However, a considerable portion of the Klamath mountains landscape has the potential for such large failures, and the impact of a single such event on a stream system may far outweigh and outlast the combined effects of numerous smaller erosion sources.

3.5 Channel Pattern and Bar Form

Channel pattern differs predictably among valley segment types (Fig. 10, top). Channel pattern is related to valley slope and to constraints imposed by hillslopes, and it reflects sediment load relative to transport capacity, and the processes by which streams route sediment from upslope and upstream sources (Richards 1982). Straight reaches dominate competent bedrock canyons, where channels are highly constrained by hillslopes. Straight and sinuous reaches are about equally common in colluvial canyons (although their sinuosity is imposed by sideslopes, rather than being formed by channel bends on a valley floor). Short braided reaches occur where landslide deposits create coarse lag deposits in the channel and backwater effects at high flow.

Alluviated canyons are more diverse in channel pattern, but predominantly sinuous, with local straight and braided reaches. Braided reaches occur at recent landslide deposits and large debris jams. The existence of a floodplain also allows development of local anabranching reaches in alluviated canyons. Anabranches usually develop from diversion of flood waters by large debris jams, and often contain cool, spring- or tributary-fed habitats in summer. These secondary channels also provide critical shelter for fishes and other organisms during high flows in winter (Brown and Hartman 1988).

Alluvial valleys are dominated by sinuous reaches, but where valley slopes are gentle they also contain fully meandering reaches. Surprisingly, we recorded no

Figure 10. Frequency distribution of channel pattern and bar form of five segment types, based on field surveys. In parentheses is number of valley segments in sample.

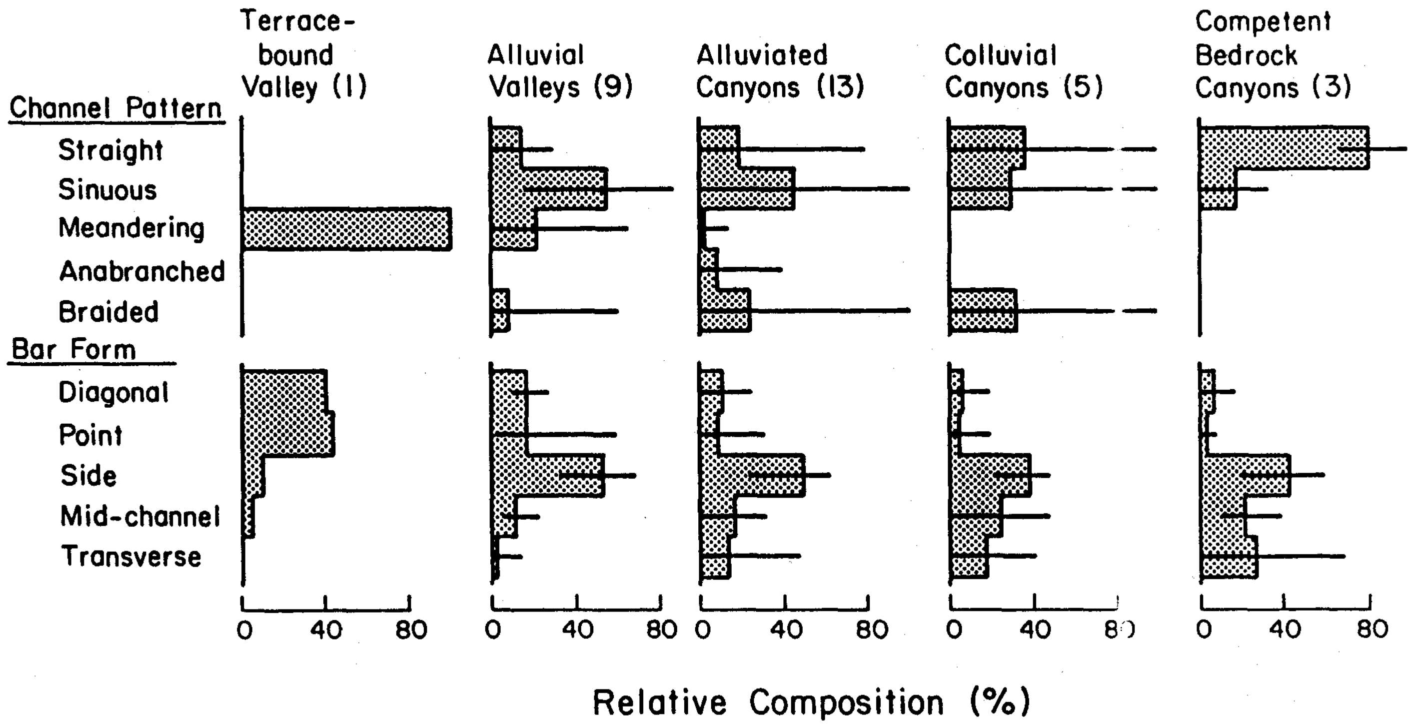

Terrace-bound Valley (1)
Alluvial Valleys (9)
Alluviated Canyons (13)
Colluvial Canyons (5)
Competent Bedrock Canyons (3)
Channel Pattern
Straight
Sinuous
Meandering
Anabranched
Braided
Bar Form
Diagonal
Point
Side
Mid-channel
Transverse
0 40 80
Relative Composition (%)

Figure 10

anabranching reaches in the alluvial valleys we surveyed. This is likely a result of extensive human disturbance in this valley type, as complexly anabranching channels can be readily observed in historic aerial photographs of many of these valleys, and we found numerous relict channels in the field. Many anabranches are derived from meander cutoffs, so that a long-term trend of channel straightening associated with increased sediment load (Lisle 1982, Lyons and Beschta 1983, Hagans et al. 1986) may drive a trend toward channel simplification. Deforestation from agriculture and logging, log drives (Sedell et al. 1991) (e.g., splash damming occurred on Sixes River in the 1930's), and channelization and bank stabilization projects not only damage secondary channels directly but also eliminate the processes that allow complex anabranches to develop and persist (Sedell and Frogatt 1984, Amoros et al. 1987, Chamberlin et al. 1991). With the loss of anabranching channels comes diminishment of critical habitat such as winter shelter and summer thermal refugia required by anadromous fish.

Although we did not quantify channel pattern in alluvial-fan-influenced valleys, field observations indicate they are dominated by sinuous and anabranching reaches. The development of comparatively unstable anabranches is fostered by cyclic formation of large debris dams, sediment deposition, and consequent channel avulsion on or near alluvial fans. Most large alluvial fans in the region are more heavily impacted by deforestation and channelization than are our study sites in middle Euchre Creek, resulting in more simplified straight or sinuous channels. However, because topographic and sedimentological conditions in the vicinity of alluvial fans favor more frequent channel switching and anabranch development, this valley type may maintain more complex channels in the face of human disturbance than do alluvial valleys.

Channel pattern in terrace-bound valleys is typically sinuous or meandering. However, these are not free meanders, as they are deeply entrenched in the valley floor, so that rapid migration or development of anabranches are largely precluded. Because their channels are less complex and skirted by erosion-resistant bedrock or saprolitic material along terrace margins, streams in terrace-bound valleys appear to be generally less sensitive to upstream disturbance than are alluvial valleys. Most terraces in southwest Oregon are bedrock-floored and therefore resistant to lateral erosion. However, where terraces are comprised of unconsolidated materials (e.g., fluvially graded landslide deposits, glacial valley fill), they are subject to bank failure and streamside landslides, particularly if channels are destabilized from upstream sediment sources or terrace scarps are deforested. Terrace-bound valleys are sensitive to channel degradation and widening which can eliminate or reduce the inundation frequncy of floodplains. When large wood is removed from the channel, rapid entrenchment ensues. Re-establishment of debris jams, beaver dams, and other sources of channel complexity in degraded terrace-bound valleys could be difficult or impossible in the absence of major pulses of very large woody material from the riparian zone or tributaries.

Correlated with differences in channel pattern is variation in bar form (Figure 10, bottom). Colluvial and competent bedrock canyons were dominated by transverse bars, mid-channel bars, and side bars. These bar forms are often associated with stable hydraulic obstructions like large boulders or bedrock outcrops, and they tend to be comprised bed materials of coarse gravel to small boulder size. Mid-channel bars are characteristic of braided reaches. Channels in alluviated canyons contained a wider range of bar forms, dominated by side bars. Point bars and diagonal bars, typical of more sinuous, low-gradient channels and formed of sand- and gravel-size materials, were more abundant in alluvial valleys and the terrace bound valley.

3.6 Streambank Texture

Because segment types differ in geomorphic surfaces and rock type, texture of materials in the streambank varies accordingly. Field data (Fig. 11) indicate that boulders and bedrock dominated most streambanks in colluvial and competent bedrock canyons. About one-third of the banks in colluvial canyons, where the stream abutted fine textured colluvium or small floodplain benches, contained large amounts of cobble and gravel. Alluviated canyons had very diverse streambanks, with those adjacent to hillslopes dominated by boulders and bedrock outcrops, others along floodplains dominated by cobble, gravel, or sand. Sand and silt were more abundant in alluvial valleys where the channel bisected wide, low floodplains formed by frequent overbank deposition of fines in ponded flood waters. More locally, streambanks formed in active channel and flood berm deposits of alluvial valleys were coarser deposits dominated by cobble and gravel. The terrace-bound valley of Sixes River had a bimodal distribution of streambank texture, with banks along narrow, inset floodplains dominated by sand and silt, alternating with bedrock-dominated banks adjacent to uplifted strath terraces.

Because bank erodibility is a function of silt and sand content of nonconsolidated materials (Schumm 1960, Richards 1982) it seems likely that alluvial valleys are more vulnerable to bank erosion than are other segment types. Textural differences between deposits derived from different geologic parent materials could further influence the resistance of banks to erosive forces, and also affect the rate at which riparian vegetation recolonizes and stabilizes flood-disturbed valley surfaces. Our field observations indicated that drainage basin geology affected the texture of floodplain deposits and stream banks. For example, silt and clay dominated the fine fraction in basins draining Otter Point metasedimentary rocks, whereas sand more frequently dominated the fine fraction in basins draning Colebrook schist and especially

Figure 11. Texture of bank materials in five valley segment types, measured as percent of transects in which particle size class was first or second most abundant in streambank exposures. In parentheses is number of segments in sample.

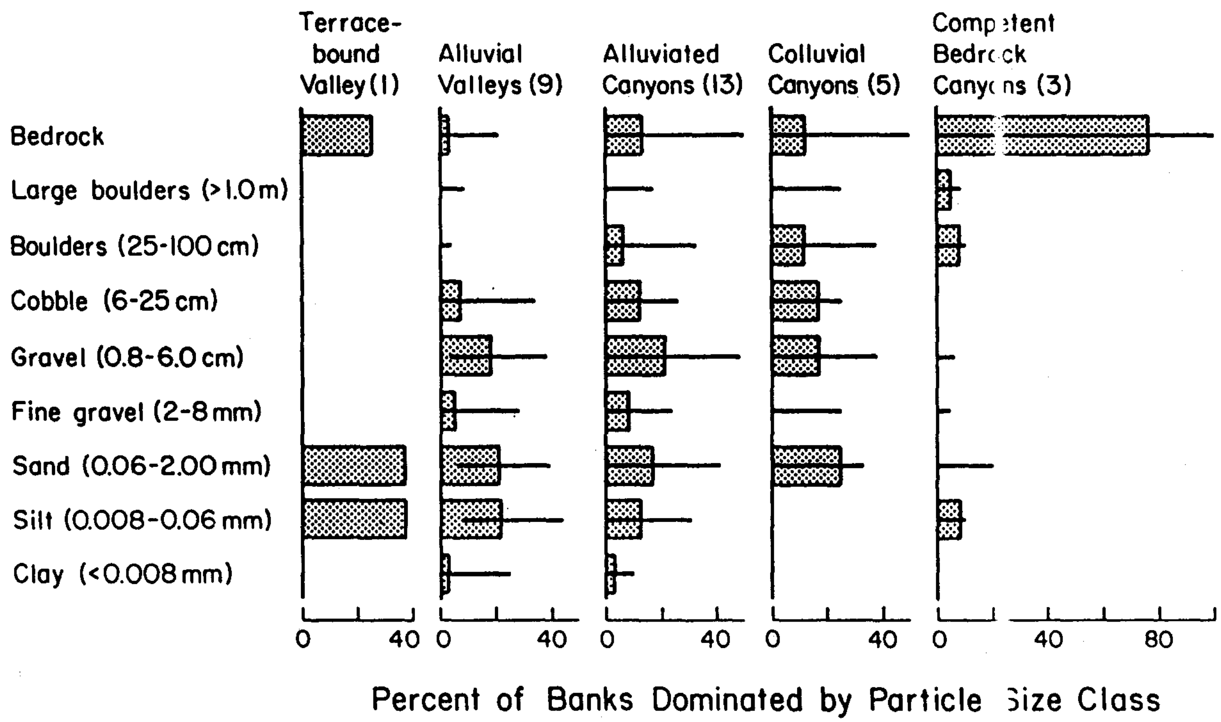

Terrace-bound Valley (1)
Alluvial Valleys (9)
Alluviated Canyons (13)
Colluvial Canyons (5)
Competent Bedrock Canyons (3)
Bedrock
Large boulders (>1.0 m)
Boulders (25-100 cm)
Cobble (6-25 cm)
Gravel (0.8-6.0 cm)
Fine gravel (2-8 mm)
Sand (0.06-2.00 mm)
Silt (0.008-0.06 mm)
Clay (<0.008 mm)
0 40 0 40 0 40 0 40 0 40 80
Percent of Banks Dominated by Particle Size Class

Figure 11

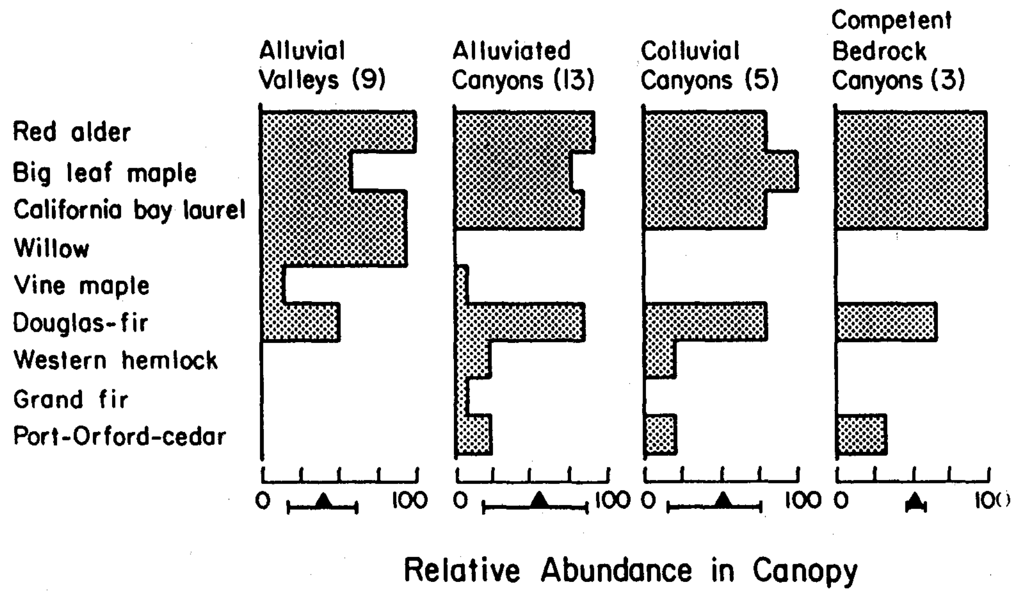
Cretaceous sedimentary rocks. This would make channels in the latter two formations especially prone to bank erosion. A more intensive sampling method than our semi-quantitative procedure would be necessary to detect such subtle variations in texture.

3.7 Riparian Vegetation and Canopy Cover

Tree species composition of riparian forests differed among segment types, with conifer species more important in canyon and alluviated canyon segments than in alluvial valleys (Fig. 12). Three hardwood species-- red alder, bigleaf maple, and California bay laurel-- dominated stands along all nearly all the streams surveyed. California bay laurel (also known as Oregon myrtle) is particularly significant ecologically in that its ability to establish by root sprouting from fallen boles and drifted logs enables it to rapidly colonize and stabilize flood-stripped surfaces. Many floodplains in the area are dominated by nearly monotypic, mature stands of this species. A fourth hardwood, willow, was common only on active floodplains in alluvial valleys and alluvial-fan-influenced valleys.

Conifer abundance and tree species diversity was greatest in canyon and alluviated canyon segment types where hillslopes more frequently impinged on channel margins. However, we observed decayed conifer stumps, dead snags, and scattered individuals of several conifer species in alluvial valleys, indicating that human activities have affected forest composition. Because of their accessibility, these flatter, low-elevation valley segments have been subject to selective logging of conifers (particularly Port-Orford-cedar, western red-cedar, and later Douglas-fir) since before the turn of the century. Further, introduction in recent decades of an exotic, water-bourne fungal disease, spread by logging, to these watersheds has caused extensive mortality of Port-

Figure 12. Relative abundance of tree species in riparian canopy and percent canopy cover of four segment types. Abundance is measured as percent of segments surveyed in which species was among the four most important taxa in overstory. In parentheses is number of segments in sample. Too few transects were measured to report reliable data for alluvial-fan-influenced valleys and terrace-bound valleys.



Alluvial Valleys (9)
Alluviated Canyons (13)
Colluvial Canyons (5)
Competent Bedrock Canyons (3)
Red alder
Big leaf maple
California bay laurel
Willow
Vine maple
Douglas-fir
Western hemlock
Grand fir
Port-Orford-cedar
0
100
Relative Abundance in Canopy

Figure 12

Orford-cedar (Zobel et al. 1985). Compared to Douglas-fir, Port-Orford-cedar is a more successful invader of hardwood-dominated riparian stands, and may play a critical role in the successional establishment of mixed conifer and hardwood stands in riparian areas. The exotic pathogen and logging have nearly eliminated this species from floodplains in alluvial valleys, where they historically were abundant. The loss of Port-Orford cedar may be critical given its apparent role in vegetation succession, as well as its large size, decay resistance, and long residence time, which confer disproportionate ecological value to fallen logs of this species in streams and on floodplain surfaces.

Canopy cover over the stream channel varied widely, decreasing from an average of about 60 percent in streams with active channel width of <10 m to 20 percent where channel width exceeded 30 m. When the effect of stream size was taken into account by regressing canopy cover against channel width ($P < 0.001$, $R^2 = 0.664$), analysis of the residuals suggested that alluvial valleys had more open canopies and alluviated canyons somewhat more dense canopies than other segment types (one-way ANOVA on residuals, $P < 0.05$). Two alluvial valleys with older riparian forest (selectively logged >50 y ago) approached the overall average canopy condition for all segment types combined, whereas many alluvial valleys that had been logged in recent decades had 20-30 percent less cover than the overall average. This pattern may result from the elimination of older, taller conifers such as Port-Orford cedar and Douglas-fir and their replacement by willow and red alder on logged and flood-disturbed floodplains. Within other segment types, we were able to discern no consistent effect of logging or vegetation successional state on canopy cover.

In individual cases, geomorphic processes and the indirect effects of land use exerted strong control over riparian vegetation in the study streams. Colluvial canyons had quite variable overstory development, and two of four had very low canopy cover (<30 percent), apparently caused by frequent or recent landslide disturbance (in one case, combined with logging) which hinders the establishment of a continuous canopy of mature trees. Lower Edson Creek also had very low canopy cover (about 18 percent). The lack of shade in Edson Creek appears to result largely from recent streambed aggradation, and destruction of stream-adjacent trees by bank erosion. Port-Orford-cedar root disease has contributed to the loss of overstory. Damage to the riparian forest of Edson Creek illustrates that simply leaving buffer zones of vegetation along major streams cannot compensate for the downstream erosional and pathological effects that originate from logged headwater areas.

Our data were not sufficient to discern any direct effect of stream-adjacent or basin bedrock geology on canopy cover. However, observations throughout the study area indicate that vegetation recovery following logging is faster on the fine-textured soils over Colebrook schist and Otter Point metasedimentary rocks than on the coarse-textured or skeletal soils common over Cretaceous sedimentary rocks, Pearse Peak diorite, and steeper slopes within the Dothan sandstones. Due to unusual chemical and physical soil conditions in serpentine areas, many never develop a closed canopy (Franklin and Dyrness 1973). However, these differences are somewhat moderated in riparian areas, where soil and air moistures are higher and fire may be less frequent or less intense.

3.8 Biological Significance of Valley Segments

Spawning of salmon and steelhead in southern Oregon coastal rivers occurs almost exclusively in segments we classified as alluviated canyons, terrace-bound valleys, and alluvial valleys (Reimers 1971, Burck and Reimers 1978, Frissell and Nawa unpublished data). In these valley segments, large, stable expanses of well-sorted gravel and cobble are available, and the presence of floodplains allows overbank flow, partially buffering the channel from the scouring and depositional effects of floods. In competent bedrock and colluvial canyons, suitable spawing gravel is patchy and large floods are not attenuated by floodplains. Salmon seldom spawn in alluvial fan-influenced valleys, perhaps because eggs and fry have a high risk of mortality in the highly unstable, anastomosing and braided channels, forcing strong natural selection against spawning in these segments (Nawa and Frissell, unpublished data). Other than in Elk River (where logging has been relatively limited), few alluvial valleys of southern Oregon coastal rivers support more than scattered spawning by chinook salmon today. Based on accounts of long-time local residents and biologists, these stream types were heavily used by chinook and probably chum salmon for spawning earlier in the century. We believe these populations have been decimated in part by aggradation and loss of channel stability, following logging-related increases in sediment load (Frissell and Liss 1986; see also Scrivener and Brownlee 1989, Holtby and Scrivener 1989).

Spatial variation in summer rearing of juvenile salmonids in river basins of the study area appears to be strongly controlled by maximum water temperature, although stream size is also important (Stein et al. 1972, Frissell et al. 1992b). In Sixes River basin, density and diversity of species and age classes declined with increasing water temperature. However, after regressing diversity against water temperature, one-way ANOVA of the residuals indicated that for a given temperature regime, total fish species diversity (excepting benthic taxa that were not sampled, e.g., Cottus spp. and lampreys) was related to segment type ($P<0.10$). For a given temperature, diversity was lowest in colluvial canyons and bedrock canyons, intermediate in alluviated canyons, and highest in alluvial valleys and terrace-bound valleys. The differences between segment types were largely due to the presence of largescale suckers (Catastomus macrocheilus) and threespine sticklebacks (Gasterosteus aculeatus) in alluvial valleys and terrace-bound valleys, and frequent co-occurrence of cutthroat trout (Oncorhynchus clarki), juvenile steelhead (O. mykiss), chinook salmon fry (O. tshawyscha), and coho salmon fry (O. kisutch) in tributary alluviated canyons of major tributaries. Evidence from Elk River (G. Reeves, U.S. Forest Service, Pacific Northwest Research Station, Corvallis, Oregon, unpublished data) indicates that alluviated canyons are used heavily during summer by juvenile steelhead, chinook salmon, coho salmon, and possibly cutthroat trout.

4. Implications for Landscape Change and Aquatic Fauna

Alluvial valleys, alluviated canyons, and terrace-bound-valleys are heavily used by fish, perhaps because they contain a diversity of in-channel and floodplain habitats meeting the spawning and rearing requirements of most species during all seasons. The importance of these low-gradient, floodplain-rich valley segments for fish habitat is critical given their inherent sensitivity to increased sediment loads and channel aggradation associated with logging and landslides. Of these segment types, terrace-bound valleys appear to be the most resistant to the adverse effects of increased sediment yield, probably because of the erosion resistance conferred by bedrock banks along the toes of uplifted terraces. Unfortunately, terrace-bound valleys are not widely distributed in the study area (Fig. 3, Table 2). The dependency of native fishes on aquatic habitats that are limited in distribution and highly vulnerable to both direct and indirect, cumulative effects of land use activities can help explain why salmon populations in most streams in southwest Oregon have collapsed since extensive logging of unstable, steeper slopes in their drainage basins (Frissell and Liss 1986).

Human activities may fragment and damage aquatic habitats more rapidly and intensively than they affect terrestrial habitats. Although the landscape of southwest Oregon is naturally vulnerable to catastrophic disturbance such as fire and large landslides, the continuing, widespread decline of several Pacific salmon and trout species suggests that human activities have artificially accelerated the rate of disturbance. Research on landscape dynamics in alluvial river valleys of Europe has stressed the reversibility of agricultural impacts on floodplains, as opposed to the largely irreversible effects of urbanization and engineering of channels for navigation and flood control (Amoros et al. 1987, Decamp et al. 1988). In southwest Oregon, urban and industrial effects are very limited. Although cultivation and grazing have affected many low-elevation alluvial river valleys, diminishment of these activities in recent decades has resulted in afforestation of many cleared lands. Afforestation of cleared floodplains and terraces occurs over a time period of a few decades, but the large-scale changes in erosion, sediment transport, and channel morphology caused by logging and logging roads on steep, upland slopes may not be reversible except over a time frame of a century or longer (Madej 1984, Hagans et al. 1986). For example, lower Sixes River, which dramatically widened following a massive landslide in the late 1800's (Diller 1903), has remained wide and shallow to the present day (Frissell unpublished data).

Logging affects a large (>75 percent) and growing portion of the landscape, and virtually all low-elevation alluvial valleys have been impacted by adjacent and upstream logging. In Fig. 13 we conceptualize how the intensity and the spatial dispersion of disturbance have been modified by humans. Historically, alluvial valleys of mainstem streams have been the most productive habitats for species like chinook, coho, and chum salmon. We speculate these valley segments, located low in the drainage network, are partly buffered from the effects of natural disturbances in headwater areas. Alluviated canyons in tributaries, by comparison, are closer to and more directly vulnerable to the effects of landslides, debris flows, and sediment pulses.

Under natural conditions, disturbance like fire and landslides were localized; although these events undoubtedly had severe effects on certain tributary habitats and their populations, their effects on downstream alluvial valleys might have been attenuated by distance and time. Large fish populations in mainstem alluvial valleys were likely more stable and less sensitive than smaller, tributary populations to variations in habitat quality. Furthermore, habitats and fish populations in alluviated canyons of other, unimpacted tributaries could help sustain populations in the basin as a whole. Over decades or centuries, each major basin could be viewed as a mosaic of connected salmon populations, anchored by a large population in the mainstem.

Logging affects watersheds in southwest Oregon differently than does natural wildfire. Based on vegetation patterns visible on early aerial photographs, major fires were patchy and a single episode rarely affected more than 25 percent of a large drainage basin. Furthermore, riparian areas were often buffered from fire. The preponderance of old-growth trees and fire-sensitive species like Port-Orford-cedar and Sitka spruce in unlogged riparian areas suggests that under natural conditions fire frequency and intensity were lower on valley floor, toeslope, and channel headwall surfaces than on adjacent slopes and ridgetops. By contrast, during this century riparian areas along larger streams have been the foci of human activities. Alluvial valleys at lower elevations have been hard-hit by both logging and agriculture.

Aside from spatial pattern and rate of disturbance, logging and wildfire differ in several important ways. Abundant large woody debris usually remains after fire. Many trees and shrubs survive fire, so that complete stand mortality is rare. Woody material and live trees help stabilize eroding slopes and channels and facillitate vegetative recovery. By contrast, clear-cut logging involves removal of nearly all large boles. Furthermore, roads, absent in natural burns, are a major and persistent cause of erosion in logged areas. Despite the likelihood that fire suppression has reduced natural disturbance frequency since early in the century (Agee 1991), this has not compensated for intense and widespread artifical disturbance in ever-expanding, logged areas.

Logging activities, when carried out at present rates, can accelerate the rate of landsliding over a comparatively large portion of the landscape, so that proportionally more tributaries are affected by sedimentation and loss of channel stability (Fig. 13). With logging rotations of 30 to 80 years, large portions of drainage basins are again deforested and made vulnerable to erosion before aquatic habitat and fish populations have recovered from the previous episode of disturbance. Further, the increased rate of erosion basin wide has contributed to chronic damage of habitat in downstream alluvial valleys, leading to depression and eventual elimination of mainstem-spawning populations of salmon. As roads and logging penetrate the last headwater forests on federal lands, the few remaining islands of undamaged aquatic habitat in tributaries are likely to be damaged before habitats at lower elevations have recovered.

The net result of extensive landscape disturbance is a native fish fauna whose populations have become fragmented as they have declined progressively in an upstream direction (Fig. 13). Isolated alluvial canyons located in tributary streams that drain unlogged, roadless areas, all on federal forest lands, now appear to serve as refugia for many of the last viable fish populations in the region. Because of their location and small size, populations in these refugia are vulnerable to loss from natural disturbance. Nevertheless, current management plans of federal agencies call for rapid, intensive logging of most of these areas, increasing the likelihood of extinction of depressed and fragmented fish populations. In response, some scientists have recently proposed protection of such watershed refugia as a necessary first step toward maintaining aquatic biodiversity and restoring native Pacific salmon populations (Frissell 1991, Johnson et al. 1991). There is a clear need for research focusing on the significance of watershed-scale refugia for sustaining aquatic biodiversity.

Figure 13. Conceptual model of cumulative effects of natural and human-caused erosion and sedimentation in southwest Oregon drainage basins (See text). Rectangles are alluviated canyon and alluvial valley segments, narrow lines in stream network are canyons, and symbols denote disturbance sources. Dashed arrows indicate sediment transfer, shading indicates habitat quality as shown in legend. Area of pie diagram is proportional to total run size, patterned sections indicate relative abundance of three salmon species. Model can represent a time series of a single basin, as shown, or to a spatial comparison of basins having different management histories.

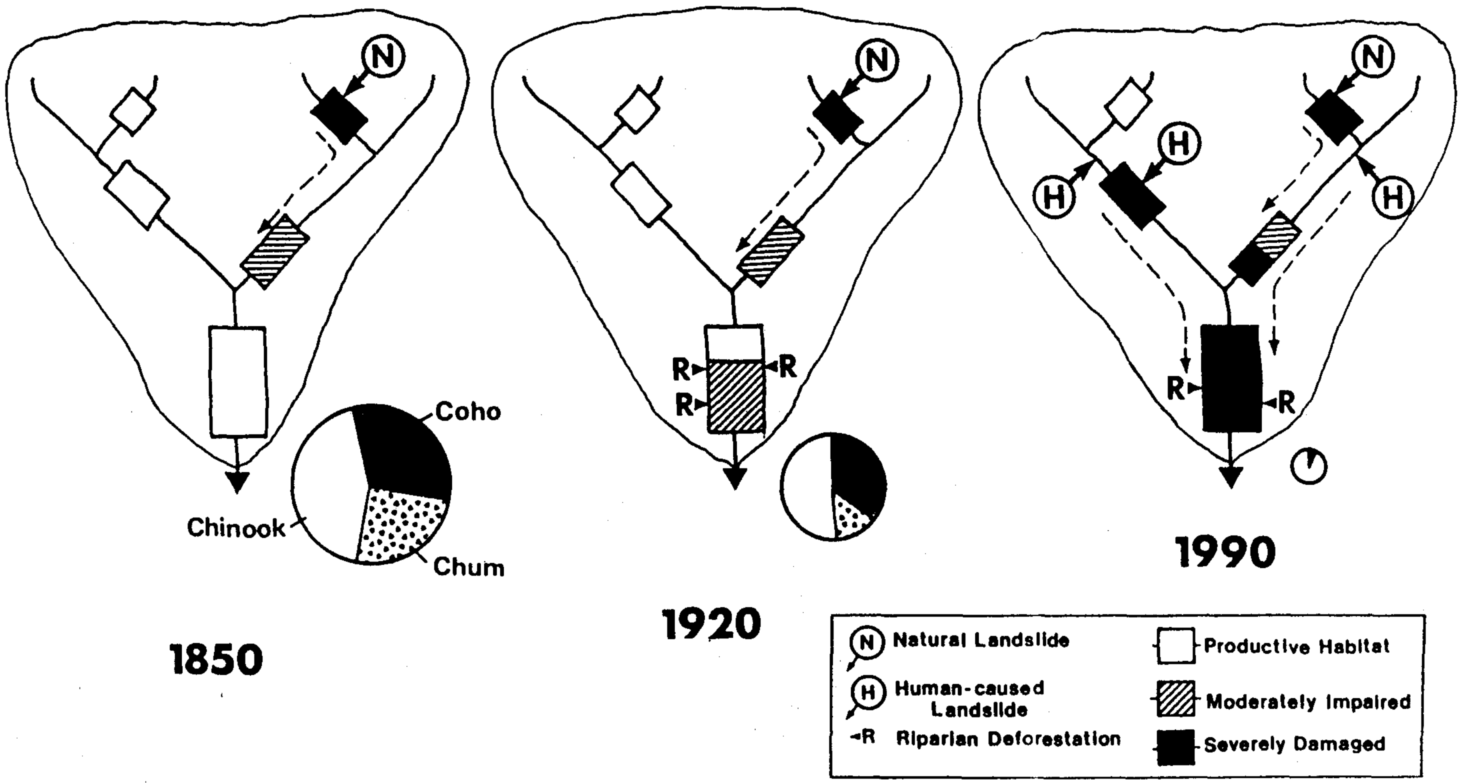

N
Coho
Chinook
Chum
1850
N
R
R
R
1920
N
H
H
H
R
R
1990
N Natural Landslide
H Human-caused Landslide
R Riparian Deforestation
Productive Habitat
Moderately Impaired
Severely Damaged

Figure 13

5. Comparison with Other Classifications

Some of our classes appear similar to those of Cupp (1989b), Rosgen (1985), and other schemes. Cupp adapted his system for Washington streams based on our early work in southwest Oregon (Frissell et al. 1986, Cupp 1989a, 1989b). However, there are important differences between some of Cupp's classes and our own, due both to geographic variation and different emphases in approach. Cupp emphasizes valley cross-sectional form and de-emphasizes geomorphic surfaces and soil textural differences. One theme of this paper has been the importance of geomorphic surfaces, slope processes, and texture of channel-adjacent deposits in interpreting and predicting the habitat conditions and potential response to disturbance of streams in different valley types. In concept our approach to valley segment classification is perhaps most closely allied with that of Platts (1979), in that it stresses terrestrial control of aquatic systems.

In most cases our segment classes can be differentiated reliably by an experienced specialist using topographic maps at the scale 1:62,500 or 1:24,000, stereo airphotos, or field data. Cupp (1989b) provides a comprehensive operational description of the procedures used to classify valley segments from maps. The classifications of Cupp (1989b) and Marion et al. (1987) appear to be conceived at the same level of resolution and with similar objectives as our valley segments. Gregory et al.'s (1991) scheme is applied at a similar scale, but is far more generalized in form, addressing only valley width and hillslope constraints.

Rosgen (1985) did not specify at what spatial scale he intends his system to be applied, but several of his stream classes appear to represent a finer level of resolution (and shorter time of persistence), perhaps at the level of stream reaches (sensu Frissell et al. 1986) rather than our valley segments. Confusion about about scale and the conceptual basis of Rosgen's scheme have caused it to be applied and interpreted inconsistently and sometimes indiscriminately in research and management. We believe most criticism (largely unpublished) of Rosgen (1985) and other classification systems has stemmed from 1) ambiguity about scale and concepts, leading to misapplication, unrealistic expectations, and inappropriate statistical assumptions, and 2) perfunctory and uncritical extrapolation of classes or information developed for one biogeoclimatic region to another, very different region.

Although fundamental differences exist between regions, there are commonalities as well. For purposes of comparison and translation, Table 5 is our best attempt to summarize correspondences between our valley segment classes and several other stream classifications. Many stream types identified in other studies-- glacial outwash valleys, for example-- have no apparent counterpart in the Klamath Mountains region. On the other hand, valley segments structurally and functionally similar to those we have described in the Klamath Mountains do appear to occur in many mountainous landscapes, especially in tectonically active coastal zones. We believe that within the Pacific coastal mountain belt, particularly the Klamath Mountains, our classification of valley segments can be more easily applied, more interpretively powerful, and is likely to be more successful in most applications than other valley classification systems we are familiar with. We are currently conducting research elsewhere in Oregon and the Great Basin to determine how these classes can be modified or supplemented to be useful across a wider range of biogeoclimatic conditions.

Table 5. Translation key for valley segment classification in southwest Oregon based on this paper (left column) and most comparable stream segment or reach types from classifications by Cupp (1989), Rosgen (1985), Marion et al. (1987), and Gregory et al. (1991).

Valley Segment Type	Cupp (1989)	Rosgen (1985)	Paustian et al. (1983)	Gregory et al. (1990)
Alluvial-Fan-Influenced Valley (AFV)	Alluvial/Colluvial Fans (F4)	D1, D2	A3,B5,C4	Unconstrained
Alluvial Valley (AV)	Alluvial Lowlands (F2); Wide, Alluviated Valley Floor (F3)	C1, C2, C3	B1, C1, C3, C7	Unconstrained
Terrace-Bound Valley (TBV)	Gently Sloping Plateaus and Terraces (F5)	F1	C2	Constrained (terraces)
Alluviated Canyon (AC)	Alluviated Mountain Valley (V4)	B2, B3, B4	B3, B7, C5	Semi-constrained (hillslopes)
Colluvial Canyon (CC)	Incised, U-shaped, Moderate or High Gradient Bottom (U2, U3)	A2, A3	B7, C5	Constrained (hillslopes)
Competent Bedrock Canyon (BRC)	V-shaped, Moderate or Steep Gradient Bottom (V1,V2); Bedrock Canyon (V3)	A1, F2, F3, F4	B7, C5	Constrained (hillslopes)
Estuary (EST)	Estuarine Delta (F1)	E1, E3, E4	E1, E2, E4	--

6. Potential Applications and Limitations

This classification of valley segments is based on general principles of geomorphic origin and development and landscape function to make it as useful and ecologically meaningful in a variety of applications. Like any general purpose classification it may not be the optimal scheme for any single application (Webster and Oliver 1990). However, we can envision few situations where this kind of classification would not improve study design, analysis, or interpretation. We have used our scheme in research to stratify analysis of stream channel response to the impacts of land use activities (Frissell et al. 1992b). The approach can also be used to identify and map valley segments most likely to be critical for anadromous fish and other species, and to predict the effects of landscape change on those habitats, populations, and biotic communities (Platts 1979, Frissell et al. 1986, Harris 1988, Swanson et al. 1990, Naiman et al. 1992). In policy, planning, and management, the classification could provide a basis for tailoring protective measures, such as forest practice requirements, to particular sites, since different segment classes differ in their sensitivity to on-site and downstream impacts. For example, Budd et al. (1987) classified stream corridors based on geomorphology to delimit buffer widths necessary to protect water quality and fish habitat during urban development. Finally, the classification could facillitate rational selection of representative or most-sensitive sites for monitoring water quality, biota, or habitat quality (Warren 1979, Frissell et al. 1986, MacDonald et al. 1991).

We should stress that any classification of valley segments accounts for variation only within a specific range of temporal and spatial scales. This scale is appropriate for landscape analysis, environmental assessment, and resource planning. Many applications, however, will require at least some information to be stratified at finer levels of resolution-- for example, the reach, pool/riffle, and microhabitat scales of

Frissell et al. (1986). Nevertheless, careful accounting for variation in valley segment characteristics can provide a critical geomorphic, ecological, and spatial context for work at finer scales (e.g., Frissell et al. 1992b).

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Chapter 3

Interactive Effects of Valley Geomorphology and Logging on Stream Habitat in South Coastal Oregon

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ABSTRACT

We surveyed 17 coastal streams in the Klamath Mountains southwest Oregon in five geomorphically-defined valley segment classes to assess the effects of geomorphology and logging on habitat of anadromous salmonid fishes. Percentage of eroding streambanks increased with logging activity, regardless of valley segment type. Large woody debris was most abundant in alluviated canyon valley segments, which have narrow floodplains and considerable side-slope influence. Abundance of woody debris debris increased with logging in alluviated canyons. Channel-spanning debris jams were common in lightly-logged basins, whereas in heavily-logged basins woody debris was primarily concentrated in lateral accumulations. Pools in hillslope-confined canyon segments were associated with bedrock and boulders, but most pools in low-gradient, floodplain-dominated alluvial valley segments were associated with large wood. Within alluviated canyon segments, pool area and riffle depth declined with logging. Size distribution and embeddedness of bed materials varied among valley segment classes and among pool and riffle types. Within alluviated canyons, surface concentrations of fine sediment were significantly higher in pools and cascades of heavily logged drainage basins. Landslides and erosion associated with logging of steep slopes appeared to be the primary cause of cumulative loss of channel stability, enlargement and destabilization of gravel bars causing loss of pool and riffle habitat, and increased deposition of fine sediments in downstream, low-gradient valley segments. However, many of these effects were detected only after accounting for natural variation imposed by valley geomorphology and drainage basin size.

1. Introduction

Detecting and predicting the effects of land use activity on stream habitat and biota is complicated because responses to disturbance occur across various scales of space and time (Frissell et al. 1986). Particularly in steep, montane watersheds, perturbations in headwater areas are often transmitted downstream, causing off-site, time-lagged impacts that can greatly exceed in magnitude and persistence the short-term, on-site effects of human activity (Leopold 1980, Coats and Miller 1981, Hagans et al. 1986). Furthermore, rarely can a human disturbance in a drainage basin be viewed as an isolated intrusion; more often, the ecosystem's response is an outcome of an interacting series of human and natural perturbations. The long-term, geological and geomorphic structure of the drainage basin however, can be viewed as a fabric or template which structures the complex response of ecosystems (Swanson et al. 1988, Frissell et al. 1986).

Many authors have shown that classification of stream systems can serve to stratify and clarify their complex structure, providing improved understanding of the function and response of streams to human impacts (Platts 1979, Warren 1979, Bravard et al. 1986, Lotspeich and Platts 1987, Mosely 1987, Harris 1988). Stream channels and aquatic habitat in different locations within a stream system differ in morphology and composition, and consequently they may vary in sensitivity to disturbance (Frissell et al. 1986, Swanson et al. 1990, Naiman et al. 1992). However, there have been relatively few attempts to apply the principles of classification in studies of streams of the west coast of North America.

Most research in Pacific Northwest streams has stressed the influence of on-site factors, such as logging of riparian zones, on channel features such as canopy cover (Gregory et al. 1987) and large woody debris (e.g., Bilby and Ward 1991). One widely applied classification scheme is driven solely by stream-adjacent, terrestrial variables (Omernik and Gallant 1986). But such approaches alone may not be sufficient to analyze and predict impacts in landscapes dominated by steep terrain and intense precipitation, where catastrophic processes like landslides and debris flows transmit effects rapidly downstream (Swanson et al. 1982, Tripp and Poulin 1986a and 1986b, Benda 1990). Because of relatively expeditious and often pulsed transfer of sediment and debris, habitat conditions and biota at any point in the stream will bear signatures of both the local channel-adjacent or riparian environment and the dynamic processes originating in upstream segments and up-slope areas.

Severe ecological and cultural consequences could result from research designs which tend to inordinately emphasize the on-site influences of human activities, and neglect both the influences of upstream or up-slope disturbance and the inherent diversity in structure and function of different stream types within a basin. Field studies may be confounded if they focus only on reach or site conditions and do not account for factors in the drainage basin as a whole, resulting in the failure to detect human impacts where they in fact are occurring. In other cases, effects attributed to riparian condition could be at least partly spurious, if in fact they are largely controlled by and contingent on conditions in the watershed as a whole. Unacknowledged geomorphic or ecological factors could render some study sites relatively insensitive to disturbance, while others might be highly vulnerable. If, as we believe, such shortcomings have been prevalent in research, current management policies that provide riparian forest buffers along major streams, but often fail to protect headwater channels and slopes, could be completely inadequate to protect stream habitat from long-term degradation (Chamberlin et al. 1991). Recent acknowledgement that native populations of anadromous fish are suffering serious declines region-wide (Nehslen et al. 1991) strongly implies that science and policy have failed to adequately identify and control the underlying causes of habitat deterioration (Frissell 1991, Frissell and Nawa 1992, Frissell submitted).

In a previous work (Frissell and Liss 1986, Frissell et al. 1992a), we described a classification of stream segments based on valley geomorphology that can be used to assess the origin, routing, and likely downstream effects of disturbances in a stream network within a large drainage basin. In this paper we apply this classification of valley segments in a multiple-basin survey and analysis of logging impacts on freshwater habitat of anadromous fishes in southwest Oregon, U.S.A.

2. Methods

2.1 Study Area

We conducted field surveys during summer of 1989 in coastal streams draining the Klamath Mountains of Curry County, southwest Oregon. The terrain is very steep and erosion prone, as it overlies highly faulted and sheared rock formations and is subject to intense rainfall during winter months. The rivers have very high peak flows, and low summer flows relative to other streams in Oregon (Nawa et al. 1988). They descend rapidly from steep, confined canyons to sediment-rich, low gradient alluvial flats. Since about 1960 logging activities have moved from comparatively gentle slopes at lower elevation on private lands to very steep, landslide-prone slopes on federally-owned lands in headwater areas. This region harbors one of the most severely endangered faunas of anadromous fish in the Pacific Northwest (Frissell, submitted). The streams provide freshwater habitat for fall-run chinook salmon (Oncorhynchus tshawytscha), coho salmon (O. kisutch), chum salmon (O. keta), steelhead (O. mykiss), and sea-run cutthroat trout (O. clarki), all of which have suffered severe declines in recent decades and are considered at risk of extinction in most basins in the study area (Nehlsen et al. 1991). More details about the geomorphology and ecology of the study area are provided in Frissell et al., (1992a).

2.2 Study Design

The objective of our field study was to compare geomorphically-defined valley segment types (described in Frissell et al. 1992a) in terms of the kinds of summer habitats they offered for fish and the apparent sensitivity of these habitats to land use activities. The factors whose effects on stream habitat we wished to account for were 1) land use history of the drainage basin; 2) geologic composition of the drainage basin; 3) valley segment type. However, we also collected field data that allowed more detailed comparisons based on correlates such as channel slope and bank material composition among study sites (Frissell et al. 1992a).

We selected 17 streams which covered a range of land use conditions within each of four geologic classes which had distinct, low-gradient valley segments at their lower ends (Table 6). We focused on low-gradient, alluviated canyon and alluvial valley segments because other work showed that these segments were the primary locations of spawning and rearing of anadromous fish and appeared most sensitive to the impacts of human activity (Frissell et al. 1992a, 1992c). We also surveyed canyon-type valley segments where they intermingled with alluvial valleys and alluviated canyons. A total of 31 valley segments ranging in length from about 100m to more than 1 km were surveyed. All of the study streams had potentially productive, low-gradient (<2% slope) fish habitat, and all but two were accessible to and used by anadromous fish. The four geologic classes we considered were 1) basins dominated by Jurassic age, sheared metasedimentary rocks of the Otter Point Formation; 2) basins dominated by Cretaceous sedimentary rocks; 3) basins dominated by Dothan Formation, mixed sedimentary rocks of Jurassic age, concentrated in the southern portion of the study area; and 4) basins comprised of a mosaic of Colebrook schist Otter Point Formation, and harder sedimentary rocks. Variation in rock material within these broadly-defined geologic units was associated with variation in valley segment morphology (Frissell et al. 1992a).

In order to attain a diversity of sites with respect to geology, valley morphology, and logging history, our design did not directly control for drainage basin area and its correlate, stream size, which affects most aspects of physical habitat. Valley segment classification partly accounts for much of this variation, for example in valley slope and channel form (Frissell et al. 1992a). However, because the study basins and streams varied about one order of magnitude in size (Table 6), it was important in data analysis (see below) to develop appropriate scaling techniques to account for the effects of stream size on such variables as wetted habitat area (e.g., Stack 1989).

Table 6. Study sites in Curry County, southwest Oregon.

Stream (River Basin)	Valley Segment Type[a]	Total m Surveyed	Drainage Area (km²)	Basin Geology[b]	Land Use History[c] Riparian	Basin	Mean Channel Slope(%)	Mean Active Channel Width (m)
Edson Cr (Sixes R)	AV_1	1030	28.1	Jop	M/SG	SG/CC	0.5	24.9
"	AV_2	440	26.9	"	M/SG	SG/CC	0.6	17.0
"	BRC	425	25.0	"	SG	SG/CC	0.8	18.3
Big Cr (Sixes R)	CC_1	114	3.9	Jop	SG	OG/M/SG	10.3	8.0
"	AC	244	3.8	"	OG/M	OG/M/SG	2.7	7.1
"	CC_2	179	3.6	"	OG	OG/M/SG	4.8	7.8
Little Dry Cr (")	CC	458	3.4	Krh	M/OG	SG/CC/M	2.3	18.5
"	AC	144	4.1	"	M/OG/SG	SG/CC/M	1.7	15.2
Dry Cr (Sixes R)	AV	889	41.7	Krh	M/SG	OG/M/SG	1.1	22.6
"	AC	1994	33.5	"	OG/M	OG/M/SG	0.4	22.1
Rock Cr (Elk R)	AV	104	3.4	Krh	SG	SG/M/OG	0.8	7.2
"	AC	237	3.2	"	SG	SG/M/OG	2.5	8.7
Anvil Cr (Elk R)	AC	357	7.2	Krh	OG/SG/M	OG/M	1.6	14.7
"	BRC	103	7.0	"	OG/M	OG/M	3.7	7.0
Chismore Fk (Euchre)	AC	771	5.4	Krh	SG	SG/M/CC	2.4	9.7
Euchre Cr	AV	1420	65.0	Jc/Jop/Krh	SG/M	SG/CC/M	0.5	25.2
"	AFV	1000	38.0	Jc/Krh	SG	SG/CC/M	0.8	32.5
"	AC	1300	20.7	"	SG/M	SG/CC/M	1.3	24.3
Cedar Cr (Euchre Cr)	AV	1050	23.4	Jop	SG	SG/CC	1.0	11.0
Lobster Cr (Rogue R)	AV	1573	144.8	Jc/Krh	SG/M	SG/CC/M	0.8	34.9
"	CC	200	125.0	Jc/Krh	SG	SG/CC/M	1.3	37.0
Quosatana Cr (Rogue R)	AC	1600	65.9	Jc/Jop	OG/M	OG/SG/CC	1.1	38.0
Deep Cr (Pistol R)	AV	596	9.2	Jop	SG	SG/CC/M	1.7	13.7
"	AC	810	8.6	Jop	SG/CC	SG/CC/M	2.5	17.4
Jack Cr (Chetco R)	AV_1	908	22.1	Jd	SG	SG/CC/M	1.3	14.3
"	AV_2	339	16.0	Jd	SG	SG/CC/M	1.5	11.2
Wheeler Cr (Winchuck R)	AC	340	18.0	Jd	SG/OG	SG/CC/M	1.8	14.4
"	BRC	260	17.6	"	SG/M	SG/CC/M	1.2	16.1
"	CC	600	16.2	"	OG/M	SG/CC/M	2.1	18.2
E. Fk Winchuck R (")	AC	1133	58.8	Jd	OG/M	OG/M/SG	1.8	21.5
"	CC	145	50.0	"	OG/M	OG/M/SG	1.5	24.6

[a] Codes as follows: AV = alluvial valley; AC = alluviated canyon; CC = coluvial canyon; BRC = competent bedrock canyon. Subscript denotes separate valley segments of the same class in a single stream.

[b] Codes for dominant basin geology: Jop = Otter Point Formation metasedimentary; Krh = Cretaceous sedimentary rocks, Rocky Peak Formation and Humbug Mountain Conglomerate; Jc = Colebrook schist; Jd = Dothan Formation, sandstones and metasedimentary rocks.

[c] Land use codes: OG = old growth forest (some trees > 200 y old); M = mature forest (most trees 75-200 y old); SG = second-growth forest (logged >15 y previous); CC = clear cuts < 15 y old.

2.3 Field Surveys

We conducted field surveys during late summer of 1989. Field sampling combined compilation of a continuous record of reach-level features, including bank erosion, woody debris, and pool-and-riffle morphology, with more detailed measurements made at selected habitat units. We simultaneously collected data on valley geomorphology and valley segment type, which are presented in Frissell et al. 1992a.

Within each valley segment we tallied the linear extent of actively eroding, unvegetated streambanks along both sides of the channel and recorded it as percent of total streambank length. We recorded the number of pieces of large woody debris (defined as >10 cm diameter and >1 m long) in each accumulation of two or more pieces present within the active channel. Because woody debris occurring as single pieces comprised only a small portion of the total debris population and usually had little effect on the stream channel, single pieces were not counted. Artificial log weirs or deflectors comprised a portion of the large wood in certain streams, and these were identified and excluded in analyses of debris jam abundance and debris loading. We classified each debris accumulation according to whether it spanned the channel perpendicularly or was oriented parallel to the channel along the margin.

At the pool/riffle level, we classified habitats in the low-flow channel following Bisson et al. (1982) and Frissell et al. (1986). For each unit, we classified the associated geomorphic features causing formation of the habitat feature as bedrock outcrop, large boulders (>1 m median diameter), small boulders (<1 m), large woody debris (> 10 cm diameter and >1 m long), small woody debris (<10 cm diameter or < 1 m long), tree roots, cobble bar, or gravel bar. A single observer visually estimated length and mean width of each unit, and measured maximum depth. Following Hankin and Reeves (1988), for a systematically selected subset of pool/riffle units (e.g., every 10th pool, every 10th riffle) we accurately measured length and width. Later we regressed observed against visually estimated habitat areas to develop a calibration factor. We fit separate calibration factors for different observers and sampling days, and habitat areas so corrected were used in all subsequent analyses. Where fewer than 10-15 units were measured, or where the correlation between estimated and measured areas did not differ from slope = 1.00 and intercept = 0.0 at the significance level of 0.05, we applied no correction factor.

For each pool or riffle unit selected for detailed measurement, we also recorded a suite of microhabitat data. We visually estimated the percent of the bed surface withi each habitat unit dominated by each particle size class. Particle size classes were defined as bedrock (massive), large boulders (>1 m median diameter), small boulders (26-100 cm diameter), cobbles (6-25 cm), gravel (0.8-6 cm), fine gravel (2-8 mm), sand (0.06-2 mm, gritty), silt (<0.06 mm, not gritty, easily suspended). We also assessed embeddedness of cobble and gravel patches in pool tailouts, riffles, glides, and side channels by estimating the degree to which these coarse particles, presumably suitable for spawning by anadromous salmonids, were buried within a matrix of sand and finer sediment. Following Platts et al. (1983), we recorded embeddedness as an index, varying from a value of 1 where most coarse particles have >75 percent of their surface covered by fine particles, to 5 where most coarse particles have <5 percent of their surface covered by fines. We measured depth at 9 equally spaced points and averaged these data to estimate mean depth of the unit.

Pieces of large woody debris within each habitat unit selected for intensive sampling were counted and, where possible, were categorized by species of origin based on wood texture, color, hardness, and bark characteristics. To assess habitat complexity and the availability of structural cover for fish, we estimated the percent by area of each habitat unit occupied by each of the following structural elements: bedrock outcrops, boulders, large woody debris, small woody debris, overhanging banks, riparian vegetation projecting imediately above the water's surface, and aquatic vegetation (macrophytes or well-developed blooms of filamentous algae).

2.4 Analysis

Because virtually all alluvial valley and alluvial-fan-influenced valley segments in the study area are affected by riparian logging, deforestation for agricultural uses, and/or extensive logging in upstream areas, we had no control for the analysis of land use effects in these segment types. Among alluviated canyon segments, however, we were able to locate a range of land use states. Because of complex variation in disturbance history, it was difficult to capture all aspects of human activity along a single, continuous, and linear land use gradient. For some analyses, we used cumulative percent of basin logged since 1940 as an index of logging activitiy. For analysis of variance we divided the basins into two groups: one group had been extensively or completely logged in riparian and upland areas, and consisted of a mosaic of second-growth and clear-cut forest (SG/CC); the second group had experienced little or no logging in riparian areas, limited logging in upland parts of the basin (generally <50% of basin logged), and therefore included large expanses of native, mature and old-growth forest (OG/M). Two streams (Edson Creek, Little Dry Creek) were anomalous in that they have been heavily logged in headwater areas but retain some mature riparian forest along their lower reaches (Table 1). These were grouped with the SG/CC group for most analyses. Portions of the riparian zones of Big Creek and lower Dry Creek were logged 40 or more years ago, but these streams were aggregated with OG/M basins for most analyses because of the substantial proportion of old-growth forest in thier drainage basins.

For variables known to be dependent on stream size, including active channel width, abundance of large woody debris, wetted area of pools or riffles, or mean and maximum depth of pools or riffles, we fitted linear regressions of each variable on drainage basin area, active channel width, or channel slope. In some cases, both axes were log-transformed to normalize the data and stabilize variances. In effect, we sought explanations for the deviation of individual data points from the overall stream size-response variable relationship. Residuals about the fitted regression line were tested against segment type (3-4 classes, with alluvial fan data excluded, and for some analyses where sample sizes were small, colluvial and bedrock canyon segments combined into one category), geology (4 classes), and land use (2 classes) "treatments" using one-way, parametric analysis of variance (ANOVA). When distributions appeared non-normal or variances were strongly unequal between classes and this could not be improved by transformation, we employed the nonparametric Kruskall-Wallis ranks test (Sokal and Rohlf 1981). In the few cases where sample sizes allowed, we tested for interaction effects between segment type, land use, and geology using two-way ANOVA. For variables not directly dependent on stream size, such as substrate particle size distribution and percentage of banks in an eroding state, we conducted appropriate ANOVA or Kruskall-Wallis tests directly on the data rather than on regression residuals.

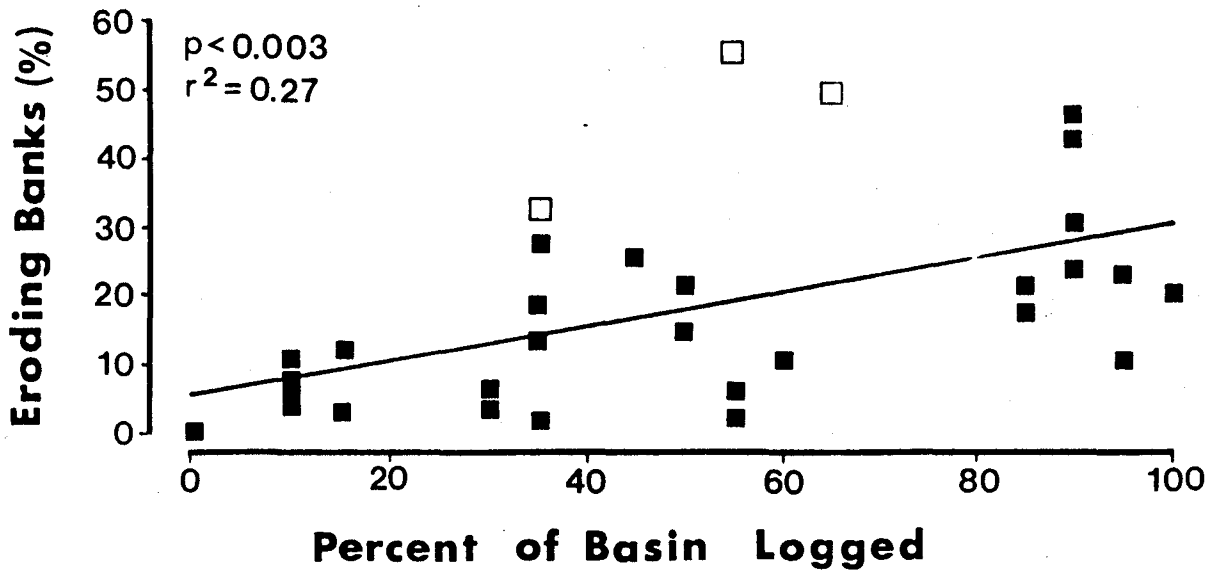
In all cases, the null hypothesis tested was that the mean or median of the response variable did not significantly differ between any two classes of the treatment variable. When we detected a statistically significant treatment effect for segment type or geology, we identified differences between treatment groups using, in the case of ANOVA, the Least Significant Differences procedure for paired comparisons (Sokal and Rohlf 1981) or, in the case of Kruskall-Wallis tests, by direct inspection of the data. We used a maximum significance level of 0.10 for most tests; we report maximum P-values to order of magnitude. Our sample size for canyons was small, so again we lumped colluvial canyon and competent bedrock canyons into a single class for some statistical analyses of segment type effects on pool-riffle or microhabitat parameters.

3. Results

3.1 Bank Erosion

Bank erosion was primarily related to the area of the drainage basin impacted by logging (Fig. 14). There was an average 4-6-fold increase in the proportion of banks in an actively eroding state between basins subject to little or no logging and basins subject to extensive logging (Fig. 14, also ANOVA of basins split into two land use classes, SG/CC and OG/M, $P<0.0001$). Basins less than 30 percent logged all had less than 15 percent of their banks in an eroding state, whereas more than 40 percent of total bank length was actively eroding

Figure 14. Proportion of stream banks that showed evidence of recent or active erosion, plotted against cumulative area of the drainage basin logged since 1940. Open boxes identify basins where logging was concentrated on steep Forest Service lands, causing exceptionally numerous or large landslides above the study site. This figure includes data from four sites not described elsewhere in this paper: Middle Fork Sixes River (alluvial valley), lower Elk River (alluvial valley), Elk River at Sunshine Bar (alluviated canyon), and Red Cedar Creek (tributary to Elk River, alluviated canyon) (Frissell and Nawa, unpublished data).



p< 0.003
r 2 = 0.27
Eroding Banks (%)
60
50
40
30
20
10
0
0
20
40
60
80
100
Percent of Basin Logged

Figure 14

in several streams draining heavily logged drainage basins.

When we examined the residuals of the regression in Fig. 14, we found a weak but significant difference among valley segment types (ANOVA, $P<0.07$). Competent bedrock canyons had relatively less bank erosion, presumably a result of the preponderance of nonerodible bedrock and boulder streambanks. Alluviated canyons had intermediate incidence of bank erosion, and erosion rates in colluvial canyons and alluvial valleys were variable but averaged higher. High incidence of bank erosion in colluvial canyons could be explained by the prevalence of soil creep and failure which cause unstable, stream-adjacent toe slopes to encroach on the channel and subsequently be sheared during floods. The dominance of streambank deposits by highly erodible, silt and sand size fractions can explain the vulnerability of alluvial valleys to bank erosion (Frissell et al. 1992a). In similar analyses basin geology did not account for variation in bank erosion or variation among residuals in the bank erosion/percent logged regression.

As expected, active channel width was highly correlated with drainage area (log-log regression, $P<0.001$). However, despite exhaustive analysis of the residuals from the channel width/area relation we could detect no clear trend in channel width in relation to land use, segment type, or basin geology.

3.2 Large Woody Debris

The distribution and abundance of woody debris are summarized in Table 7. Frequency of debris jams within the active channel did not differ significantly among segment types, except that alluvial fan-influenced valleys (mean = 8.8 jams

Table 7. Linear frequency, spatial arrangement, and size of accumulations of large woody debris in the study streams. Data not available for Euchre Creek alluvial valley, and proportion of jams spanning the channel was not recorded for Euchre Creek alluvial-fan-influenced valleys.

Site[a]	Mean Frequency (Jams per 100 m)	Mean Jam Size (No. of Pieces)	Proportion Spanning Channel (%)	Total LWD abundance (Pieces per 100 m)
Edson BRC	0.9	4.0	0	3.6
Anvil BRC	3.2	6.0	50	19.2
Wheeler BRC[b]	3.5	10.9	11	38.1
Big CC_1	4.4	7.8	40	34.3
Big CC_2	3.6	5.2	40	18.7
Little Dry CC	3.2	5.4	21	17.3
Wheeler CC	2.3	10.4	21	23.9
E. Fk Winchuck CC[b]	2.1	6.3	0	13.1
Big AC	4.9	8.8	77	43.1
Little Dry AC	3.6	8.6	22	31.0
Dry AC	1.4	7.4	14	10.4
Rock AC	5.0	14.1	50	70.5
Anvil AC[b]	2.5	10.4	25	26.0
Chismore AC	3.6	15.2	32	54.7
Euchre AC	4.4	29.9	8	131.6
Quosatana AC[b]	1.4	16.5	0	23.1
Deep AC	6.1	11.2	10	68.3
Wheeler AC	4.4	6.4	7	28.2
E. Fk Winchuck AC[b]	2.2	6.4	8	14.1
Edson AV_1	5.2	8.5	13	44.2
Edson AV_2	2.6	3.9	18	10.1
Dry AV	1.2	8.0	13	9.6
Rock AV	2.3	6.4	22	14.7
Cedar AV	1.9	6.6	14	12.5
Lobster AV	1.4	10.2	12	14.3
Deep AV[b]	5.3	9.5	16	50.3
Jack AV_1	1.6	5.8	14	9.3
Jack AV_2	2.2	6.2	21	13.6
Euchre AFV_1	5.4	18.5	-	121.8
Euchre AFV_2	12.2	12.0	-	145.6

[a] Codes indicate valley segment type: BRC = competent bedrock canyon, CC = colluvial canyon, AC = alluviated canyon, AV = alluvial valley, AFV = alluvial-fan-influenced valley.

[b] Artificial structures were present, but are excluded from these data.

per 100 m) had a higher frequency than other types (range of means 0.9-3.8) (one-way ANOVA, P<0.10). Similarly, the size of debris jams was not strongly related to land use or channel width, but differed significantly among segment types (one-way ANOVA, P<0.05). The mean number of pieces in jams of alluvial-fan-influenced valleys (mean = 15.3) and alluviated canyons (mean = 12.7) was roughly double that of all other segment types (range in means 5.2-7.2). Accordingly, the total number of large wood pieces counted (those incorporated in jams) per 100 m of stream also varied by segment type (ANOVA, P<0.001); abundance was significantly higher (P<0.10) in alluvial-fan-influenced valleys (mean = 133) than alluviated canyons (mean = 49), and significantly lower than either of these in all other segment types (range in means 4.4 to 24 pieces per 100 m). Total abundance of wood in accumulations was not correlated with active channel width.

We could discern little effect of land use on large woody debris when data were lumped without regard to segment type. However, when we stratified the analysis by segment type, we found that logging was associated with a doubling of both jam frequency (one-way ANOVA, P<0.04) and overall debris abundance (ANOVA, P<0.03) in alluviated canyons. No trends were detected in other segment types, but this could partly reflect small sample size. The number of pieces of large woody debris per 100 m in our study streams corresponds well to to values reported from elsewhere along the Pacific coast (e.g., Sedell et al. 1988, Bilby and Ward 1991), except in some logged basins (e.g., Euchre Creek, Deep Creek) where very large accumulations have formed in alluviated canyons and alluvial fans.

We did not measure size of debris pieces, but it appeared from field observations that, consistent with other studies (e.g., Hartman and Scrivener 1990, Andrus et al. 1988), piece size was smaller in heavily logged basins, and very large pieces (>50 cm diameter and >10 m long) were more abundant in streams whose riparian areas had not been logged. Debris jams in heavily logged basins, although often formed around key logs of large size that were residual from the pre-logging stand, were usually dominated by small pieces of debris originating from logging slash or second-growth forests. Fragmented, rapidly-decaying, and punky boles of red alder were numerous in these jams.

The spatial configuration and presumably the stability of debris jams differed between heavily logged and lightly impacted basins, but was primarily affected by channel width. As channel width increased, the proportion of debris jams spanning the channel declined (regression, R^2 = 0.195, $P<0.02$) and the proportion of lateral jams (those confined to channel margins) increased (R^2 = 0.423, $P<0.001$). When we classified the residuals of the channel width regressions by land use state of the basin, heavily logged basins had a significantly higher proportion of lateral jams (ANOVA, $P<0.04$) and fewer cross-channel jams (ANOVA, $P<0.02$). For a given channel width, more of the debris accumulations projected into and across the active channel in lightly-logged basins, whereas in heavily-logged basins more jams were swept laterally along the banks.

We assessed species composition of in-channel woody debris during microhabitat surveys. Coniferous species dominated colluvial canyons and competent bedrock canyons, debris of coniferous and hardwood origin was coequal in alluviated canyons, and red alder dominated in alluvial valleys and alluvial fan-influenced valleys. Port-Orford-cedar, although usually a minor component of the canopy (Frissell et al. 1992a), was represented disproportionately as a structural component in stream channels. We commonly observed residual debris from this decay-resistant species even in valley segments where mature specimens appeared to have been eliminated decades earlier by logging and disease.

3.3 Pool- and Riffle-Forming Features

Woody debris, boulders, bedrock outcrops, tree-root-defended streambanks, and gravel or cobble bars were the major geomorphic features responsible for creating and shaping pools and riffles. We compared segment types in terms of the relative importance of these different features in creating pools, and found major differences that correlated with valley geomorphology (Table 8). Overall, bedrock and boulders declined in influence with decreasing channel slope, decreasing hillslope interaction, and increasing stream size, and the importance of large wood, tree roots, and gravel bars as pool-forming features increased. This roughly corresponds with a gradient from competent bedrock canyons, which are narrow and steeper, through the wider, gently-sloping alluvial valleys and alluvial-fan-influenced valleys.

Bedrock and boulders were the dominant pool-forming features in competent bedrock canyons, colluvial canyons, and alluviated canyons, but were significantly less common in alluvial valleys and alluvial fan-influenced valleys (ANOVA, $P<0.08$). The importance of large wood varied with the opposite trend (ANOVA, $P<0.03$): wood was the primary pool-forming feature in alluvial fan-influenced valleys, alluviated canyons, and alluvial valleys, moderately important in colluvial canyons, and of small influence in bedrock canyons. Since overall abundance of woody debris varied little among the latter four segment types, these

Table 8. Mean percent of pool habitats in each valley segment type associated with each of seven morphogenetic features. Segment codes as in previous tables.

	AFV	AV	AC	CC	BRC
Bedrock	0.0	12.9	23.0	43.0	43.6
Boulders	0.0	10.4	26.0	48.4	42.7
Large Wood	81.9	45.0	39.1	22.4	9.5
Roots	9.3	17.0	6.2	0.0	4.1
Cutbank	0.0	8.0	3.1	0.0	0.0
Gravel Bar	4.1	3.4	2.6	6.2	0.0
Beaver dam	0.0	3.1	0.0	0.0	0.0

data suggest that wood present in colluvial and bedrock canyons was substantially less effective at influencing channel morphology than was wood in alluvial valleys. In narrow canyons, where flood flows reach high stage heights, many of the jams of woody debris we counted had been rafted onto rocks along the channel margin or elevated high over the low-flow channel. By contrast, much of the large wood seen in alluvial valleys was embedded in the channel bed and banks.

Other, more transient morphogenetic features were less common overall, but tree roots were significantly more abundant in alluvial valleys and alluvial fan-influenced valleys than other segments (ANOVA, $P<0.05$), and pools formed at eroding cutbanks were seen more often in alluvial valleys and alluviated canyons than other segments (ANOVA $P<0.056$). Beaver dams were rare in the surveyed streams, with just two recorded, both in alluvial valleys. Tree roots and cutbanks are widespread features but the percentages reported in Table 3 are low because if large wood, boulders, or bedrock were present we attributed pool formation primarily to these larger flow obstructions (Lisle 1986); we classified only pools where no such "hard" feature was present as formed primarily by cutbanks, tree roots, or gravel bars.

The relationship between logging impacts and pool-forming features is not clear. Although we detected differences between lightly-logged and heavily-logged basins, inspection of the data indicated these differences could mostly be attributed to the disproportionate representation of segment types in the two land use classes (e.g., almost all alluvial valleys were in the heavily-impacted category). When we confined the analysis to alluviated canyons, the only segment type for which we had a good sample size in both land use categories, we detected no significant logging effects on pool-forming features.