WALL-BASE CHANNELS: THEIR EVOLUTION, DISTRIBUTION, AND USE BY JUVENILE COHO SALMON IN THE CLEARWATER RIVER, WASHINGTON

N. Phil Peterson
Washington Department of Fisheries
P.O. Box 9155
Yakima, Washington 98909

Leslie M. Reid
Department of Geological Sciences
University of Washington
Seattle, Washington 98195

ABSTRACT: Wall-base channels are a type of channel formed on floodplain or terrace surfaces by the channeling of runoff through swales created by the migration of the mainstem stream. Channels appear to develop either along abandoned meander scars or in swales between scroll bars, but in most cases follow the foot of the valley- or upper terrace-wall quite closely. Such channels are heavily colonized by coho salmon fry in late spring and again in autumn. Where the channels are associated with ponds or swamps they form a highly productive habitat for the overwintering fish. Productivity varies between sites and is related to the physical characteristics and stage of geomorphological development of the channels and ponds. Under present conditions a significant proportion of the smolts produced by the Clearwater basin comes from wall-base channels, and the importance of this habitat is expected to be even greater for higher levels of escapement.

INTRODUCTION

On the terraces and floodplains of western Olympic Peninsula rivers a variety of channel types originate on the terraces themselves or in small catchments on the abutting slope. This slope may be either the valley wall or the riser to an adjacent and higher terrace. These terrace channels are not to be confused with typical valley tributaries that flow across the terrace to their confluence with the main river. Swanson and Lienkaemper (1980) have grouped all of the terrace channels into one category: the terrace tributary.

On the basis of field work in the Clearwater basin of Western Washington (fig. 1), we recognize three types of terrace channels (fig. 2). In order of their removal from active fluvial processes they are: 1) overflow channels, 2) percolation-fed channels, and 3) wall-base channels. Differences in the physical characteristics of these tributaries are a basis for the wide variety of biological habitats found along mainstem rivers, and a variety of forms exist within each of these general channel types. Specific forms have been examined in detail in the past. Peterson (1982b), for example, describes fish utilization of "riverine ponds," a subset of

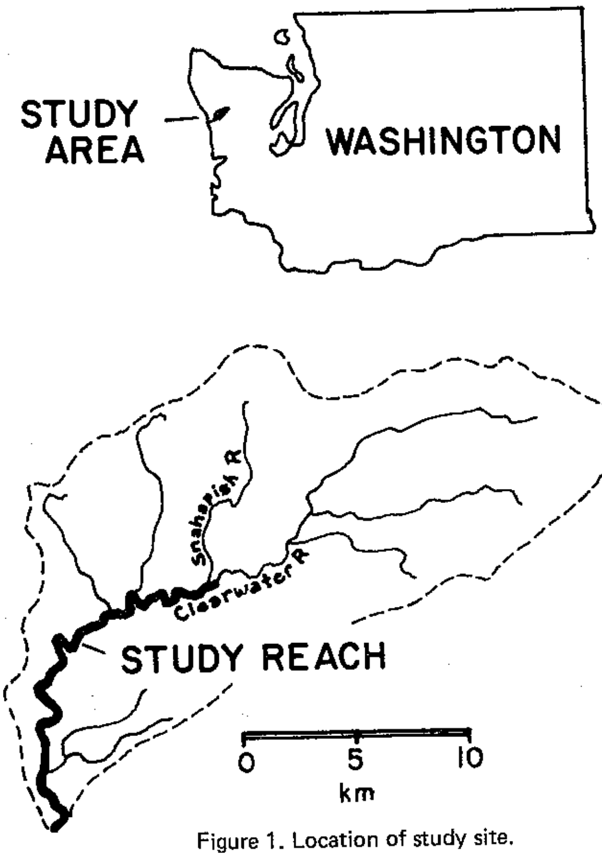

Figure 1. Location of study site.

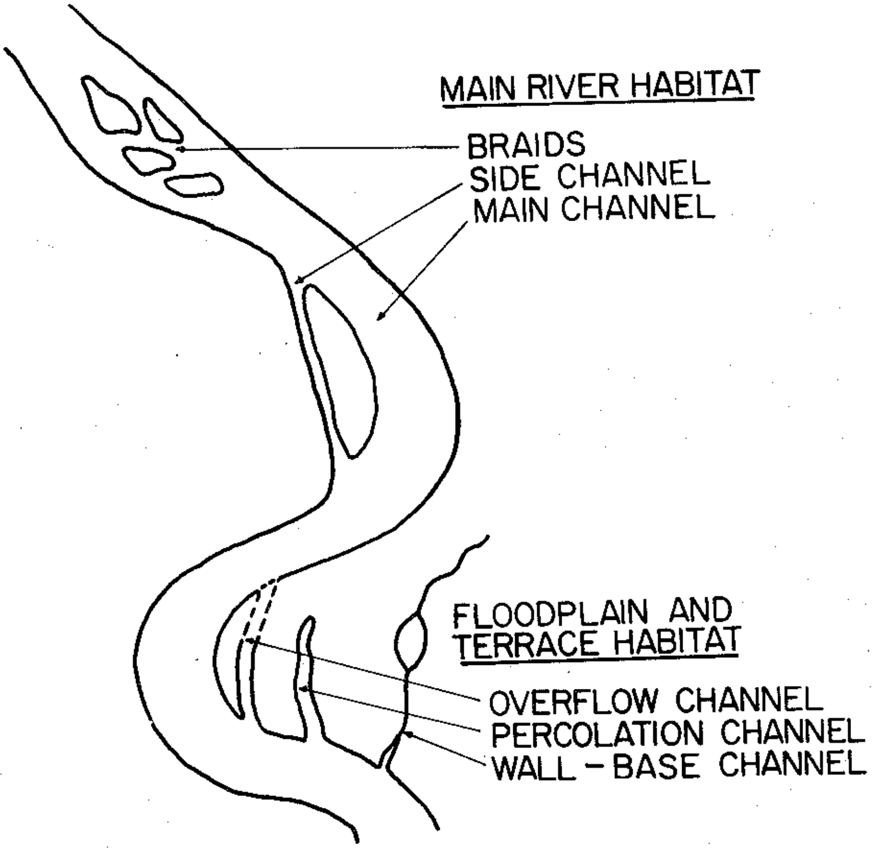

Figure 2. Major habitat types in and along main rivers on the Olympic Peninsula.

the wall-base channels, and Sedell et al. (1983) discuss a variety of side-channel types.

Overflow channels usually carry water only during floods. Often such channels are found along abandoned mainstem channels although in other cases the overflow channels may form by repeated scouring of depressions on the active floodplain. Percolation fed channels seem to be most common on braided rivers and apparently form when the head of a braid strand or overflow channel is blocked by sediment and organic debris. Flow from the mainstem river continues to percolate through the channel fill and emerges as a spring lower in the channel. Such channels are common along the South Fork Hoh River, a moderately braided, glacier-fed stream immediately northeast of the Clearwater basin.

This paper is primarily concerned with the final type of terrace tributary, the wall-base channel. We have chosen the name "wall base" because these channels are usually found along the back edge of a terrace or floodplain, at the base of the abutting slope (fig. 3). Their profile is commonly broken by the presence of a pond or swamp. At some sites channelized flow begins at the outlet of the depression, while at other sites channelization occurs below springs emanating from the terrace wall above. Some of the observed wall-base channels receive most of their flow from drainage of similar features on older terraces above.

Most of the wall-base channels in the Clearwater share the following characteristics: 1) silt substrate, 2) small catchments (usually less than 50 ha), 3) outlet water darkly stained by organic leachates. Since these channels are small and of low gradient and their catchments are of low relief and are heavily vegetated, they carry relatively little suspended sediment even during peak flows. Individual wall-base channels differ widely, however, in habitat quality and biological productivity, and these differences generally reflect the physical and biological characteristics of their ponded area.

Most of the wall-base channels in the Clearwater basin lack areas where salmon can spawn. However, these habitats are used extensively by juvenile coho salmon that move into them from the main river. The first recruitment of fry occurs in late spring and early summer, when the fish have an average size of 45-65 mm. During the first major freshets of the fall, fish of the same brood again move in, this time at an average size of 80-100 mm. Peterson (1982a) describes the recruitment of the 1976 brood coho into two wall-base channels with associated ponds that he refers to as "riverine ponds."

The purpose of this paper is to document further the importance of this habitat type to the salmon resource in the Clearwater River and to present a geomorphological view of the wall-base channels. We feel that it is necessary to understand how such channels form and develop if one is to evaluate the distribution and significance of this habitat type.

Study Area

We conducted our observations in the 375 km^2 Clearwater River basin on the western slopes of the Olympic Mountains. The Clearwater basin receives approximately 350 cm of rain annually,

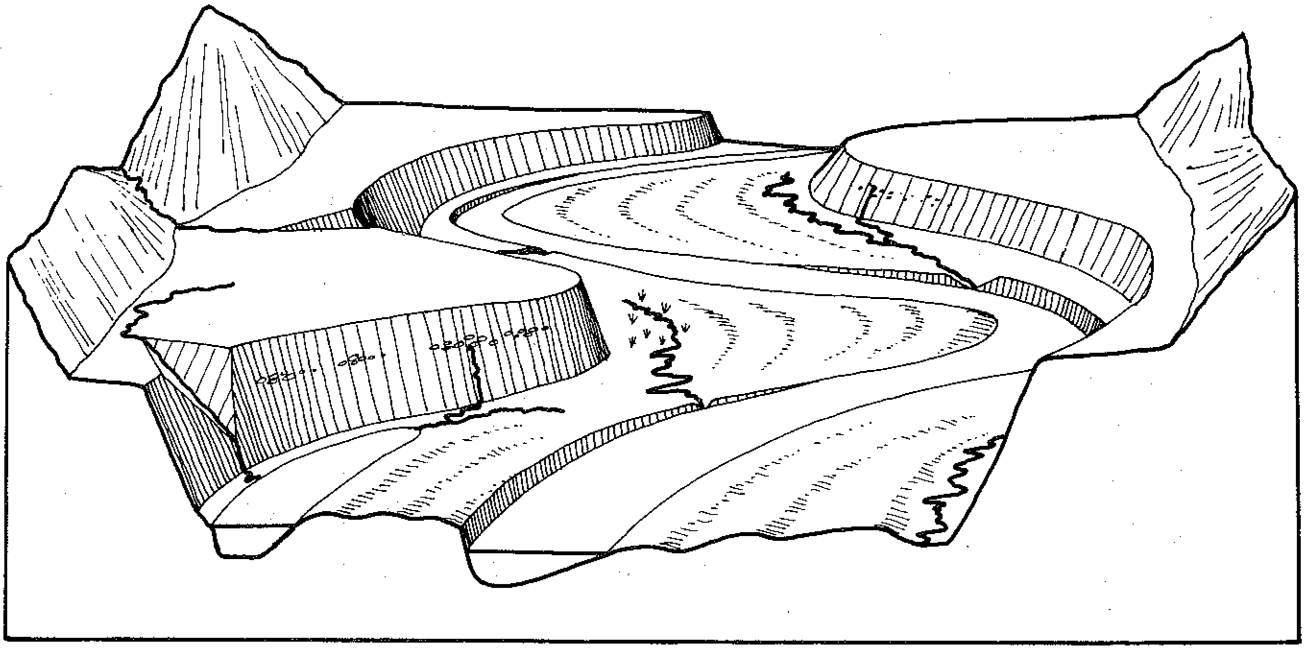

Figure 3. Up-valley oblique view of meandering river and wall-base channels, showing examples of associated habitat types.

about 80 to 90 percent of this eventually reaching the river either in the form of saturation overland flow or as subsurface flow. Drainage density in the area averages 9.3 km/km^2 on the bedrock hillslopes but is lower on the glaciofluvial terraces which form the vally floors. On these terraces rain infiltrates quickly into the deep permeable gravels and emerges as springs and seeps in the terrace wall below. Strong seasonality of the precipitation results in a difference of three orders of magnitude between summer low flows and winter high flows in major tributary basins.

Bedrock in the area consists of the Tertiary marine sandstones, siltstones, and graywackes of the Hoh lithologic assemblage. The basin was largely ice-free during both the Salmon Springs glaciation (about 47,000 to 34,000 years before present) and the Fraser glaciation (about 28,000 to 10,000 years before present) (Crandell 1964, Heusser 1977), but during the Salmon Springs glaciation a lobe of the Hoh glacier overran the Hoh-Clearwater divide in the headwaters of the Snahapish River near the middle of the basin. Glacial outwash from the Hoh and Queets glaciers also entered the Clearwater basin at other low divides. During the Fraser glaciation even outwash contribution appears to have been minimal; the only ice in the watershed appears to have been minor alpine glaciers in the highest parts of the catchment.

Bedrock hillslopes average 20° in the western part of the basin and 30° in the higher, eastern part. The major tributary valleys and the mainstem valley, however, are floored by nearly flat-lying terrace desposits ranging in elevation from a few meters to 100 meters above the present river. The lowermost terrace (Class I, fig. 4) corresponds to the present active floodplain, and includes surfaces of about 1 to 2 meters above the river's winter baseflow stage. These surfaces are generally vegetated by thickets of alder (Alnus rubra); older examples contain young sitka spruce (Picea sitchensis), while the youngest ones are not more than gravel bars. Overbank silt deposits are still accumulating on these surfaces, and inundation is likely to occur at least once every year.

Class II terraces (fig. 4) stand between 2 and 3 meters above the winter baseflow stage and are distinguished from Class I terraces mainly on the basis of vegetation. Cottonwood (Populus trichocarpa) and big-leaf maple (Acer macrophyllum) are common on these terraces and sitka

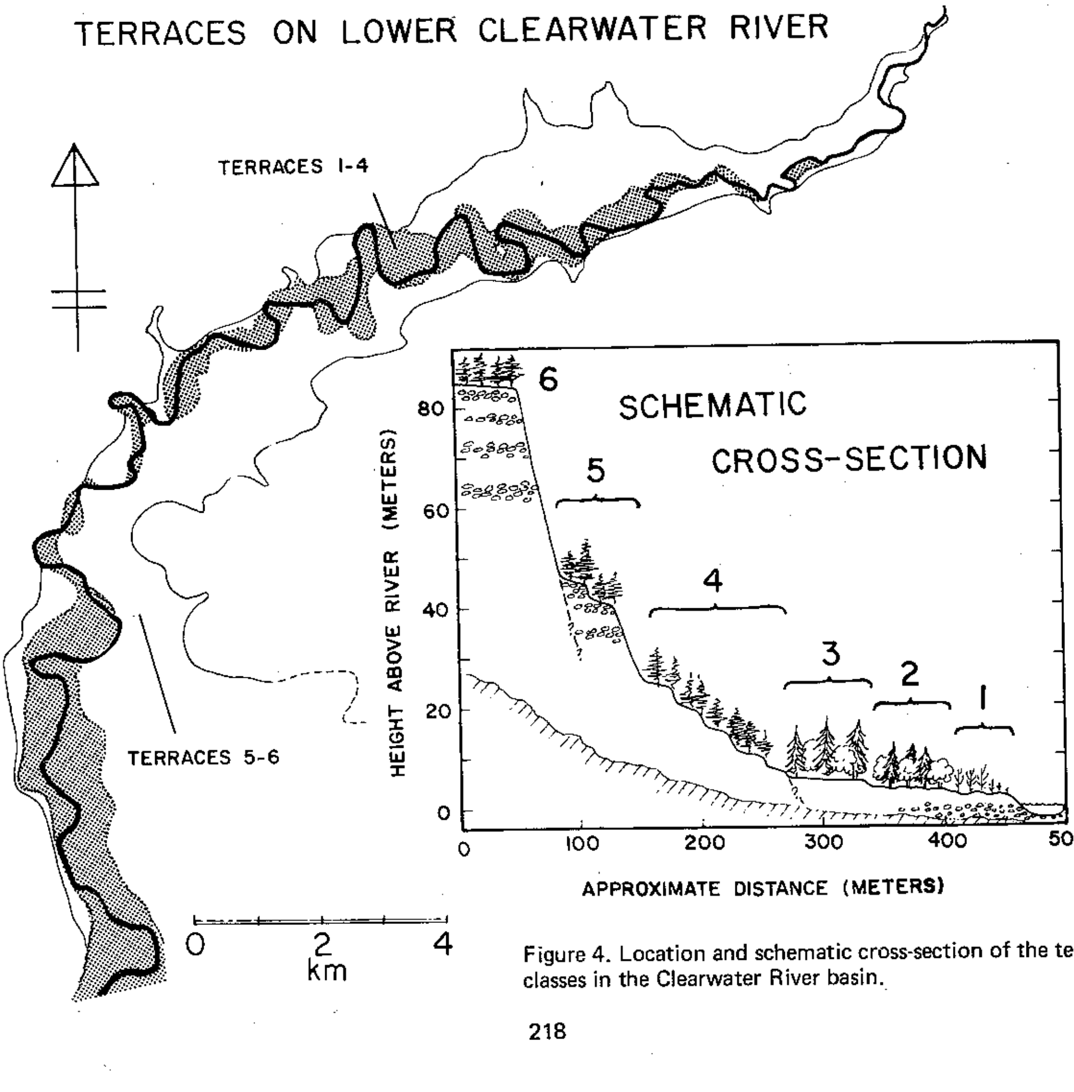

Figure 4. Location and schematic cross-section of the terrace classes in the Clearwater River basin.

spruce is frequently seen. Soils here are of the Hoh series (L. Halloin, soil scientist, Department of Natural Resources, Forks, WA, pers. comm.) and differ from those of the Class I terraces only in the presence of weak structure and a subtle color change near the surface. Silt depths reach 1 m or more on Class II terraces as compared to the few tens of centimeters measured on a 60-year-old Class I terrace. The correspondence between the elevation above the river of the upper limit of sand deposits on the first two terrace classes suggests that both are related to present river activity and a ridge and swale microtopography produced by migration of the mainstem channel is quite evident on these surfaces.

Class III terraces include surfaces of about 3 to 5 m above the river, and thus are well above flood level. These sites support big-leaf maple, sitka spruce, and hemlock (Tsuga heterophylla). The size of the trees suggests that the surfaces have been stable for at least several centuries and may thus date back to markedly different basin conditions. Soils here belong to the Queets series (Halloin, pers. comm.); are weakly developed and are distinguished mostly on the basis of increasing structure and color near the surface. The ridge and swale topography so evident on the younger surfaces is subdued at these sites.

A fourth sequence of terraces (Class IV, fig. 4), stands between 5 and 25 m above the river level and supports the hemlock-fir forest typical of the rest of the catchment. Soils here are more strongly developed, locally exhibiting an orange B horizon.

The final two terrace groups (Class V and VI) formed as Pleistocene glacial outwash deposits and now stand as distinct sets of surfaces at about 40 m and 100 m above the river level. Both are notably rich in gravels and cobbles and support the climax hemlock-fir typical of the area. These terraces are found along the lower 40 km of the main Clearwater, downstream of the points that outwash from the Hoh glacier entered the valley.

The Clearwater River meanders in its downstream reach with an average sinuosity of 1.6 and meander wavelength of about 1 km. Channel gradient averages 0.0024 percent, and the river's profile exhibits a smooth exponential decrease in gradient downstream, despite occasional bedrock outcrops in the channel. The meander pattern is irregular, but bends are actively migrating, as shown by vegetation zonation on the insides of bends. The meander belt is wide enough that 30 percent of the bends impinge upon bedrock valley walls, while an additional 50 percent are eroding into the Pleistocene terrace deposits.

Physical Environment

Meandering channels--The frequency with which wall-base channels are encountered and the regularity of their character and distribution strongly suggest that these forms are a product of the fluvial processes which are responsible for the construction of the floodplains upon which the channels develop. As the flow rounds a meander bend, momentum carries the high velocity core of the flow outward, enhancing the river's capacity to erode its back just downstream of the apex of the bend. The channel thus widens slightly, decreasing the depth and velocity over the point bar on the inside of the bend and causing sediment to be deposited there. This process restores the river's cross section and advances the bend slightly outward and downstream, and sediments that had been held in storage in the floodplain deposits are once again entrained by the river.

As the bend gradually migrates, the length of the stream is increased, and this in turn decreases the average gradient and the radius of the curvature of the bend. As migration continues, the bend approaches the river channel downstream of the following bend until, eventually, overbank floodwaters may scour an overflow channel through the narrowing neck of land separating the bends. Increased erosion of the overflow channel may eventually divert most of the river's flow to the new channel, leaving the old channel filled with slow moving water where sediment is readily deposited. The head and mouth of the cutoff bend are soon choked with sediment, and the deepest part of the old channel, corresponding to the bend itself, remains as an oxbow lake. Cutoffs may also occur when the downstream migration of the bend cuts through the peninsula separating two bends. In either case, cutoffs are expected to be most common on bends of high amplitude and on those which are themselves prevented from downstream migration, as might occur if a bend impinges upon an erosion-resistant valley wall.

In some streams cutoffs are uncommon and the entire sequence of bends migrates gradually downstream. Such a migration pattern may leave a ridge and swale microtopography on the floodplain, but would not be associated with oxbow lakes.

In a meandering stream the floodplain is created by the outward growth of the point bar, and thus at any site the growing floodplain is initially the height of the gravel bars deposited by the stream. Migration of the channel moves the locus of the point-bar deposition outwards, leaving a series of concentric "scroll bars" at locations of particularly high point bar deposition. When the river floods over its banks it deposits a layer of sand and silt on the point bar deposits, gradually increasing the height of the floodplain. If the bend is migrating at a uniform rate and the valley is not aggrading, the maximum depth of over-bank deposits will probably be toward the valley wall, where sediments have been accumulating the longest. In contrast, where a river valley is aggrading or a bend becomes stable for a prolonged period, the high rate of deposition near the banks may cause the formation of a natural levee, which may further confine the channel.

Formation of wall-base channels--The initial localization and incision of wall base channels is expected to result from either: 1) the cutoff of meander bends, or 2) the interception and channeling of runoff from upper terraces by scroll bars or overflow channels. Channels similar in form have elsewhere been attributed to the growth of natural levees along a river (Swanson et al. 1980). Tributary streams entering the valley are prevented from joining the main river because of the intervening levee, and instead flow down-valley parallel to the river. Such tributaries were termed "Yazoo channels" by Lobeck (1939). This explanation, however, does not apply to channels along the actively migrating Clearwater River, where natural levees are absent.

The character of many of the wall-base channels of the Clearwater basin suggests they were formed by the cutting off of meander bends. These channels are associated with linear ponds and swamps which appear to follow old channel scars in the manner of oxbow lakes. Two of these riverine ponds were investigated in detail (Peterson 1982b). Pond 1, the younger of the two ponds, reaches a maximum depth of 3 m and its bottom is covered by about 20 cm of silt underlain by a grey sand. The pond is located on a Class II terrace which is about 3 m above the river level, and the pond surface is approximately 1 m below the terrace surface. The estimated depth of 2 m for the river at this point places the pond's bottom at close to the same level as the present river bed, which supports the hypothesized origin of the pond as a recently abandoned meander bend.

The second pond examined, Pond 2, is located on a Class III terrace. This pond and one close by exhibit the linear character typical of oxbow lakes. Here, however, the ponds are floored by organic muck and clay and are less then 2 meters deep, suggesting that they have been filling in for some time. Another example located on the same terrace class has filled in completely and remains only as a seasonal, sedge-covered swamp.

The second mechanism expected to form wall-base channels is the accumulation of runoff from the adjacent valley or the terrace wall in floodplain swales. The glacio-fluvial terraces characteristic of Olympic river valleys are generally formed of interbedded permeable and less-permeable sediments, and springs are thus common on terrace walls. Runoff from these sources flows down onto the surface of a lower terrace or floodplain, where it is diverted down-valley by the ridges and swales left by the main channel as it migrated across its floodplain. The diverted runoff is generally held close to the valley or terrace wall by the innermost swale until it reaches its confluence with the main channel at a point just upstream of the apex of the next meander bend.

Modification of habitat--Once the path of a wall-base channel is fixed, it is subject to a number of modifying processes. If the channel was formed by the cutoff of a meander, overbank and lateral deposition continue along the river, raising the height of the floodplain and further filling in the head and mouth of the new oxbow. Until the sediments deposited at the head reach the height of the floodplain the old channel is likely to serve as an overflow channel, and during this time coarse sediments may be deposited in the pond. After the pond is isolated, it is subjected to overbank deposition with decreasing frequency and the pond deposits become finer in texture. Meanwhile the pond's outlet is establishing a stable channel, which may be further modified by drainage of overbank floodwaters across the floodplain and down the channel. This increased discharge would enhance the stream's ability to transport sediment and erode its channel. As the floodplain grows in height, this component of the channel's discharge becomes less significant.

Because wall-base channels are located at the foot of steep valley and terrace walls, they also receive sediment from above, in the form of either colluvium from hillslope erosion or alluvium from small catchments on the adjacent slope. Eventually this sediment will fill in the ponds and swamps. The channels, however, have gradients steeper than the average valley gradient and in general maintain a uniform profile without an excessive buildup of colluvial debris.

Beavers are also expected to modify wall-base channel habitat. At one of the observed sites, the construction of a beaver dam at the pond's mouth appears to have raised the water level enough to have caused overtopping at another location and the formation of another outlet stream. The profile of the new outlet stream is still under adjustment and a gully is growing headward toward the pond. The gully could eventually drain the pond to a lower level, but it is more likely that further beaver activity will prevent that effect. In other cases beaver dams have caused local aggradation in the channels themselves, but these changes are usually subject to adjustment by major storm events.

Distribution of habitat--Of the 31 meander bends present along the lower 34 km of the Clearwater, 22 are known to have at least one wall-base channel associated with them (fig. 5). Channels are probably associated with an additional seven bends, but these will require field verification to confirm their presence (fig. 5). Most of the observed wall-base channels are on terrace Classes I-III, although several were found on Class IV surfaces. Filled in ponds and meander scars on the Pleistocene terraces (Classes V and VI) indicate that similar channels were once present on these surfaces.

Above the confluence with the Snahapish River, 34 km from the mouth of the Clearwater, the Clearwater floodplain narrows, the river straightens somewhat, and becomes smaller. Channels are also present along tributaries of the Clearwater, and here too, their size and frequency reflect the size, sinuosity, and width of floodplain of the mainstem stream. Casual observations along other meandering streams of the western Olympics and eastern Cascades suggest that wall-base channels are a common feature of sinuous streams.

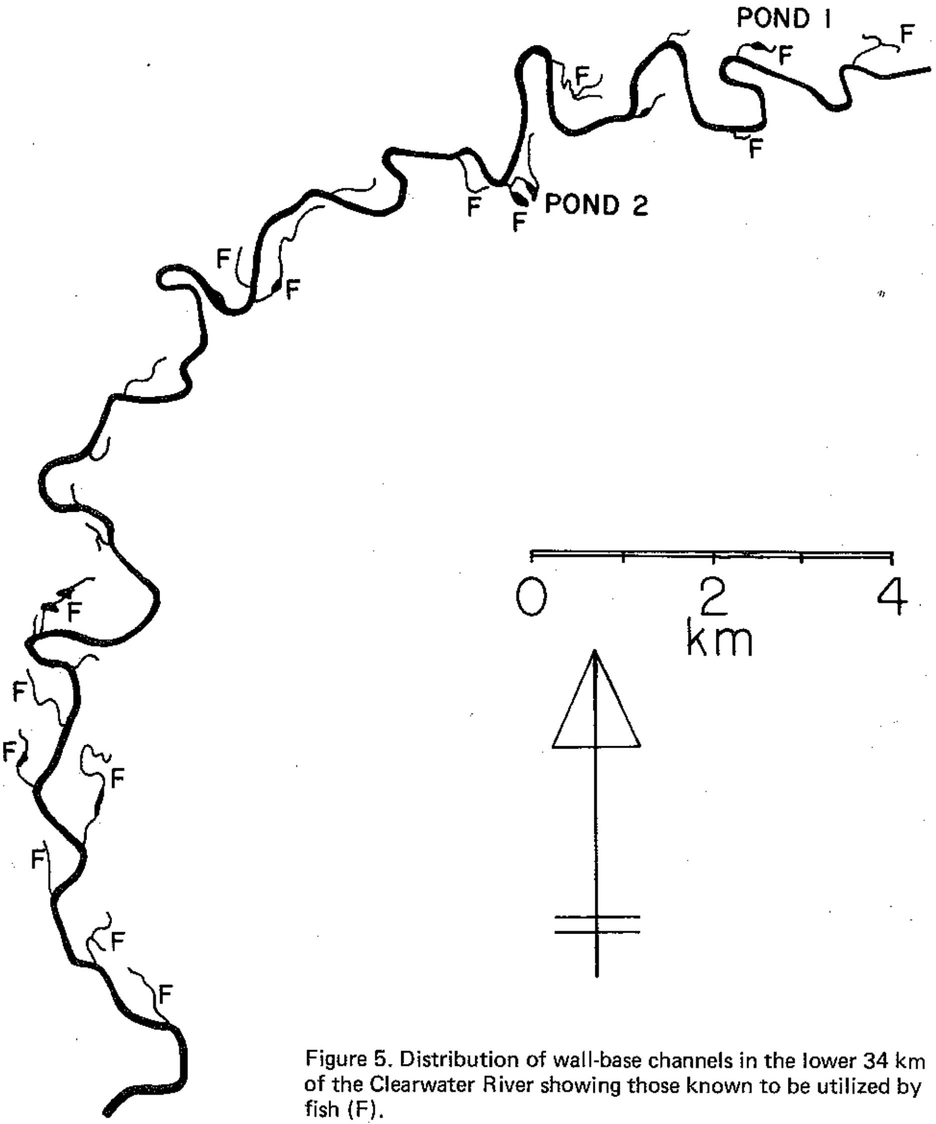

Figure 5. Distribution of wall-base channels in the lower 34 km of the Clearwater River showing those known to be utilized by fish (F).

Habitat Utilization by Coho

Of the 23 confirmed wall-base channels in the lower 34 km of the Clearwater River, 17 have been checked for use by juvenile coho. Fifteen were being used and the two that were not were inaccessible to juvenile fish because of steep cascades at the mouths. In these cases channels are located on older terraces which had been excavated in bedrock, and the channels' profiles are thus controlled by erosion resistant outcrops on the steep terrace risers.

As noted previously, most of the wall-base channels along the Clearwater River lack areas where salmon can spawn; therefore, a brief review of the coho's life history up to the time they begin to use the channels is necessary to explain their presence. Generally, coho spawn and rear in the valley tributaries and, to a lesser degree, the main river. After emergence from the spawning gravel the early stream life of coho fry is characterized by a habitat colonization period. During this time fry begin to establish individual territories in specific pools. As a result competition ensues and behaviorally displaced individuals seek territories in downstream areas (Chapman 1962). Density independent behavior (Au 1972) and environmental factors (Hartman et al. 1982) also operate at this time to disperse fry downstream. Through this dispersal and colonization process, the tributaries are colonized from the uppermost spawning site to their mouth. Some fry, especialy those spawned in short tributaries or near the mouths of long tributaries, enter the main river and rear there through the summer, residing principally in and around accumulations of wood debris (W. Wood, Fisheries Biologist, Washington Department of Fisheries, Forks, Washington, unpublished data).

<u>Recruitment of Fish into Wall-Base Channels</u>--Except for the rare case where spawning occurs in the upper reaches of a wall-base channel, all recruitment to these sites is through upstream movement from the main river. Movement data collected at upstream and downstream trapping facilities on two wall-base channels, the outlets of

Pond 1 and Pond 2, show two distinct periods of recruitment, one in the spring and early summer and another in the fall and early winter (fig. 6).

Fry recruited during spring and summer range in size from 45-65 mm. They colonize both the channelized portion of the wall-base channels and the ponds, if present. Little movement into wall-base channels has been recorded during the summer, although an occasional summer storm triggers some upstream movement.

The magnitude of the spring movement is probably a function of the number of fry in the main river. Fry populations in the main river must in turn be controlled by the previous fall's escapement and the density-independent mechanisms that disperse fry from the tributaries, such as the number, magnitude, and timing of spring freshets. Of the three immigrations that have been monitored at Ponds 1 and 2, the largest numbered nearly 1,000 fry at Pond 2 in 1978, while 200 to 500 fish entered each site on other occasions (Cederholm and Scarlett 1981).

Most of the fish move in beginning with the first major freshet of the fall, usually in late October (fig. 7). This timing suggests that this behavior pattern has developed in response to the large winter storms that are typical of western Washington. In most years river stages that are above the threshold level for initiating upstream migration occur frequently enough that flow probably does not limit the size of the migration. It is possible, however, that extreme storms might displace additional fish that otherwise would have remained in upstream valley tributary or main river habitat. As with the spring migration, the magnitude of the fall movements must ultimately be controlled by the size of the recruitable fingerling population. The largest recorded fall migration numbered just over 9,500 coho fingerling into Ponds 1 and 2 in the fall of 1977 (Peterson 1982a).

It appears that the fall recruits come principally from the main river. Marking experiments of coho in the main Clearwater River show that juvenile coho travelled as far as 33 km downstream before entering the pond (Peterson 1982a; Cederholm and Scarlett 1981).

Residence in the wall-base habitat--Little is known of the fishes' behavior while residing in wall-base channels and associated ponds. During the winter of 1983, however, some upstream migrants into Pond 2 were observed to pass

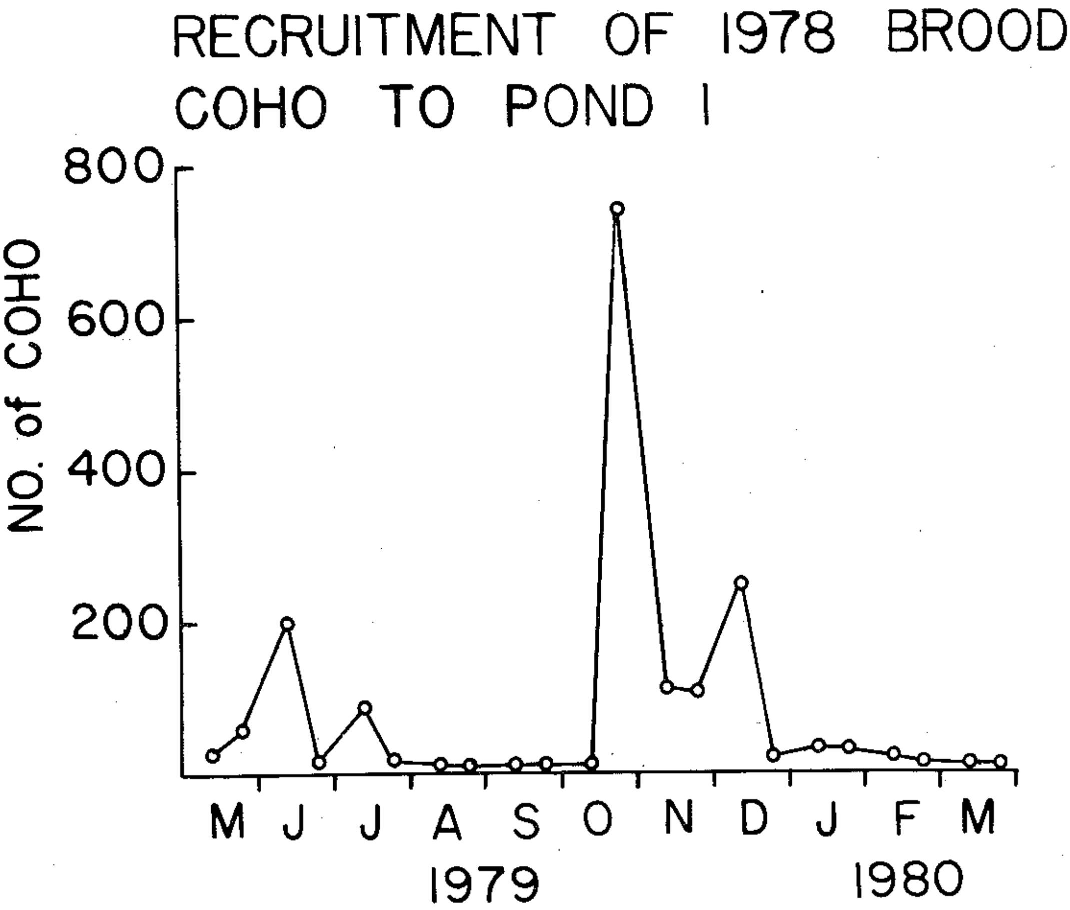

Figure 6. Recruitment of the 1978 brood Clearwater River coho to Pond 1.

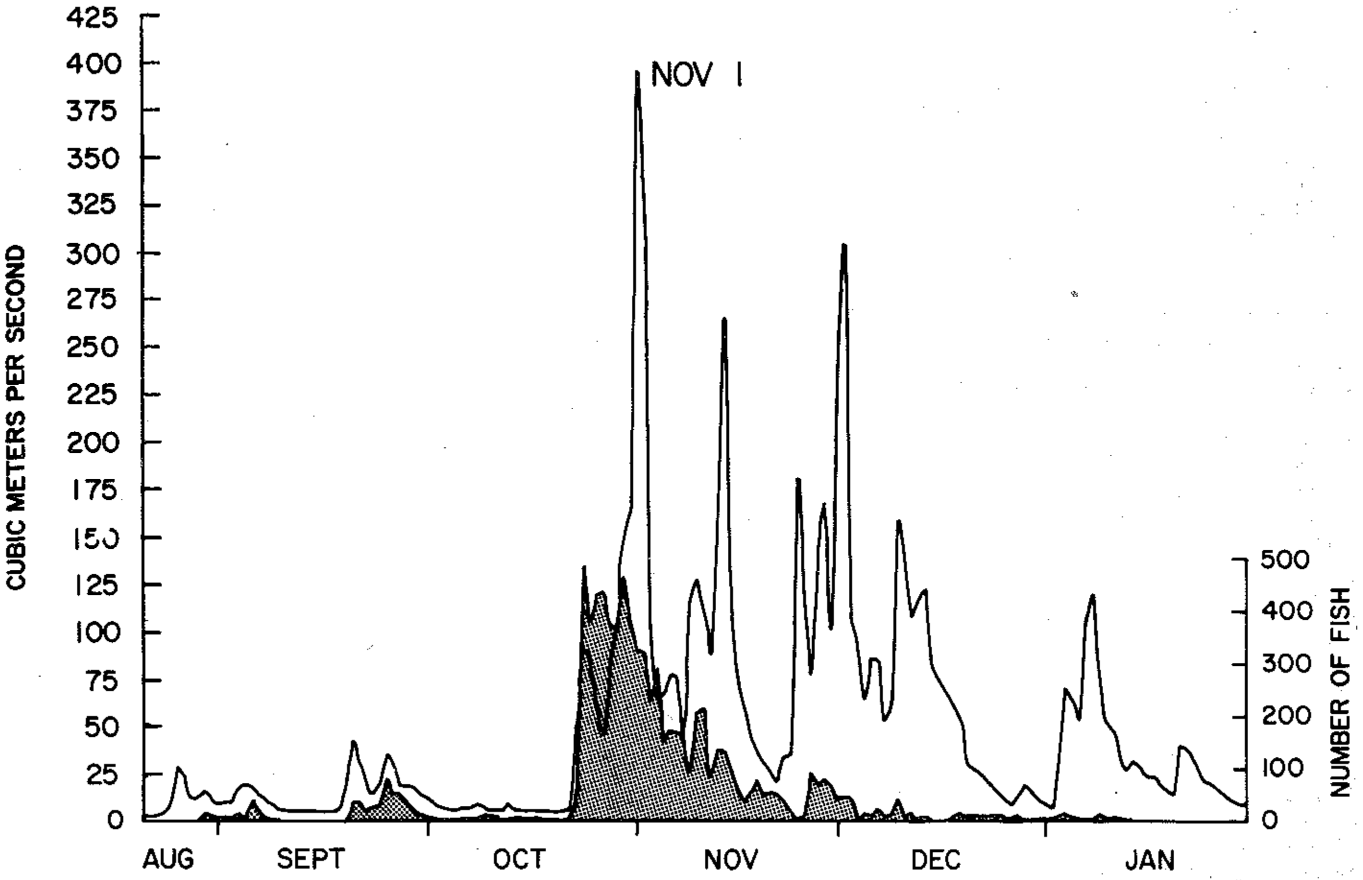

Figure 7. Plot of the peak daily discharge of the Clearwater River and the total number of fish entering Pond 1 and 2. Stippled area represents the number of fish and corresponds to the right hand vertical axis (Peterson 1982a).

through the pond and assume residency in the inlet stream and its associated sedge swamps. Preliminary results of the 1983 work indicate that many of these fish move back into the pond in the early spring and achieve considerable growth before leaving as smolts. Fish were also observed in the inlet areas of Pond 1.

Observation of feeding rises in Pond 1 indicates that fish distribution was fairly uniform. However, in Pond 2 the fish were very patchily distributed, and in 2 of 3 years they were observed in a tight school beginning in January. This schooling behavior could be a response to heavy predation.

Survival and growth of overwintering fish in different wall-base channels and their associated ponds appear to be influenced by habitat structure (Peterson 1982b). Pond 1 consistently has good survival (75 percent) and relatively small smolts (110 mm average) while Pond 2 has poorer survival (25 percent) and larger smolts (130 mm average). Size differences appear to be a direct result of pond productivity, and survival differences may be indirectly related to pond depth. A recently completed observational study of predator activity on these two ponds may help to explain the differences. Although results are still being analyzed it appears that Pond 2 has certain characteristics that tend to concentrate specific predators (Zarnowitz and Raedeke, in prep.).

Wall-base channels without ponds are also being studied, and preliminary results of recently completed work suggest that overwinter survival is in the range observed for channels with ponds, although the sites without ponds, generally produce smaller fish. The size differences between smolts from wall-base channels that have ponds is probably due to the differences in productivity between the sites, since current recruitment levels are not high enough to cause density-related growth depression. This may not be the case in channels that have limited ponded areas, where the observed magnitude of winter recruitment may "overload" the productive capacity of the small, silt-bottomed streams. Fish entering Pond 2 after spending the winter in the inlet stream had grown little, but after the fish entered the pond they grew significantly before leaving as smolts. These data suggest that channels without ponds may be relatively unproductive.

DISCUSSION

Wall-base channels are an important part of the habitat base supporting our wild coho salmon resource. Recent work on winter redistribution of juvenile coho, pioneered by Bustard and Narver (1975) and followed by studies in the Clearwater basin (Peterson 1982a; Cederholm and Scarlett 1981) clearly show that smolt populations from large river systems are the product of numerous complementary habitat types. Some of these habitats are important only seasonally. The wall-base channel and its associated ponds and swamps serve primarily as winter refuge and thus support presmolt development. Secondarily, the habitats serve as summer rearing habitat for fry. Maximum smolt production from large river systems cannot be achieved unless harvest managers implement escapement strategies that take into account "seeding" for all habitat components. Likewise, habitat managers need to protect each link of the supportive habitat network.

Wall-base channels are the result of predictable fluvial processes on actively migrating sinuous channels of the western Olympic Peninsula. As such, these features are expected to be common along similar streams elsewhere, and aerial photographs and field observations indicate that wall-base channels and other terrace habitat types are common on rivers such as the Hoh, Queets, and Quinault. In systems like these, it has been suggested that a relatively high proportion of the coho salmon biomass may be supported by terrace habitats (Sedell et al. 1983).

A significant number of coho smolts produced in the Clearwater basin apparently come from wall-base channel habitat. The Washington Department of Fisheries (WDF) has made estimates of the total smolt yield from the Clearwater beginning in 1981 (Seiler, in prep.). Estimates are made by applying a trapping efficiency to the total catch of a main river sampling device located near the mouth of the Clearwater. These trapping efficiencies are based on the recapture rate of known numbers of coded wire tagged smolts released from upriver valley tributary traps, operated by the Quinault Tribal fisheries staff.

Estimates of the valley tributary production potential for the Clearwater basin (Cederholm, unpublished data) show that 72 percent of the expected smolt yield from the valley tributaries should have been caught by the Quinaults' smolt traps in 1982. If the production rate, calculated using Quinault data is applied to the untrapped valley tributary habitat the total is 25 percent below the number estimated for the entire system from the WDF study. In addition, the statistically larger size (∿11 mm) of the untagged smolts caught by the mainstem sampler, suggests a different source for these fish.

In 1983 ∿10 percent of the Clearwater smolt population migrated from six wall-base channels where we operated smolt traps. Considering all factors we estimate 20-25 percent of the Clearwater total smolt yield annually comes from wall-base channel habitat.

The capacity of different wall-base channel habitats to support winter and early spring coho populations is expected to differ as a result of differences in the size and biotic character of their ponded areas. A planting experiment conducted during the winter of 1983 indicates that the capacity for smolt production is at least 3,000 smolts per surface acre at Pond 1, which is probably the least productive of the five major natural ponds along the Clearwater River. At present, wall-base channels with ponds do not receive enough natural recruitment to tax their productive capacity for food. With increased coho escapement to the Clearwater River it may be possible to produce more fry and fingerling in the system, resulting in a probable increase in the magnitude of the spring and fall movements. Since the valley tributary habitat is colonized first, increased population pressure there would result in greater dispersal of fry to the main river and subsequently to the wall-base channels. This habitat type is thus expected to become an even more significant contributor of smolts at higher escapements.

Until work began on the Clearwater River in the late 1970's, this habitat type had been overlooked by salmon managers. Even today most of these small terrace channels are not included in inventories of important salmon habitat. Now both harvest and habitat managers for the State of Washington have incorporated this habitat type into their management plans, and thus a more complete inventory of these features is necessary. This inventory should be facilitated by an understanding of how such channels form, since such an understanding helps to predict their location and distribution.

The location of wall-base channels on the lower terraces makes them particularly susceptible to cultural development. Even in the relatively remote Clearwater basin, there are examples of valuable pond and swamp habitat that have been partially filled by cedar waste from shake mills or overburden from gravel pits. In two instances the ponded areas are no longer accessible to fish because outlets are completely blocked.

This habitat type and the associated fish behavior offer a promising opportunity for natural enhancement. If overwinter survival can be increased or the productivity of some of these sites expanded by excavating ponds where none exist, we may significantly increase smolt populations. The cost of new construction, however, may be prohibitive, and purposeful siting and reclamation of borrow pits may be the best way to enhance winter habitat in the riverine environment. The overwintering coho populations of riverine ponds are particularly valuable since they represent fish that were spawning in most tributaries upstream of the site. When the pond populations return as adults, spawning in their natal streams, they will thus contribute progeny to habitats throughout the watershed.

ACKNOWLEDGMENTS

We wish to thank Mr. C. Jeff Cederholm for the use of unpublished data used in Figure 6.

LITERATURE CITED

Au, D. W. K. 1972. Population dynamics of the coho salmon and its response to logging in three coastal streams. Ph.D. dissertation, Oregon State Univ., Corvallis. 245 p.

Bustard, D. R. and E. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32:667-680.

Cederholm, C. J. and W. S. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Salmon and Trout Migratory Behavior Symposium, E. L. Brannon and W. O. Salo, eds.

Chapman, D. W. 1962. Aggressive behavior in juvenile coho salmon as a cause of emigration. J. Fish. Res. Bd. Can. 19(6):1047-1080.

Crandell, D. R. 1964. Pleistocene glaciations of the southwest Olympic Peninsula. U.S. Geol. Surv. Prof. Pap. 501-B, p. 135-139.

Hartman, G. F., B. C. Anderson, J. C. Scrivner. 1982. Seaward movement of coho salmon (*Oncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal stream in British Columbia. Can. J. Fish. Aquat. Sci. 36:588-597.

Heusser, C. J. 1977. Quaternary palynology of the Pacific Slope of Washington. Quaternary Res. 8:282-306.

Lobeck, A. K. 1939. *Geomorphology*. McGraw-Hill, New York, 731 p.

Peterson, N. P. 1982a. Immigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Can. J. Fish. Aquat. Sci. 39:1308-1310.

Peterson, N. P. 1982b. Population characteristics of juvenile coho salmon (*Oncorhynchus kisutch*) overwintering in riverine ponds. Can. J. Fish. Aquat. Sci. 39:1303-1307.

Sedell, J. R., J. E. Yuska, R. W. Speaker. 1983. A study of west side fisheries in Olympic National Park, Washington. U.S. Dept. of the Interior. Contract No. CX-9000-0-E 081.

Seiler, D., S. Neuhauser, M. Ackley. In prep. Upstream/downstream salmonid trapping, 1981-82. Wash. Dept. of Fish. Progress Rept.

Swanson, F. J. and G. W. Lienkaemper. 1980. Interactions among fluvial processes, forest vegetation, and aquatic ecosystems, South Fork Hoh River, Olympic National Park, Washington. In *Proceedings of the Second Conference on Scientific Research in National Parks*.