GEOMORPHIC AND RIPARIAN INFLUENCES ON THE DISTRIBUTION AND ABUNDANCE OF SALMONIDS IN A CASCADE MOUNTAIN STREAM[1]

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Abstract: Abundance of resident cutthroat (Salmo clarki) *and rainbow* (Salmo gairdneri) *trout was generally 1.5 to 3.5 times greater in unconstrained reaches than in constrained reaches of Lookout Creek, a fourth-order tributary to the McKenzie River, Oregon. The presence of adult rainbow trout depressed juvenile abundance in pools with little habitat complexity but had no effect in pools with more heterogeneous structure. The greater abundance of trout in unconstrained reaches was related to habitat structure, the influence of the riparian canopy on stream productivity, and the effect of channel morphology on stream hydraulics. Valley floor landforms are major determinants of channel complexity and habitat structure, providing a hierarchical geomorphic context for interpreting riparian influences on patterns of abundance and distribution of salmonids within a basin.*

The viability of cutthroat trout (*Salmo clarki*) populations in steep Cascade Mountain streams is dependent on the recruitment of juveniles within a stream reach and the quality of rearing and refuge habitat. Recruitment is particularly important because cutthroat trout in these streams are residents that may complete their life history within a 20- to 100-m reach (Miller 1957; Wyatt 1959; Aho 1977). Factors that influence recruitment include availability of suitable habitat and the presence of predators. Age 0 trout initially occupy the margins of the stream channel and move to faster-deeper habitats as they grow. Habitats at the lateral boundary of the main channel are structured by the interaction of streamflow with boulders, wood debris, and the geomorphic constraints of the valley floor.

Valley floor structure can influence stream ecosystems by influencing channel morphology and by regulating energy input and processing (Gregory and others 1989). Mechanisms of this influence become apparent when drainage networks are organized hierarchically by reach type, channel unit, and habitat subunit. Reach types are delineated by the type and degree of local constraint imposed by the valley wall at the channel margin. Reaches are constrained by bedrock intrusions, landslides, earthflows, and alluvial fans. Streams within constrained reaches tend to be relatively straight, single-channels with little lateral heterogeneity. Unconstrained each types are characterized by complex, often braided channels with extensive floodplains.

The stream channel in both constrained and unconstrained reaches is composed of longitudinal sequences of channel units with distinct hydraulic and geomorphic structure (Grant 1986) that are longer than one channel width and identifiable as pools, riffles, rapids and cascades. Channel units are divisible into habitat subunits less than one channel width in length. The subunit scale of hydraulic and geomorphic features corresponds to descriptions of fish habitat frequently used in ecological research. Subunits at the stream margin (lateral habitats such as eddies and backwaters) are characterized by low velocity, heterogeneous substratum, abundant detritus, and structural protection from high discharge. This combination of physical and biotic conditions provides gradients of depth and velocity, cover, and access to invertebrate food that make lateral habitats particularly suited to the requirements of young-of-the-year cutthroat trout (Moore 1987). The importance of off channel pools, side channels, and tributaries for both rearing and winter habitat has been well documented (Bustard and Narver 1975; Tschaplinski and Hartman 1983; Hartman and Brown 1987). These studies have focused on the importance to juvenile salmonids of habitats adjacent to the main channel. However, the effects of habitat complexity, in the context of valley floor geomorphology, has not been examined.

In an earlier study of riparian influence on cutthroat trout populations, Moore and Gregory (1988a) observed that the abundance of age 0+ fish was generally proportional to the area of lateral habitat in third-order, Cascade Mountain streams. In a manipulation of subunit structure, Moore and Gregory (1988b) found that increasing lateral habitat from 12 percent to 24 percent of total stream area resulted in 2.2 times greater density of age 0+ cutthroat trout. Juvenile trout populations were virtually eliminated in stream sections where lateral habitat was reduced. In the present study, the objective was to examine the relationship between juvenile trout and lateral habitat subunits at the stream reach and channel unit levels of organization. Also, the abundance of adult trout relative to reach type was considered as were possible effects of physical structure on interactions between juvenile and adult fish.

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Methods

Observations of fish populations and measurements of stream structure were made in Lookout Creek, a fourth-order stream in the H.J. Andrews Experimental Forest in the Cascade Mountains, Oregon, USA. In constrained reaches, this stream flows through 450-yr-old stands of conifers dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). In unconstrained reaches, conifers are less abundant and near-stream vegetation is dominated by willow (*Salix* sp.) and red alder (*Alnus rubra*) Stream reaches were mapped and characterized in terms of a constriction ratio. Constriction ratio equals the width of valley floor less than 3 meters above low stream flow divided by the active channel width. At Lookout Creek, the least constrained reach (constriction ratio = 5.6) is located in a depositional area above an earthflow-constricted reach and has a wide valley floor and multiple secondary channels. The most constrained reach (constriction ratio = 1.3) has a single channel flowing through a steep walled canyon at the toe of an earthflow. Mapping evaluated the degree of constraint on the stream and also measured geomorphic channel units and habitat subunits for 6.2 km of Lookout Creek. Habitat complexity in channel units was defined arbitrarily, based on the distribution of subunits. If one subunit class comprised more than 70 percent of the channel unit area, the unit was considered to have low complexity. If the channel unit had high subunit richness and evenness (four or more subunit classes, each comprising at least 15 percent of the area), the unit was considered to have high complexity. Differences in channel unit and subunit habitat area was examined with a Kruskal Wallis test of ranked classes (Sokal and Rohlf 1981).

Fish populations in Lookout Creek were censused by snorkeling observation during the summer of 1987. All reaches, channel units, and habitat subunits were examined. Divers recorded the species, length, and habitat use of every fish observed. Cutthroat and rainbow trout, Sculpin (*Cottus* spp.) and dace (*Rhinichthys* sp.) are the only fish present in the study reaches. The distribution of habitat sub-units within each reach was measured during summer base flow in 1987 and during winter base flow in 1988.

Results

The pattern of habitat utilization was the same in each of the reaches of Lookout Creek. After emergence, juveniles established territories in lateral habitats exclusively and remained there for at least six weeks. The abundance of juvenile cutthroat trout in Lookout Creek was greater in unconstrained and semi-constrained reaches than in constrained reaches. Abundance also increased along a downstream to upstream gradient, but, except for the extreme downstream reach, the density of juveniles was always greater in less constrained reaches than in adjacent reaches with comparatively greater constraint (fig. 1).

Age 1+ and older fish had a distribution that was similar to that of juveniles, but the pattern was modified by the presence of large structural elements (boulders and wood) in the most constrained reach (fig. 2). The greatest density of fish was generally in the unconstrained reaches. However, one constrained reach had a particularly high abundance of adult trout. This reach was at the toe of an active earthflow that has introduced numerous large boulders (> 2 m diameter) to the channel. These boulders created channel roughness that entrained large woody debris and modified stream structure to create a variety of habitat types within the reach. Deep pools and backwater habitats were particularly abundant in this reach.

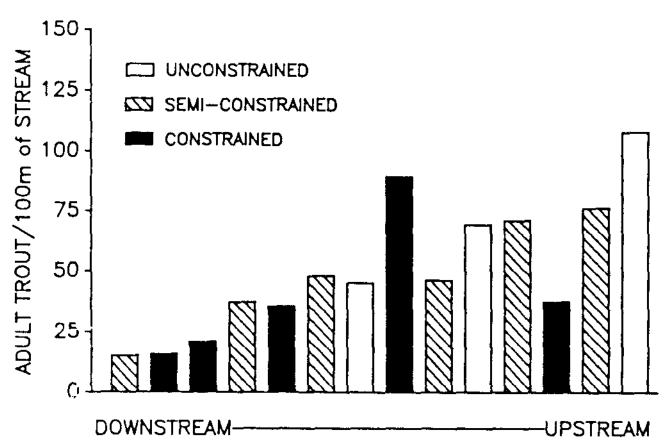

Figure 1 – Abundance of juvenile cutthroat trout in sequential reach types of Lookout Creek during the summer of 1987. Reach types are classified by the degree of constraint on the active stream channel. Abundance expressed as number of fish per 100 m of stream length.

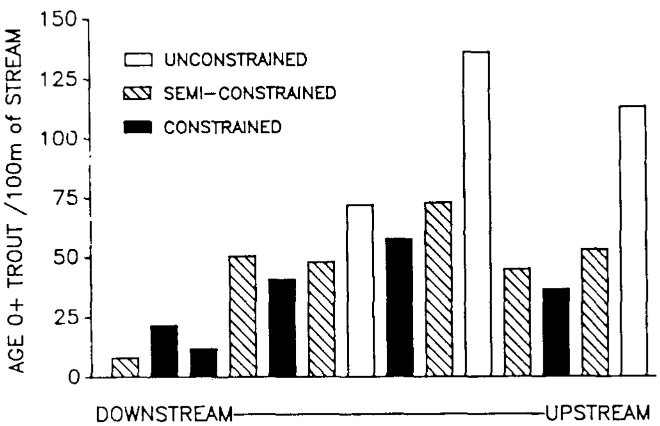

Figure 2 — Abundance of adult cutthroat trout in sequential reaches of Lookout Creek during the summer of 1987.

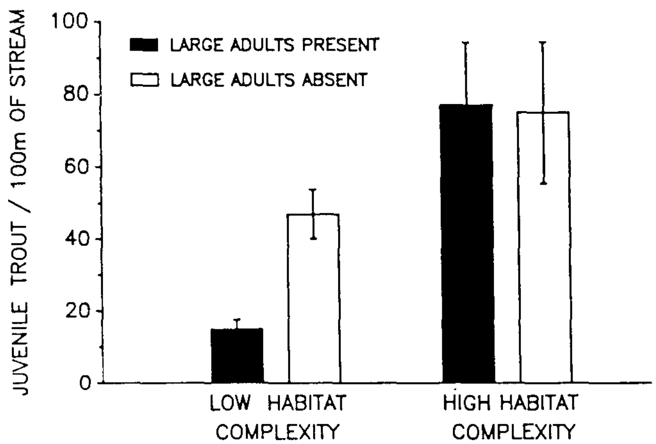

Figure 3 — Density of adult and juvenile cutthroat trout in channel units of Lookout Creek. Density expressed as number of fish per 100m² of wetted channel area.

The pattern of fish abundance in the study reaches was influenced by the distribution of channel units within each reach and the differential utilization of channel units by both adults and juveniles. The density of adult cutthroat and rainbow trout was greatest in pool channel units (fig. 3). Juvenile cutthroat trout were found in all channel unit types, but had the greatest densities in riffle and secondary channels. The differences in juvenile abundance between constrained and unconstrained reaches was not attributable to simple differences in channel unit structure between reaches. The area of secondary channels was greater in unconstrained reaches than in constrained reaches (9.0 percent and 2.3 percent respectively, $P < 0.05$). There was no difference in the area of riffle channel units in different reach types ($P > 0.10$). The average proportion of total stream area in pool channel units was greater in constrained reaches (37.7 percent) than in unconstrained reaches (21.7 percent).

Unconstrained reaches had more complex channel unit and subunit structure than did constrained reaches. Channel units were shorter and the sequence of channel unit classes were more varied in unconstrained reaches than in constrained reaches. Channel units in unconstrained reaches had a greater percentage of area in lateral habitat subunits ($P < 0.05$) and had a more heterogeneous distribution of subunit habitats. In September, when stream discharge was 18 cfs, habitat distribution was expressed as the average percentage of channel unit area within each reach:

	Reach Type[1]	
Subunit	Constrained	Unconstrained
Hydraulic Jump	4.2	2.0
Chute	12.4	9.9
Riffle	16.5	20.1
Tranquil (Pool)	39.4	32.4
Lateral Eddies and Backwaters[2]	9.6	6.2
Exposed Channel	17.9	19.4
	100.0	100.0

[1] Constrained n=88, unconstrained n=78,
[2] $P < 0.05$, Kruskal Wallis test

Unconstrained reaches also had a greater diversity of habitats and increased availability of refuge habitat during floods. Equivalent measurements taken at higher flows (approximately 200 cfs), indicate that fast-water habitat subunits (hydraulic jumps and chutes) dominated the subunit distribution of channel units in constrained reaches. A hydraulic jump is defined by the dominance of very turbulent, supercritical flow. Chute subunits are areas of localized flow convergence, characterized by velocities at the threshold of supercritical flow. Although the area of fast-water subunits also increased at high streamflow, in unconstrained reaches the relative distribution of subunits did not change and the area of lateral habitat subunits increased nearly 60 percent.

In pool channel units, increased habitat complexity altered the patterns of juvenile abundance when large rainbow trout were present. The structure of pool channel units was variable both between and within reach types. Habitat complexity in pools was generally greater in the unconstrained reaches but complexity was strongly affected by the distribution and abundance of boulders and large wood debris within the channel unit (fig. 4). In pools with low habitat complexity, juvenile abundance was lowest in the presence of large adult trout ($p < 0.01$, Kruskal Wallis test, fig. 5). In pools with high habitat complexity, juvenile abundance was similar regardless of the presence or absence of large adults.

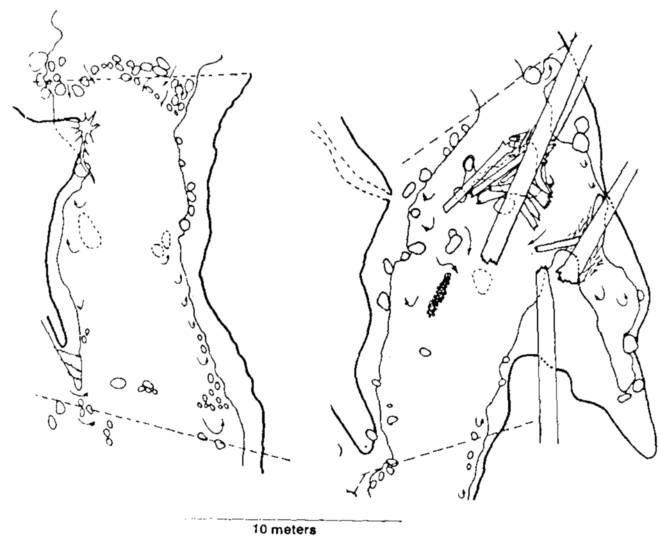

Figure 4 – Examples of pools with low (left) and high (right) levels of habitat complexity. Darker lines show margins of the active channel, lighter lines show the edge of the wetted channel, boulders and wood. Both pools are located in unconstrained reaches of Lookout Creek. Pools with lowest habitat complexity were similar to the pool on the left but had fewer small boulders along the margins.

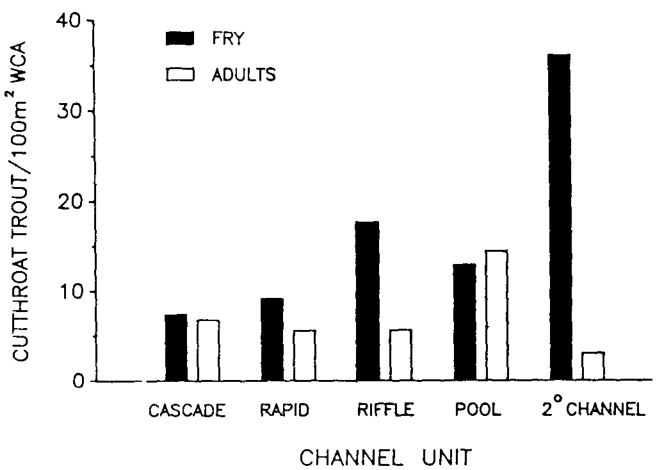

Figure 5 – Comparison of juvenile abundance in pools with low and high levels of habitat complexity and the presence or absence of large (length > 22 cm) rainbow trout. Habitat complexity was evaluated by a combination of subunit diversity, depth, and abundance of large boulders and wood. Error bars are +/- one SE, N = 10.

Discussion

Populations of juvenile cutthroat trout are apparently regulated by reach-level effects on stream habitat structure and stream productivity. Habitat structure and productivity, in turn, are both influenced by the geomorphic structure and interactions between the stream, the valley floor, and the adjacent hillslopes. The relationship between reach type and habitat structure (particularly lateral habitats) plays a key role in recruitment to trout populations. The strong correlation between lateral habitat area and number of age 0 cutthroat trout in a reach ($r = 0.983$; Moore and Gregory 1988b) underscores the importance of lateral habitats in the early life history of these fish. In the Cascade Mountains, cutthroat trout emerge during a period of declining streamflow after the winter rainy season. However, velocity in main channel habitats easily exceeds the swimming capacity of 20-30 mm long cutthroat trout. If the margins of the stream channel are abrupt and have either deep water or fast current, juvenile cutthroat trout will be displaced downstream until they reach suitable habitats. In addition to the losses from a particular reach, downstream movement also increases exposure to predators and potentially reduces the abundance of fry throughout the stream section.

Adult trout abundance was also related to reach type, but was additionally influenced by the availability of channel units (pools) with complex structure. The maintenance of complex structure in stream channels results in the development of channel units with a variety of habitat subunits. The greater abundance of cutthroat trout in the unconstrained reaches of Lookout Creek is apparently a function of the effects of riparian vegetation and geomorphic complexity on the structure of appropriate habitats.

Because unconstrained reaches of Lookout Creek have a more open canopy, more light energy is available, and primary production is greater than in the constrained reaches (Gregory and others 1989). Greater light intensity and increased production in the unconstrained reaches may, in addition to habitat effects, contribute to the greater abundance of fish in these reaches. Previous research has demonstrated that cutthroat trout population density and biomass are greater in recently logged (open clearcut) stream sites than in streams with mature coniferous stands (Aho 1977; Murphy and Hall 1981; Murphy and others 1981). The abundance of macroinvertebrates and the availability of drifting prey may be greater in reaches with open riparian canopies because of the effect of increased light on primary production, detritus quality, and prey capture efficiency (Gregory 1980; Wilzbach and others 1986). These studies have emphasized the influence of riparian setting on the production of food and related trout growth. Interpretation of these results, however, could be enhanced by an assessment of habitat structure and geomorphic setting.

Much of the organization of trout populations appears to be derived from the effects of reach level geomorphology on local levels of habitat. Intraspecific interactions play a smaller, but demonstrable role in regulating the distribution of juveniles. Both of these processes are further modified by the effects of riparian vegetation on habitat structure and food production. This pattern is consistent with models of community regulation that incorporate variable levels of physical disturbance and abiotic control (i.e., Menge and Sutherland 1987). Stream systems provide gradients of physical harshness and complexity of habitat structure that are appropriate for analysis with the Menge- Sutherland model (Schlosser 1982; Peckarsky 1983). In this study, gradients of physical harshness occur in at least two dimensions, longitudinal changes associated with reach type and lateral differences in habitat structure. Unconstrained reaches can be considered less harsh because the energy of flood events is dissipated across the broad valley floor. The physical processes that regulate the initial recruitment of trout result in greater abundance in these areas. Following the establishment of an age class, however, habitat complexity, interactions with possible predators, and system productivity have subsequent influence on the structure of populations.

The importance of valley floor habitats has been frequently demonstrated in large river systems with complex fish communities. In large rivers, lateral habitats of the floodplain riparian zone include side channels, oxbow lakes, marshes, ponds, and tributary streams. Fish production and community richness are strongly correlated with the area of floodplain in a given reach (Welcomme 1985). Channelization of these systems has resulted in decreased habitat heterogeneity, decreased production, and decreased trophic complexity as well as lower standing stock and richness of fish communities (Hortle and Lake 1983). In Cascade Mountain streams, fish community structure is much less complex than in large, low-gradient, river systems. Floodplain geomorphology and lateral habitats, however, have an analogous function in the structuring of fish populations. Community organization in both large and small streams can be better understood by considering the effects of the geomorphic structure of channel units, the stream reach, and the valley floor.

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