more sensitive at detecting forestry influences in south coastal basins than variables describing pool geometry.

In addition to the forest cover variable, the mean density of wood in pools was negatively related to the percent area of sedimentary rock types. Large wood is delivered to salmonid-bearing streams in forested, montane basins by chronic channel-adjacent processes such as bank erosion and by episodic hillslope processes such as landsliding (Bilby and Bisson 1998). Less mass wasting debris reached streams of the Elk River basin in sedimentary rock types than in either igneous-intrusive or metasedimentary rock types (McHugh 1986). Additionally, meta-sedimentary rock types experienced more mass wasting on lower slopes under intact forest than the other rock types (McHugh 1986). These considerations may in part account for the negative relationship we found between wood density and sedimentary rock types.

Linear regression explained a greater proportion of the variation in the mean density of large wood in pools when landscape characteristics were summarized at the sub-catchment scale than at finer or coarser spatial scales. The relatively low proportion of variation explained at the corridor scale suggested that wood was delivered from sources in addition to those immediately adjacent to surveyed valley segments. Approximately half the volume of wood in mainstem Cummins Creek, an Oregon Coast Range wilderness stream, was delivered from upslope sources, primarily by debris flows through lower order tributaries (McGarry 1994). Although debris flows may be more prevalent in Oregon Coast Range and Cascade Mountains river basins, debris flows in the Elk River basin do deliver to higher order channels (Ryan and Grant 1991). The sub-network scale included many of the lower order tributaries capable of delivering debris flow-transported wood to surveyed valley segments. Perhaps as a result, explanatory power was greater at the sub-network than at the corridor scale. More variation was explained by regression at the sub-catchment scale than at the sub-network scale. Analytical units at the sub-catchment scale encompassed unmapped lower order tributaries and upslope areas capable of delivering wood from unchannelized hillslope processes. As spatial extent expanded upstream beyond the sub-catchment scale, the proportion of variation explained by landscape characteristics decreased. This suggested that regression relationships at the network and catchment scales were less reflective of processes influencing wood dynamics. We did not determine the distance upstream that explanatory power began to decline. Identification of any such upstream threshold may help in comparing the importance of fluvial transport and other wood delivery processes and, therefore, in designing riparian protection.

With landscape characteristics summarized at the network scale, an approximately equal proportion of variation in the mean density of wood in pools was explained by substituting road density (km/km^2) for the forest cover variable in regression with percent area of sedimentary rock types. Road density and the percent area in forests of medium to very large diameter trees were negatively correlated at all five spatial scales. The degree of correlation increased with increasing spatial extent, suggesting that roads and forest disturbances were not always sited together. Similar to our findings, percent area harvested and road density were highly correlated with each other and were almost equally correlated with a channel response variable, change in stream width, for catchments in the South Umpqua River basin (Dose and Roper 1994).

Although road density and forest cover can be highly correlated, one or the other variable may have more explanatory power for a particular response (Bradford and Irvine 2000) or at a particular spatial scale, as we found. Roads and timber removal share effects on some of the processes that shape stream ecosystems (e.g., increasing landsliding or surface runoff rates) but not all (e.g., increasing direct solar radiation) (Hicks et al. 1991) and may differ in the quality, timing, or magnitude of those effects shared (e.g., Jones and Grant 1996; Jones 2000). Roads may have intercepted debris flows that would have otherwise delivered wood to streams (Jones et al. 2000). However, the mean density of wood in pools was probably more influenced by decreasing the amount of wood available for delivery to Elk River tributaries through timber removal. This was suggested by two findings: 1) valley segment variation in the mean density of wood in pools was better explained by the regression model containing the forest cover variable at each scale than by the corresponding model containing road density; and 2) the only significant relationship to road density was at the network scale, which was one of the two spatial scales that road density and the forest cover variable were most strongly related. Before concluding that conditions of aquatic habitat or biota are unrelated to silivicultural activities, examining relationships with both forest cover and road density appears prudent, particularly when these are summarized at finer spatial scales. Additionally, primary influences may be indicated by determining if a response variable is related to road density or forest cover or both and at what scales.

SUMMARY AND CONCLUSIONS

The utility of multi-scale analysis for understanding relationships between landscape characteristics and stream habitat was demonstrated for a mountainous area where forestry is the primary land use. At each spatial scale except the catchment, the percent area in sedimentary rock types and the percent area in forests of medium to very large diameter trees explained more variation in the mean density of wood in pools than any other regression model. These findings suggested that similar processes were operating at these spatial scales to affect wood density and that having larger, older trees on the hillslope was important to providing large wood in the channel. The greatest proportion of variation in the mean density of wood in pools was explained with landscape characteristics summarized at the sub-catchment scale. Source areas for important processes were probably not fully encompassed at finer scales, but at coarser scales, source areas were included that were less connected to large wood dynamics in surveyed channels. In contrast to the mean density of wood in pools, mean maximum depth and volume of pools were each directly related to catchment area, which explained more variation than landscape characteristics at any spatial scale. Exploring relationships at multiple spatial scales can identify riparian and upslope areas that are most tightly linked to aquatic habitat. Among-scale similarities and differences in relationships can suggest key processes responsible for those relationships. Understanding gained from multi-scale studies can help choose analysis or modeling units for bio-regional assessments of aquatic systems. Such understanding can also be directly applied when designing land management strategies to reduce impacts on, or supply habitat elements to, streams.

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CHAPTER 5

Summary and Conclusions

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This study illustrated the value of multiple year and multiple spatial scale analyses for understanding relationships among juvenile anadromous salmonids, their freshwater habitat, and landscape characteristics. Chapters 2 and 3 highlighted the relevancy of multi-year habitat selection and use studies. Interannual patterns provided a context for, and reinforced confidence in, results from any one year. Among-year differences in selection ratios for juvenile salmonids lead to consideration of factors that may have influenced habitat selection and use, such as environmental conditions and competition (Chapter 2). Multiple years of data allowed determination of how frequently the level of use by juvenile ocean-type chinook salmon was differentiated using valley segment and channel unit features (Chapter 3). Additionally, the specific features most correlated with valley segment use and the transferability of results could be compared among years.

In many cases, if only one or two years of data had been examined, as is common in habitat selection and use studies, conclusions may have differed substantially from those in this study. For example, I might have erroneously concluded that juvenile ocean-type chinook salmon were generally randomly distributed in Elk River tributaries and that their use of valley segments was unrelated to freshwater habitat features. Instead, because multiple years were examined, it was clear that valley segment and channel unit features could often distinguish among valley segments for level of use by juvenile chinook salmon (Chapter 3). Observations in this study were congruent with findings from other systems of substantial interannual variation in stream fish population abundance (Grossman et al. 1990; Ham and Pearsons 2000) and reinforced warnings of problems that may arise when examining fish-habitat relationships over a limited temporal extent (Platts and Nelson 1988). With few notable exceptions (e.g., Long Term Ecological Research (LTER) program), scientific institutions are neither structured nor funded to support longer-term studies. However, critical understanding about stream ecosystems and potential for long-term, land-use effects may not emerge with any other approach (e.g., Hall et al. 1987; Tschaplinski 2000).

Analyses at multiple spatial scales within the Elk River basin also provided valuable insights. First, members of the juvenile anadromous salmonid assemblage selected habitat types at multiple spatial scales (Chapter 2). Second, the distribution of juvenile ocean-type chinook salmon was routinely influenced by both valley segment- and channel unit-scale features (Chapter 3). And third, multi-scale analysis identified riparian and upslope areas most tightly linked to stream habitat condition and suggested processes responsible for observed patterns (Chapter 4).

Habitat selection and use by juvenile salmonids were influenced by characteristics at the stream system and valley segment scales (Chapters 2 and 3). Ocean-type chinook salmon always selected for the mainstem, coastal cutthroat trout and steelhead selected for the tributaries or were randomly distributed at the stream system scale, and coho salmon selected for the mainstem in some years but for tributaries in others (Chapter 2). Although juvenile salmonids appeared not to differentiate between the two valley segment types in the mainstem, unconstrained valleys in the tributaries were either selected or avoided by all four species. Chinook salmon, coho salmon, and cutthroat trout often selected unconstrained valleys, but steelhead often avoided these (Chapter 2). Additionally, the influence of unconstrained valleys was the most statistically significant variable distinguishing between valley segments that were highly used by juvenile chinook salmon and those that were not (Chapter 3).

The importance of unconstrained valleys to juvenile salmonids in Elk River tributaries may derive from characteristics not routinely measured in fish habitat surveys. Unconstrained valleys rarely differed statistically from other valley segment types for any examined channel unit feature (e.g., mean maximum depth of pools; mean density of wood in pools; frequency of pools) (Chapter 2). Unconstrained valleys may, however, support relatively high levels of primary production and aquatic macroinvertebrate biomass (Zucker 1993), nutrient and particulate retention (Lamberti et al. 1989), and groundwater upwelling (Edwards 1998; Baxter and Hauer 2000) that should increase their suitability to spawning adults and rearing juveniles for each salmonid species. On the other hand, water velocities are typically lower (Gregory et al. 1991) and summer water temperatures can be more variable from increased solar heating (McSwain 1987) in unconstrained valleys than in other valley segment types. These characteristics may be less suitable for steelhead than the other salmonids (Bisson et al. 1988; Hicks 1989; Bjornn and Reiser 1991) and help explain why steelhead avoided unconstrained valleys.

Habitat selection and use by juvenile salmonids were also influenced by characteristics at the channel unit scale (Chapters 2 and 3). Pools were selected by all species in the tributaries and by each species except steelhead in the mainstem (Chapter 2). Relative to fastwater, all four species selected less strongly for mainstem pools than for tributary pools, suggesting the heightened importance of pools in the tributaries. Although juvenile ocean-type chinook salmon in the Elk River used and often selected pools, neither the frequency nor percent area of pools helped distinguish between valley segments that were highly used by this species and those that were not (Chapter 3). Three other channel unit features, mean maximum depth of pools, mean density of large wood in pools, and mean volume of pools, were however, significantly related to level of use by juvenile chinook salmon (Chapter 3). Obtaining a better understanding of the differences between steelhead and the other salmonids in selection for pools in the mainstem and unconstrained valleys in the tributaries should improve habitat management and protection for all four species.

The assumption that animals choose resources at multiple spatial scales often structures habitat selection studies in terrestrial systems (e.g., Johnson 1980; Orians and Wittenberger 1991). Poff (1997) proposed a multi-scale conceptual model of stream systems wherein the presence of a species at a specific location is a consequence of its traits matching landscape filters in a series that progresses from the watershed to the micro-habitat. Results suggesting that juvenile salmonids selected and used habitat features at the three examined spatial scales in Elk River are consistent with these views (Chapters 2 and 3). A logical outcome of a multi-scale perspective of selection is the need to understand, manage, and protect habitat features from the landscape to the micro-habitat. Regional conservation goals for salmonids may be best advanced by simultaneously protecting and restoring the processes that create fine-scale, ephemeral features (e.g., deep pools) and the functions of coarse-scale, persistent geomorphic features (e.g., unconstrained valleys) that are important to fish.

A multi-scale perspective may be useful also for understanding relationships between landscape characteristics and channel unit features that are important to juvenile salmonids (Chapter 4). At each spatial scale except the catchment, the density of wood in pools was negatively related to the percent area in resistant sedimentary rock types and positively related to the percent area in mature to old forest. The sub-catchment-scale model explained the greatest proportion of variation in wood density. These findings suggested that although spatial scales were similar in processes affecting wood density, finer spatial scales (i.e., corridor and sub-network scales) omitted source areas for key wood delivery processes, and the coarser spatial scales (i.e., network and catchment) included source areas for processes less tightly coupled to wood dynamics in surveyed channels. Exploring relationships at multiple spatial scales can identify riparian and upslope areas that are most tightly linked to aquatic habitat. Among-scale similarities and differences in relationships can suggest key processes responsible for those relationships.

Spatial position of valley segments may have influenced their use by juvenile salmonids. Although the spatial arrangement of habitat patches is commonly thought to affect the distribution and abundance of biota (Dunning et al.1992; Wiens et al. 1993; Schlosser 1995; Hanski and Gilpin 1997), this has only recently been considered for trout (D'Angelo et al. 1995; Baran et al. 1997; Baxter and Hauer 2000) and salmon (Kocik and Ferreri 1998; Inoue and Nakano 1999). Valley segments near unconstrained valleys in Elk River tributaries were more highly used by juvenile chinook salmon than those farther away (Chapter 3). Unconstrained valleys may be key spawning areas for chinook salmon (Burck and Reimers 1978; Frissell 1992) from which juveniles in excess of available habitat may disperse. Unconstrained valleys may also supply downstream valley segments with key resources, such as drifting macroinvertebrate prey, that may increase habitat suitability for juvenile chinook salmon. Exploring the assumptions underlying the composite variable, influence of unconstrained valleys, is an important next step. Such research might include determining if unconstrained valleys are sources of juvenile fish, key resources or both; how location in the stream network affects the influence of an unconstrained valley on another valley segment; and which attributes or processes fish perceive when selecting a valley segment.

Methods for characterizing spatial association in stream networks are not widely available. Spatial dependence in terrestrial systems has been quantified by point and surface pattern analyses (Isaaks and Srivastava 1989; Legendre and Fortin 1989; Legendre 1993; Carroll and Pearson 2000). In the few published geostatistical analyses of streams, the phenomenon of interest was expressed as fine-scale patches in the stream (Cooper et al. 1997), coarse-scale patches in the landscape (Dunham and Rieman 1999) or points in a reach (Geist et al. 2000). Methods for line pattern analysis are available and appropriate to describe spatial dependence in networks (Legendre and Fortin 1989), however I found no applications for terrestrial or stream ecosystems. Most methods to describe spatial dependence are ill suited to the study of rivers when relatively few coarse-grained analytical units that differ in length and spacing, such as valley segments, are used. For example, a dataset much larger than that available at the valley segment scale for Elk River tributaries, 30-50 pairs of locations for each distance class or spatial lag, would have been required for semivariogram analysis (Rossi et al. 1992). Such considerations influenced my decision to apply parametric methods in assessing spatial relationships between fish and their habitat (Chapter 3) and in relating channel unit features to landscape characteristics (Chapter 4). Implications of violating the independence assumptions were evaluated with randomization procedures for discriminant analyses (Chapter 3) and with plots of stream distances versus absolute differences between residuals for linear regression analyses (Chapter 4). Results suggested that parametric tests of significance were only marginally affected by spatial dependence. However, I was not entirely satisfied with either approach. Advancing techniques to analyze spatial dependence in streams appears to be an interesting, beneficial, and timely direction of study.

Because all valley segments used as units of analysis were taken from the Elk River and its tributaries, rather than from a more spatially extensive population, the scope of direct statistical inference is the Elk River basin. However through less formal schemes of inference (Shrader-Frechette and McCoy 1993), understanding derived from this long-term case study should have relevance to basins with similar climatic, geologic, and biotic characteristics. Few coastal Oregon basins are as diverse as the Elk River in this suite of characteristics. Thus, when taken in its entirety, the Elk River may directly represent a relatively limited area. On the other hand, this diversity of characteristics may broaden the applicability of findings from Elk River beyond the south coast to a wider variety of basins. Case studies, such as the Alsea Watershed Study or that conducted at Carnation Creek, BC have been invaluable in their contributions to advancing understanding of stream ecosystems and effects of watershed management on salmonids (Hall et al. 1987; Tschaplinski 2000). I recognize the many constraints of a case study such as this but suggest that these results be considered for their value in suggesting testable hypotheses (Conquest and Ralph 1998), in developing techniques applicable in broader-scale assessments of aquatic resources, and in augmenting a growing body of knowledge regarding relationships between juvenile salmonids and their freshwater habitat at multiple spatial scales over time.

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Cover photos are a competent bedrock canyon on the South Fork Elk River, top; buried post-flood wood in the bank of the Elk River; and a bedrock canyon in the Elk River basin, Oregon, bottom. All photos by Sharon Clarke.