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A SYSTEM OF NAMING HABITAT TYPES IN SMALL STREAMS, WITH EXAMPLES OF HABITAT UTILIZATION BY SALMONIDS DURING LOW STREAMFLOW[1]

Peter A. Bisson, Jennifer L. Nielsen, Ray A. Palmason and Larry E. Grove[2]

Abstract.--Fish habitat in small streams is classified into a number of types according to location within the channel, pattern of water flow, and nature of flow controlling structures. Riffles are divided into three habitat types: low gradient riffles, rapids, and cascades. Pools are divided into six types: secondary channel pools, backwater pools, trench pools, plunge pools, lateral scour pools, and dammed pools. Glides, the last habitat type, are intermediate in many characteristics between riffles and pools. Habitat utilization by salmonids was studied during summer low streamflow conditions in four western Washington streams. Most age 0+ coho salmon (*Oncorhynchus kisutch*) reared in pools, particularly backwaters, and preferred cover provided by rootwads. A few large coho occupied riffles and sought the cover of overhanging terrestrial vegetation and undercut banks. Age 0+ steelhead trout (*Salmo gairdneri*) selected riffles with large wood debris; while age 1+ steelhead preferred plunge, trench, and lateral scour pools with wood debris and undercut banks. The largest individuals of both steelhead age classes were found in swiftly flowing riffle habitats. Age 0+ cutthroat trout (*S. clarki*) preferred low gradient riffles but switched to glides and plunge pools when steelhead and coho were present, thus suggesting that they had been competitively displaced from a preferred habitat. Age 1+ and 2+ cutthroat preferred backwater pools when coho were absent but avoided them when coho were present. Cutthroat of all age classes generally favored cover provided by wood debris in both pool and riffle habitats.

INTRODUCTION

Identification of the important components of stream habitat is essential if we are to accurately assess environmental change, understand ecological segregation within multispecies communities, or determine the need for stream enhancement projects. Most fishes in small streams are habitat specialists (Gorman and Karr 1978) and utilize specific locations within stream channels throughout their freshwater life cycles in response to different spawning, feeding, and overwintering requirements (Northcote 1978). Within the Salmonidae competition plays a key role in habitat utilization when food is limited (Kalleberg 1958; Keenleyside and Yamamoto 1962; Hartman 1965; Chapman 1966a; Mason 1969; and many others) and such density dependent interactions result in habitat partitioning that facilitates the coexistence of several species as well as multiple age classes (Rosenzweig 1981). Habitat shifts can occur when conditions unsuitable to feeding develop (Hunt 1969; Bustard and Narver 1975a; Mason 1976; Peterson 1980) leading to the breakdown of territories and the aggregation of individuals into protected spaces. Utilization of particular locations within the stream varies greatly in time and space, and although small streams tend to be structurally complex, few if any areas of the channel are not occupied at one time or another.

Fishery biologists have traditionally classified streams into a variety of zones based on channel characteristics (e.g. Platts 1974; Moreau and Legendre 1979), associated biota (e.g., Huet 1959), or a combination of physical, chemical, and biological features (e.g. Binns and Eiserman 1979). Habitat requirements have often been presented as tolerance ranges or preferenda for certain water quality conditions. While tolerance limits for such parameters as

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dissolved oxygen and temperature have been defined with relative precision for many fish species, lack of a precise language describing the components of the physical environment may limit our ability to predict a stream's productivity for a species of interest. The often-used names 'riffle' and 'pool' convey a notion of relative water depth and current velocity, but beyond this they give little indication of living conditions relative to substrate, flow patterns, and cover. Not surprisingly, considerable variation exists in fish utilization of these general categories within the stream (Allen 1969). The terminology discussed in this paper represents an attempt to classify habitat in greater detail. Results of limited field evaluations indicate that the system can be a useful tool in assessing stream conditions and in describing spatial segregation among coexisting fish populations.

METHODS

Terminology

There appears to be no widely accepted set of habitat definitions for small streams. Although riffles and pools are the basic units of channel morphology and will always develop in natural streams as a mechanism of self-adjustment to the law of least time rate of energy expenditure (Yang 1971), the actual configuration and hydraulic properties of these units are highly variable. The continuous gradation in depth and velocity between pools and riffles has spawned terms such as 'run', which appear frequently in fisheries literature, often without detailed explanation. In attempting to construct a precise and consistent set of descriptive terms we have utilized definitions from the Glossary of Geology (Gary et al. 1974) wherever possible.

Riffles

Three types of riffle habitats were identified. Low gradient riffles (Fig. 1) were shallow (< 20 cm deep) stream reaches with moderate current velocity (20-50 cm/sec) and moderate turbulence. Substrate was usually composed of gravel, pebble, and cobble-sized particles (2-256 mm). An upper gradient limit for this habitat type was arbitarily set at 4%. Rapids (Fig. 2) possessed a gradient greater than 4% with swiftly flowing water (>50 cm/sec)

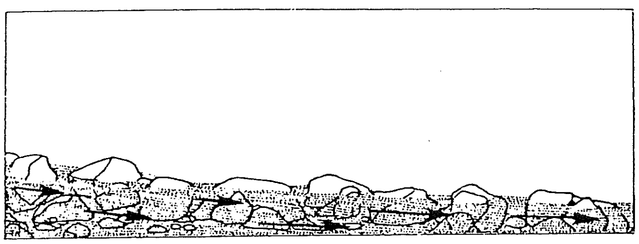

Figure 1. Low gradient riffle.

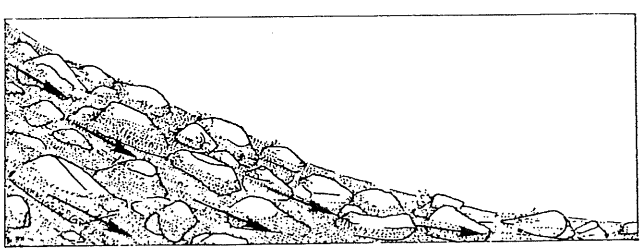

Figure 2. Rapids.

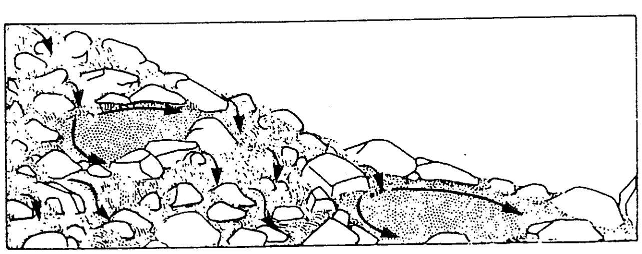

Figure 3. Cascade.

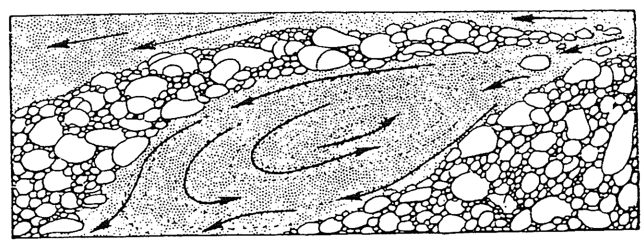

Figure 4. Secondary channel pool.

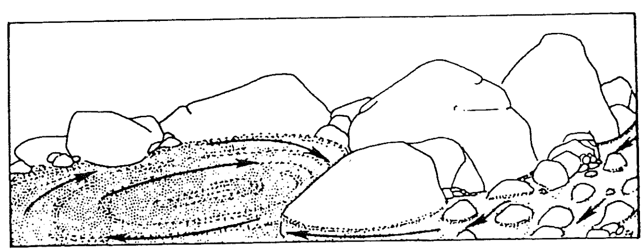

Figure 5. Backwater pool associated with boulders.

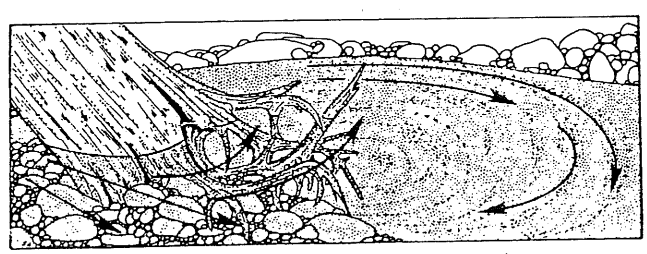

Figure 6. Backwater pool associated with rootwad.

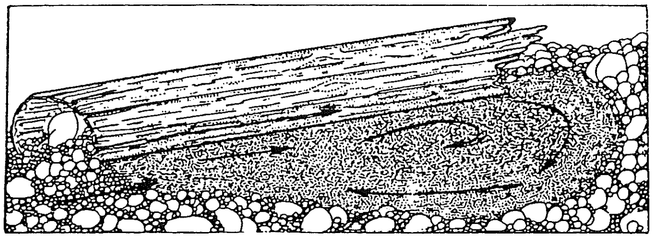
Figure 7. Backwater pool associated with large debris.

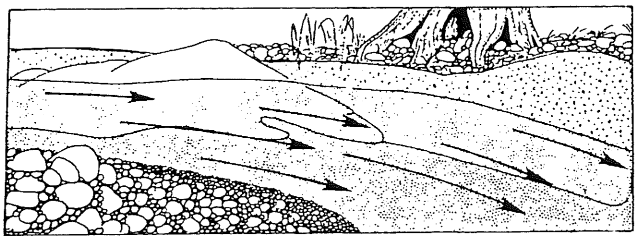
Figure 8. Trench pool associated with bedrock.

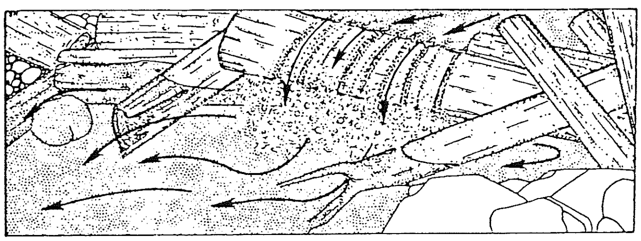
Figure 9. Plunge pool associated with large debris.

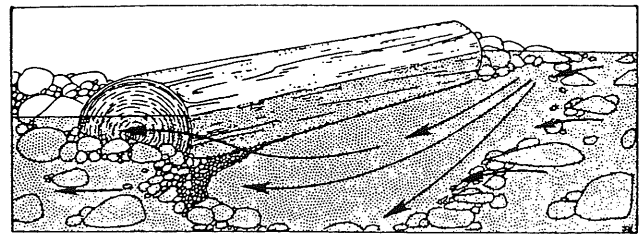
Figure 10. Lateral scour pool associated with large debris.

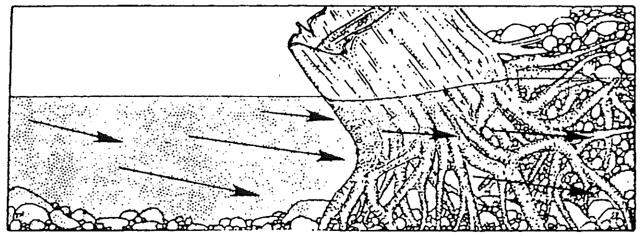
Figure 11. Lateral scour pool associated with rootwad.

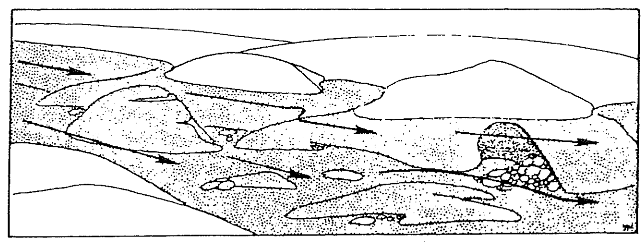
Figure 12. Lateral scour pool associated with bedrock.

having considerable turbulence. The substrate of rapids was generally coarser than the substrate of low gradient riffles, and during low streamflow conditions large boulders typically protruded through the surface. Cascades (Fig. 3), the third type of riffle habitat, were the steepest. Unlike rapids, which had an even gradient, cascades consisted of a series of small steps of alternating small waterfalls and shallow pools. The usual substrate of cascades was bedrock or an accumulation of boulders; however, this habitat type was occasionally found on the downstream face of woody debris dams.

Pools

During low streamflow conditions there were six pool types, which were associated with the presence of bedrock outcroppings, large rocks, or large tree stems and rootwads in the channel. Secondary channel pools (Fig. 4) were those that remained within the bankful margins of the stream after freshets. During the survey period (June-September) most of these pools had disappeared, and those remaining had little flow through them. Secondary channel pools were usually associated with gravel bars, but many contained sand and silt substrates. Backwater pools (Figs. 5-7) were found along channel margins and were caused by eddies behind large obstructions such as rootwads or boulders. This pool type was often quite shallow (>30 cm) and tended to be dominated by fine-grained substrates. Like secondary channel pools, backwater pools possessed current velocities that were very low. Trench pools (Fig. 8) were long, generally deep slots in a stable substrate. Channel cross sections were typically U-shaped with a coarse-grained bottom flanked by bedrock walls. Current velocities in trench pools were the swiftest of any pool type and the direction of flow was most uniform. Plunge pools (Fig. 9) occurred where the stream passed over a complete or nearly complete channel obstruction and dropped vertically into the streambed below, scouring out a depression. This pool type was often large, quite deep (>1 m), and possessed a complex flow pattern radiating from the point of water entry. Substrate particle size was also highly variable. Lateral scour pools (Figs. 10-12) differed from plunge pools in that the flow was directed to one side of the stream by a partial channel obstruction. Often an undercut bank was associated with this pool type. Dammed pools

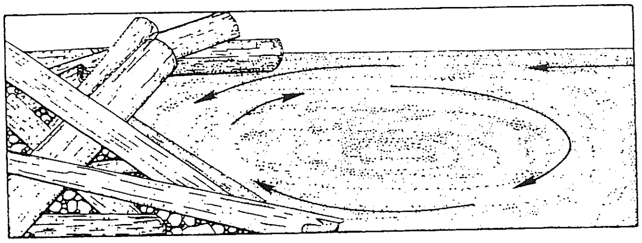

Figure 13. Dammed pool associated with large debris.

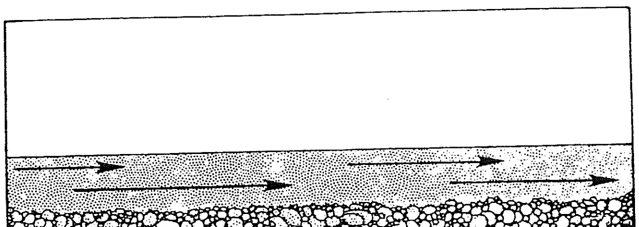

Figure 14. Glide.

(Fig. 13) consisted of water impounded upstream from a complete or nearly complete channel blockage. Typical causes of dammed pools were debris jams, rock landslides, or beaver dams. Depending upon the size of the blockage, dammed pools could be very large. Water velocity in this pool type was characteristically low and substrates tended toward smaller gravels and sand.

Glides

A third general habitat category existed that possessed attributes of both riffles and pools. Glides (Fig. 14) were characterized by moderately shallow water (10-30 cm deep) with an even flow that lacked pronounced turbulence. Although they were most frequently located at the transition between a pool and the head of a riffle, glides were occasionally found in long, low gradient stream reaches with stable banks and no major flow obstructions. The typical substrate was gravel and cobbles. The term 'run' has been applied to this habitat type, but we feel that the designation 'glide' is a more precise descriptor of the habitat conditions. Similar usage of the term has previously been adopted by Cuinat et al. (1975) and Chapman and Knudsen (1980).

Cover

Eight distinct kinds of cover for fishes were identified. These included three kinds of wood debris - rootwads, large debris (tree stems), and small debris (branches, twigs, etc.) - that differed in the amount of overhead cover and flow modifications they provided within the channel. Overhanging terrestrial vegetation and undercut banks were two kinds of cover that were largely governed by the condition of the riparian zone. Water turbulence acted as cover when the presence of bubbles prevented a clear view of the water beneath (Lewis 1969). Rocks functioned as cover in two ways, by providing overhanging ledges and by providing crevices for hiding. Finally, maximum depth was itself a form of cover from non-diving terrestrial predators (Stewart 1970). We assumed that the primary function of cover during the summer was protection from predation.

Sample Locations and Inventory Techniques

Sample locations were chosen to encompass a wide variety of stream conditions in western Washington. Nineteen sites consisting of channel reaches 0.2 - 1.3 km long were located in four streams. Three of the streams (Newaukum River, Salmon Creek, Thrash Creek) were Chehalis River tributaries; the fourth stream (Fall River) was part of the Willapa Bay drainage system. The sites included 700 individual habitats totaling approximately 7,800 m axial length, 33,600 m^2 wetted surface area, and 8,900 m^3 volume. Channels ranged in size from third to fifth order with 1-8% gradient. Parent rock type was either sandstone or basalt. Streamside vegetation varied according to forest management history; recently clearcut sites were dominated by shrubs, second growth forested sites were dominated by red aler (Alnus rubra), and old growth forested sites were dominated by mixed conifers. All sample locations possessed natural populations of salmonids, although some sites were above upstream migration blockages and contained only resident non-migratory cutthroat trout. There was no evidence that any of the sites had been fished by anglers.

Each stream reach was surveyed on foot and the location of different habitat types, as well as significant flow controlling structures, was drawn to scale on a map (Fig. 15). Contour lines based on depth measurements were drawn within pools to enable volume estimation. Wetted surface areas were determined by counting squares on gridded paper that was superimposed on the maps. Axial length was figured as the distance along the thalweg or greatest linear dimension of a habitat unit parallel to the direction of flow. Reach summaries were constructed by summing the lengths, areas, and volumes of each habitat type and expressing each group as a percentage of the total. The amount of cover in each habitat was rated on a relative abundance scale of 0-3, where a score of zero indicated that the particular kind of cover was essentially absent and a score of three indicated a very abundant condition. Substrate was noted as predominant type, i.e., the physical and/or biological type most prevalent within a habitat unit.

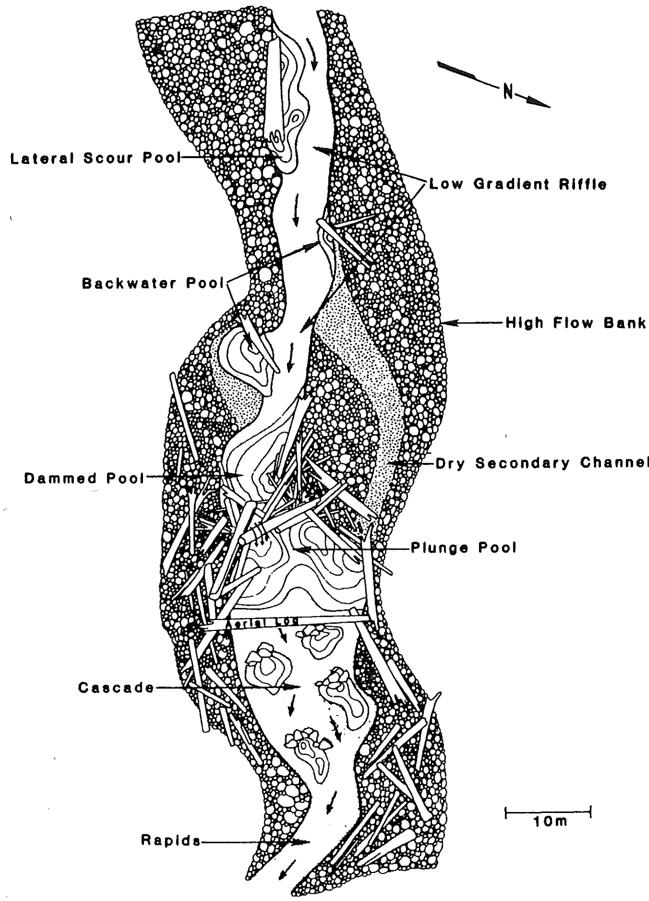

Figure 15. An example of a stream channel map showing locations of various habitat types.

Fish populations were sampled by isolating individual habitat types with blocking nets and electrofishing the habitat three times, retaining separately the fish captured on each pass. Individual biomasses were determined from length-weight relationships (Bisson and Sedell 1982 in press) and age class abundance was figured from size frequency distributions and scale samples. Population density and biomass estimates were based on a removal summation method of calculation (Carle and Strub 1978). Sculpins (*Cottus* spp.) were also captured but their biomasses are not reported in this paper. Approximately 28% of the total number of habitats inventoried were sampled for fish populations, resulting in the capture of 11,385 salmon and trout.

In order to quantify habitat utilization by species and individual age classes it was necessary to relate the fraction of the population found within a particular habitat type to the relative abundance of that habitat type in the stream. The formula used was based on the electivity index of Ivlev (1961):

$$(1)\ \text{Utilization} = \frac{\text{habitat specific density} - \text{average total density}}{\text{average total density}}$$

where

habitat specific density = average density in the habitat type of interest

average total density = average density over the entire stream reach, all habitats combined

Values of this habitat utilization coefficient theoretically range from minus one, indicating total non-use of a habitat type, to positive infinity as a greater proportion of the population resides in the habitat type of interest. A value of zero indicates that the population occurs in the habitat type in proportion to that type's abundance in the stream.

FIELD TRIALS

Habitat Characteristics

Although variation in size and frequency of habitat types was related to stream order, basin geology, and land management history, average dimensions of the different habitats are given in Table 1 for comparison. Overall, glides had the greatest individual length and surface area but pools had the greatest volume. Despite their relatively large size, glides were infrequent and accounted for a small fraction of total stream space. Pools were the dominant habitat category, accounting for about 50% of stream length and almost 80% of stream volume. Lateral scour pools were the most common type and also possessed the greatest surface area. Secondary channel pools, backwater pools, and dammed pools were smallest and least frequent. None of the sample sites contained beaver dams, log jams, or major landslides, thus accounting for the absence of large dammed pools in the reaches that were surveyed. Low gradient riffles were both the largest and most abundant riffles type, while rapids and cascades tended to be small and less frequent. Riffles averaged 40% of stream length but accounted for only 16% of stream volume

Large woody debris, including rootwads, was the most abundant cover in pools, while rocks were the primary cover in riffles. Depth was important cover in pools having large water volumes (lateral scout, plunge, and trench). Turbulence created cover where falling water formed bubbles in plunge pools, rapids, and cascades. In general, cover quantity and diversity was greater in pools than in riffles or glides.

Habitat Utilization

During the summer very few individuals of any fish species occupied secondary channel pools (Table 2). Many of these habitats had become isolated from the main channel and they often possessed high temperatures and dense algal growths. Although it is likely that secondary channel pools are utilized at other times of the year, particularly in large rivers (Sedell et al. 1980), lack of use of these habitats during low streamflow periods by salmonids is similar to the findings of studies of other stream fishes (Tramer 1977; Williams and Coad 1979).

Backwater pools were heavily utilized by age 0+ coho salmon, although coho in backwaters were smaller than average (Table 3). Preferential use of this habitat type by coho may have been related to a dependency on terrestrial food during summer that has been found by other investigators (Chapman 1966b; Mundie 1969). No other species displayed as strong an association with backwater pools as did coho; however, where anadromous forms were absent, yearling and older cutthroat also preferred this habitat type. In general, fish size in backwaters tended to be smaller than average.

Trench pools were selectively utilized by coho and yearling steelhead, and by age 1+ and 2+ cutthroat in anadromous zones. Where coho and steelhead were absent, all cutthroat age classes exhibited a mild avoidance of this pool type. Underyearling cutthroat collected from trench pools were smaller than average. Plunge pools were selected by coho, yearling steelhead, and all cutthroat age classes except age 0+ fish in areas upstream from an anadromous zone. Coho in plunge pools were the largest of those taken in any pool type.

Lateral scour pools were preferred by older age classes of both steelhead and cutthroat. Individuals collected from this pool type were average size, except for age 0+ cutthroat which tended to be slightly smaller than average in non-anadromous areas. Owing to the relative abundance of this habitat type, over 25% of all salmonids occurred in lateral scour pools.

An insufficient number of dammed pools were sampled to yield satisfactory evidence of relative habitat utilization or average fish weight. Flow pattern in this pool type would seem to be favorable to coho and there is ample evidence from other studies (Bustard and Narver 1975b; Nickelson and Hafele 1979; Everest and Meehan 1981) that coho utilize impounded water in streams. Provided there is sufficient depth and cover, dammed pools should also provide favorable habitat for age 1+ steelhead and age 1+ and older cutthroat.

Low gradient riffles were selectively occupied by underyearling steelhead and

Table 1. Average habitat size and percent of total stream (in parenthesis).

Habitat Type	n	Average Habitat Size / % of Total: Length (m)	Area (m^2)	Volume (m^3)
Pools				
Secondary Channel	26	9 (<1)	34 (<1)	8 (<1)
Backwater	74	8 (10)	29 (7)	8 (7)
Trench	34	15 (8)	70 (8)	26 (10)
Plunge	38	14 (5)	77 (5)	45 (10)
Lateral Scour	146	16 (28)	102 (35)	43 (50)
Dammed	5	7 (<1)	30 (<1)	18 (1)
Riffles				
Low Gradient Riffles	197	11 (26)	51 (25)	7 (12)
Rapids	114	7 (13)	25 (9)	3 (3)
Cascades	21	8 (<1)	30 (<1)	6 (<1)
Glides	43	15 (9)	92 (11)	15 (6)

Table 2. Habitat specific utilization coefficients.

Habitat Type	Anadromous Zone						Above Anadromous Zone		
	Coho	Steelhead		Cutthroat			Cutthroat		
	0+	0+	1+	0+	1+	2+	0+	1+	2+
Pools									
Secondary Channel	-1.00	-0.99	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Backwater	6.74	-0.46	0.21	-1.00	-0.52	-0.75	-0.36	0.42	0.80
Trench	1.07	0.14	1.16	-1.00	0.54	0.99	-0.21	-0.16	-0.23
Plunge	0.93	0.10	2.23	1.41	0.79	0.92	-0.54	1.09	1.61
Lateral Scour	-0.46	0.07	0.89	-0.08	1.14	1.83	0.18	1.04	0.88
Dammed	Insufficient Samples								
Riffles									
Low Gradient	-0.75	0.50	-0.70	0.26	-0.23	-0.71	0.45	-0.73	-0.78
Rapids	-0.99	0.50	0.98	-0.45	-0.67	-0.20	-0.10	-0.83	-0.90
Cascades	-0.97	0.79	0.58	-1.00	0.70	-1.00	-0.24	-0.80	-0.89
Glides	-0.91	0.34	0.86	1.42	-0.77	-0.92	0.00	-0.79	-0.33

Table 3. Size differences among salmonids captured in individual habitat types, expressed as percent deviation from overall average weight. Data for n $\leq$ 5 are omitted.

Habitat Type	Anadromous Zone						Above Anadromous Zone		
	Coho	Steelhead		Cutthroat			Cutthroat		
	0+	0+	1+	0+	1+	2+	0+	1+	2+
Pools									
Backwater	-12	-11	-2		+4	-9	+27	-2	-21
Trench	-2	0	+5		-1	+3	-21	-5	
Plunge	+14	-1	-2		-4	+2	+8	-2	+3
Lateral Scour	+1	-2	-5		+4	+4	-9	0	+1
Riffles									
Low Gradient	+1	+5	-16		-13	-7	+11	+26	
Rapids	+21	+12	+15		+10		-20	+7	
Cascades		+29	-4		+18		-8	-6	
Glides	+5	-15	-19			-26	+6	-9	

cutthroat, and were not preferentially used by other age classes. Cutthroat in anadromous zones were smaller than average while those in non-anadromous areas were larger than average, thus suggesting that competition with steelhead had reduced cutthroat growth rates in low gradient riffles. Evidence for competitive dominance of underyearling cutthroat by underyearling steelhead was also provided by the reduced utilization of low gradient riffles by cutthroat where steelhead were present compared to sites where steelhead were absent. Platts (1977) found that cutthroat were displaced to secondary habitats in the presence of juvenile chinook salmon and steelhead, but Hartman and Gill (1968) speculated that differences in the distribution of underyearling cutthroat and steelhead were related to microhabitat variation in spawning preferences of adults.

Utilization of rapids and cascades was limited mostly to steelhead. Both habitats were strongly avoided by most coho, yet the few individuals that occurred in rapids were much larger than average. Underyearling and yearling steelhead favored both habitats and seemed to grow well there. Chapman and Bjornn (1969) have also observed that steelhead occupy swifter water as they become larger and these authors felt that preference for faster water was associated with increased exposure to food organisms. However, while steelhead preferred fast water riffles, cutthroat, for the most part, did not.

Glides were selectively utilized only by steelhead and by underyearling cutthroat. Insufficient numbers of age 0+ cutthroat were collected from sites possessing coho and steelhead to permit determination of size variation; however, ages 0+ and 1+ steelhead occurring in glides were the smallest of those found in any habitat type.

Cover Associations

In both pool and riffle habitats the densities of age 1+ and older trout tended to increase in association with increased cover (Table 4) but age 0+ salmon and trout were relatively unaffected by cover conditions, although some positive associations did exist between underyearling densities and certain cover types. Our finding that older trout were more responsive to increased cover agrees with the

Table 4. Average correlations (r^2) between age class density and cover types within habitats.

Cover Type	Coho 0+	Steelhead 0+	Steelhead 1+	Cutthroat 0+	Cutthroat 1+	Cutthroat 2+
	Pools					
Rootwad	+0.19	-0.05	+0.34	+0.05	+0.04	+0.13
Large Wood Debris	-0.27	-0.11	+0.23	+0.05	+0.40	+0.25
Small Wood Debris	-0.16	-0.07	+0.18	+0.20	+0.15	+0.17
Terrestrial Vegetation	0.00	+0.12	+0.09	-0.24	+0.04	+0.12
Undercut Bank	0.00	+0.12	+0.26	-0.13	+0.22	+0.37
Turbulence	-0.01	-0.26	-0.04	-0.34	+0.05	+0.21
Underwater Boulders	-0.78	-0.25	-0.54	-0.49	-0.23	-0.09
Maximum Depth	-0.14	-0.29	-0.02	-0.42	+0.03	+0.44
	Riffles					
Rootwad	-0.03	-0.21	-0.29	+0.02	-0.16	+0.24
Large Wood Debris	-0.03	+0.31	+0.42	-0.30	+0.46	+0.43
Small Wood Debris	0.00	+0.03	+0.11	+0.40	+0.07	+0.27
Terrestrial Vegetation	+0.80	+0.11	-0.13	-0.04	+0.07	+0.11
Undercut Bank	+0.37	-0.50	-0.42	0.00	+0.35	+0.43
Turbulence	-0.42	-0.27	+0.19	-0.31	+0.40	+0.20
Underwater Boulders	-0.46	-0.08	-0.19	-0.25	+0.43	-0.07
Maximum Depth	-0.51	-0.20	+0.46	-0.45	+0.43	+0.57

stream enhancement results of Saunders and Smith (1962) and Hunt (1978), who noted that cover additions improved the productivity of older trout more than it did underyearlings.

Wood debris proved to be a preferred cover type for age 1+ steelhead and age 1+ and 2+ cutthroat. The strongest associations were observed with large debris pieces, especially in riffle habitats. Preference of yearling steelhead for large debris has been documented by Bustard and Narver (1975a) and both Osborn (1981) and June (1981) have shown that older cutthroat rely heavily on large wood debris for cover. Underyearling steelhead did not respond positively to increased wood debris in pools but utilized large debris in riffles. Underyearling cutthroat showed a slight positive response to increased debris in pools and a definite preference for small debris in riffles. The utilization of small debris by underyearling cutthroat may be similar to the cover preferences of age 0+ brown trout (S. trutta), which have been shown to decline following small debris removal (Mortensen 1977). Age 0+ coho exhibited a mild positive response to increased rootwad abundance in pools, but were unaffected by other kinds of debris. Association of coho with wood debris has been previously demonstrated by Lister and Genoe (1970) and Bustard and Narver (1975a, 1975b).

Overhanging terrestrial vegetation and undercut banks along riffles were strongly preferred by coho, although riffles were inhabited by relatively few individuals of this species (Table 2). Overhead banks and vegetation may have been selected because they provided more terrestrial food, resulting in bigger fish (Table 3). It seems unlikely that coho used these kinds of cover for shade because no obvious preferences for bank cover were observed in pools, and Ruggles (1966) has shown that addition of shade structures to experimental channels actually reduced coho holding capacity. Weak positive responses to increased bank undercuts and overhanging vegetation along riffles were displayed by age 1+ and 2+ cutthroat, which, like coho, were rare there. However, steelhead in riffles did not select overhanging vegetation and actually appeared to avoid riffles with undercut banks. Ages 0+ and 1+ steelhead and ages 1+ and 2+ cutthroat showed mild preferences for bank cover in pools.

Turbulence and underwater boulders were not selected by most species, except yearling cutthroat in riffles. The absence of significant response by steelhead to increased boulder cover was surprising in view of the strong attachment to this cover type shown for steelhead by Hartman (1965) and Facchin and Slaney (1977), and increases in age 1+ steelhead carrying capacity following experimental boulder placement in a Vancouver Island stream (Ward and Slaney 1979). We have no explanation for this disparity in observations except to speculate that increased turbulence and boulder density may have hindered feeding activity by making visual sighting of food organisms more difficult. Within habitats, deeper water was preferentially utilized only by age 1+ and older trout. Underyearlings of all species avoided deep water, preferring instead to reside in shallower areas along habitat margins. Positive associations between increased depth and fish size have been observed in both rainbow trout (Lewis 1969) and cutthroat (Griffith 1972).

APPLICATION OF THE SYSTEM

The system of naming habitat types that is described in this paper proved to be workable during low streamflow conditions. The habitat types became easy to recognize after some practice, and disagreements between independent classifiers were usually few. Approximately 100 m of stream channel could be mapped by one person in a day depending upon channel complexity. However, rapid inventory of the habitat types present in a stream, without dimensional measurements, could proceed much faster.

We were generally less satisfied with the cover evaluations. The majority of disagreements arose over what numerical score was to be assigned to the cover conditions within a particular habitat. In addition, the technique that was employed treated all kinds of cover equally, and it was obvious that a score of 3 (very abundant) for one cover type was not necessarily equivalent, in terms of overhead shading or protection from predation, to a high score for another cover type. For example, the kind of cover provided by wood debris, bank characteristics, or channel morphology was different from one another in nature and did not fit well into an equally weighted scale that was based on relative abundance. Wesche (1980) has discussed the subjectivity involved in measuring cover and has proposed a cover rating that intregrates bank, channel, and substrate characteristics for both small and large streams. Other workers have devised comprehensive numerical indices of habitat conditions that have been used to predict stream carrying capacity, (Bovee and Cochnauer 1977; Binns and Eisermann 1979) but these models do not easily separate fish preference for habitat type from preference for cover type.

We found that within individual habitats certain kinds of cover were preferred to others; however, a more rigorous approach would be to follow population changes after experimentally adding different kinds of cover to streams. For example, Boussu (1954) added small debris (interwoven willow branches) to a Montana stream and recorded large increased in underyearling and yearling rainbow trout and brook char biomasses. More recently, Ward and Slaney (1979) found that logs and boulders placed together in riffle areas of a Vancouver Island stream significantly enhanced ages 1+ and 2+ steelhead, but were not heavily utilized by underyearling coho. The results of our summer field studies indicate that wood debris, especially large stems and rootwads, was the most generally favored cover type and may hold the greatest promise for enhancement projects.

Although the terms 'selected' and 'preferred' have been applied in this paper to habitat and cover utilization by salmon and trout, it is likely that the spatial segregation we observed was an outcome of both physical habitat requirements and biological interactions. What appeared to be a preferred habitat in one stream was not always so in another; cutthroat trout, for example, occurred in different habitats when coho and steelhead were present than when they were the sole salmonid species. Chapman (1966a) has pointed out the importance of interspecific competition in governing habitat selection by salmonids, but behavioral observations have shown that competitive displacment can occur both within a single age class (Mason 1969) and between cohorts of a species (Jenkins 1969). The intensity of territorial defense in certain tropical reef fishes is related to physical habitat conditions, high quality habitats being aggressively defended (Itzkowitz 1979). However, Slaney and Northcote (1974) have shown that when food is abundant territories are small and agression is minimized in underyearling rainbow trout. Thus, the actual location of fishes in a stream channel will be influenced by the presence of competitor and predator species, population density, and food availability, as well as preferences for specific habitat types.

The complex interaction of a fish population with its physical and biological environment usually makes it difficult, if not impossible, to accurately predict either the standing crop or production of a species of interest in a particular stream. What can be determined, however, is the suitability of stream conditions irrespective of a species' presence or absence, which may be due to a variety of factors other than physical habitat. The detailed classification system presented here can be used to assess stream suitability once specific habitat and cover associations are known. We might predict, for example, that underyearling coho will be favored in streams possessing many backwater pools with rootwad cover and terrestrial vegetation overhanging the riffles, whereas yearling and older cutthroat will be favored where there are deep plunge and lateral scour pools with large logs and undercut banks. Although the system worked for the western Washington streams we studied, it is by no means comprehensive. Other habitat types may exist in larger rivers, or in small streams during freshets, and these will require additional description.

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