Seasonal Changes in Habitat Use by Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Oregon Coastal Streams

Thomas E. Nickelson, Jeffrey D. Rodgers, Steven L. Johnson, and Mario F. Solazzi

Research and Development Section, Oregon Department of Fish and Wildlife, 850 SW 15th St., Corvallis, OR 97333, USA

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Habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) during spring, summer, and winter was examined in Oregon coastal streams. Coho salmon fry were most abundant in backwater pools during spring. During summer, juvenile coho salmon were more abundant in pools of all types than they were in glides or riffles. During winter, juvenile coho salmon were most abundant in alcoves and beaver ponds. Because of the apparent strong preference for alcove and beaver pond habitat during winter and the rarity of that habitat in coastal streams, we concluded that if spawning escapement is adequate, the production of wild coho salmon smolts in most coho salmon spawning streams on the Oregon Coast is probably limited by the availability of adequate winter habitat.

L'habitat utilisé par les juvéniles du saumon coho (*Oncorhynchus kisutch*) pendant le printemps, l'été et l'hiver a été étudié dans des cours d'eau côtiers de l'Orégon. Au printemps, les alevins étaient les plus abondants dans les fosses d'eau calme. Pendant l'été, les juvéniles étaient plus abondants dans tous les types de fosses plutôt que dans les descentes et sur les hauts fonds. Pendant l'hiver, les juvéniles étaient les plus abondants dans les enfoncements latéraux et les étangs de castors. Étant donné la forte préférence apparente pour les enfoncements latéraux et les étangs de castors pendant l'hiver et la rareté de ces habitats en cours d'eau côtiers, les auteurs concluent que si la remontée de géniteurs est suffisante, la production de smolts de saumon coho sauvage dans la plus grande partie des cours d'eau à coho de la côte de l'Orégon est probablement limitée par la disponibilité d'habitats hivernaux adéquats.

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During strategic resource planning, biologists often estimate the smolt production potential of a stream or basin for anadromous salmonids without the benefit of measures of smolt outmigration (e.g. Columbia Basin Fish and Wildlife Authority 1990; USDA Forest Service 1990; land management plans currently being developed by the U.S. Bureau of Land Management for western Oregon). The most common method being used to assess the potential of a stream to produce smolts is to apply a density (smolts per square metre) to estimates of the summer surface area of the stream (Columbia Basin Fish and Wildlife Authority 1989, 1990). This method relies on the assumption that all habitat types (i.e. riffles, pools, glides) have the same potential or, when pool area is estimated separately, that all types of pools have the same potential. The primary weakness of this method is that it assumes that smolt production is limited by summer surface area, thus totally ignoring the quantity and quality of habitat during other times of the year.

Recent advances in stream habitat classification (Bisson et al. 1982) and habitat inventory methods (Hankin and Reeves 1988) have made it possible to easily estimate the quantity of different types of habitat in streams during different seasons of the year. The habitat classification also provides a framework for evaluating habitat quality. The purpose of this study was to use that framework to determine the types of stream habitat used by juvenile coho salmon (*Oncorhynchus kisutch*) inhabiting Oregon coastal streams during spring, summer, and winter and to quantify the density of juvenile coho salmon associated with different types of habitat.

A number of investigators have examined the habitat preferences of coho salmon in recent years in Alaska (Heifetz et al. 1986; Murphy et al. 1986, 1989), British Columbia (Bustard and Narver 1975a; Tschaplinski and Hartman 1983; Swales et al. 1986, 1988; Hartman and Brown 1987; Swales and Levings 1989), and Washington (Bisson et al. 1982, 1988; Peterson 1982a, 1982b). However, few of these papers present data on coho salmon density in different stream habitats, and little has been published about the seasonal habitat preferences of juvenile coho salmon in the southern portion of their range.

Methods

Study Design

Our approach was to sample different types of natural habitat over a broad range of streams to determine (1) the average density of juvenile coho salmon associated with each type of habitat and (2) the extent to which that density varied seasonally. We sampled specific habitat types and fish populations in streams located in Oregon coastal river basins from the Nehalem River south to the Coquille River (Fig. 1), an area that included most of the range of coho salmon on the Oregon coast (Oregon Department of Fish and Wildlife 1982).

Because we intended that our density estimates reflect the average potential of different types of habitat to support juvenile coho salmon in Oregon coastal streams, it was necessary for the streams that we sampled to be adequately seeded. The inclusion of underseeded streams, and therefore low densities of coho salmon, would result in an underestimate of the habitat potential and also could mask any differences in the relative use of different types of habitat. Unfortunately, many Oregon coastal streams have had poor spawning escapements since the

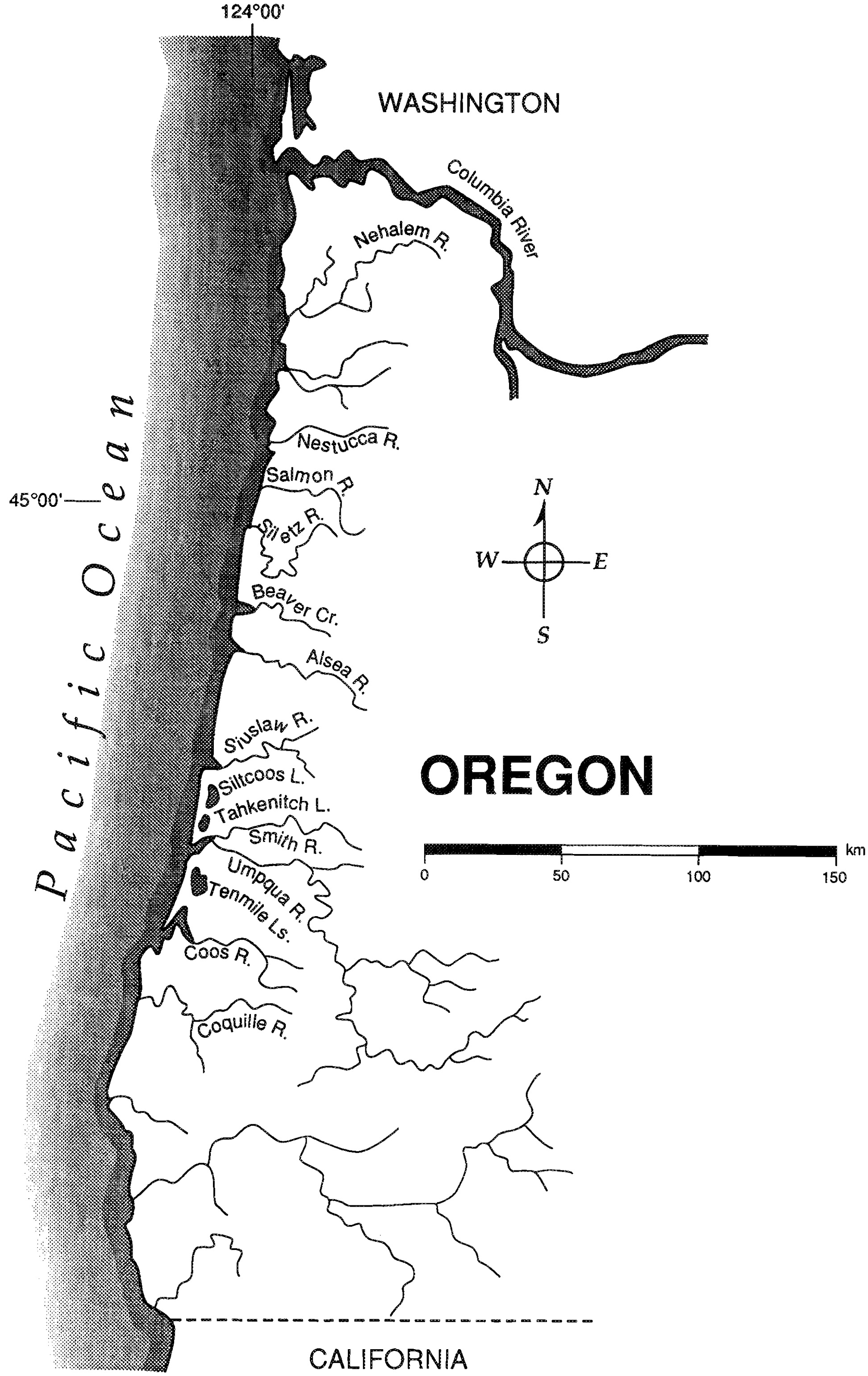

FIG. 1. Coastal Oregon basins where juvenile coho salmon populations and habitat were sampled.

mid-1970s (Oregon Department of Fish and Wildlife 1982; Jacobs 1989), increasing the likelihood of underseeded juvenile rearing habitat.

To reduce the possibility that we would sample underseeded streams, we sampled streams during the spring that had spawning populations of at least 25 spawners/km the previous fall (Jacobs 1989), a level of spawners that should be adequate to seed juvenile rearing habitat (Beidler et al. 1980). However, because information on spawner abundance is limited to a few streams, and we sampled many more streams during summer than during spring, the seeding level of many of the streams that we sampled during summer was unknown. Therefore, for our analysis of summer habitat use, we included only streams that had an average density in pools of at least 1.0 fish/m^2. Earlier work with stocking levels of juvenile coho salmon (Nickelson et al. 1986) suggested that this density would result

TABLE 1. Stream habitat types as modified from Bisson et al. (1982).

Habitat type	Characteristics
Pools	
Dammed pool	A pool impounded upstream from a complete or nearly complete channel blockage (including beaver ponds)
Backwater pool	An eddy or slack water along the channel margin separated from the main current by a gravel bar or small channel obstruction
Alcove	A slack water along the channel margin separated from the main current by streambanks or large channel obstructions such that it remains quiet even at high flows
Scour pool	A scoured basin either (1) near the channel margin caused by flow being directed to one side of the stream by a partial channel obstruction or (2) near the center of the channel usually caused by a channel constriction or high-gradient rapid
Plunge pool	A basin scoured by a vertical drop over a channel obstruction
Trench pool	A long, usually deep slot in a stable substrate (often bedrock)
Glide	A moderately shallow reach with an even flow and no pronounced turbulence
Riffles	
Riffle	A shallow reach of gradient ≤4% with moderate curent velocity and moderate turbulence
Rapid	A shallow reach of gradient >4% with high current velocity and considerable turbulence
Cascade	A series of small steps of alternating small waterfalls and small pools

in full occupation of rearing space in all pools. To insure an adequate number of juvenile coho salmon to seed winter habitat, we resampled streams during the winter that had an average density during summer of at least 0.7 fish/m^2. We found average densities during winter to be similar between streams regardless of whether average summer densities were 0.7–1.0 or ≥1.0 fish/m^2, indicating that even the lower density streams appeared to be fully seeded in winter.

Classification of Habitat Types

We use the method described by Bisson et al. (1982) to classify habitat components. This method sorts stream habitat into three basic categories: pools, riffles, and glides. It further divides pools and riffles into easily identifiable types based on their hydraulic characteristics (Table 1).

We made two modifications to the Bisson classification scheme. First, in addition to the lateral scour pool they described, we identified a midchannel scour pool. It is characterized by a downward scour that results in a bowl shape as opposed to a lateral scour pool that tends to be deep on one side. We combined midchannel and lateral scour pools into a single category: scour pool (Table 1). Second, we classified secondary channels, which were rare, by their appropriate habitat type and treated them the same as main-channel habitats because they were just smaller versions of the main-channel habitats with similar hydraulic characteristics.

We also classified backwater pools during winter into two types: (1) those with low current velocity, even at high flows, which we termed "alcoves" after Helm (1985), and (2) those with moderate to high current velocity during high flow, for which we retained the term "backwater pool." Alcoves are formed by impounded water backing up into quiet water areas along the channel margin and are protected by the streambank or by large channel obstructions whereas backwater pools are formed by eddies behind small channel obstructions and are often separated from the main current by gravel bars only. Alcoves were treated separately from backwaters only during winter because the distinction is only important at high flow, they tend to be rare, and they are often dry at summer flow levels.

Study Area

A typical study stream had low gradient (<3%) and was dominated by scour pools and riffles. Stream order (Strahler 1957) ranged from second to sixth. The riparian zone generally consisted of an overstory of red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), western redcedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), and western hemlock (*Tsuga heterophylla*) and an understory of salmonberry (*Rubus spectabilis*), salal (*Gaultheria shallon*), vine maple (*A. circinatum*), and sword fern (*Polystichum munitum*). Typical summer and winter water temperatures ranged between 11 and 17°C and between 4 and 9°C, respectively. In addition to coho salmon, steelhead (*O. mykiss*), coastal cutthroat trout (*O. clarki*), and sculpins (*Cottus* spp.) were usually present.

Sampling Techniques

Sampling took place following fry emergence during spring (March–May), during the summer low flow period (August–mid-October), or during winter following a bankfull flow event (December–mid-February). We sampled 15 streams and 150 habitat units during spring in 1986, 1987, and 1989, 52 streams and 519 habitat units during summer in the years 1985–90, and 31 streams and 289 habitat units during winter in the years 1985–89.

We estimated the population of juvenile coho salmon in each habitat unit using either a mark–recapture census (Chapman 1951) or a two- or three-pass removal estimate (Seber and LeCren 1967). The upper and lower ends of the unit were blocked with seines, and fish were collected using electrofishing equipment and seines. We estimated the surface area of each unit by measuring the length and multiplying by the average of several width measurements. During winter, we also measured the maximum depth of each pool.

Analysis

We have found that mark–recapture population estimates are more accurate than removal population estimates, accounting for 30% more of a coho salmon population than do the removal estimates (Rodgers et al. 1992). Therefore, to standardize our population estimates, we multiplied all removal population estimates by 1.3 to make them consistent with the mark–recapture population estimates. This affected about 30% of our data. All population estimates were converted to density (fish per square metre).

We calculated standard descriptive statistics for the coho salmon density for each habitat type except cascades for each of the three seasons. Cascades were excluded because of the extremely small number sampled (two in summer, three in winter). Cascades are uncommon in the low-gradient streams coho salmon typically inhabit.

We used a natural logarithm transformation on the various data when necessary to correct for nonnormal distributions or heterogeneous variances (Snedecor and Cochran 1967; Sokal and Rohlf 1969). This transformation normalized the densities for all seasons and equalized the variances among habitat types for spring (Bartlett's test, $P > 0.05$). However, the transformation would not equalize the variances among habitat types for summer or winter (Bartlett's test, $P \leq 0.01$).

We used analysis of variance (ANOVA) to test the hypothesis of no difference in mean density of juvenile coho salmon among habitat types within each season. When ANOVA F tests were significant, we followed them with a stepwise paired comparison. We used Ryan's Q test (Einot and Gabriel 1975), as recommended by Day and Quinn (1989), to compare pairs of means of the transformed habitat-specific densities of coho salmon when variances were homogeneous. We used Games–Howell (GH) test (Games and Howell 1976; Day and Quinn 1989) when variances were heterogeneous. This test was used because the pooled estimate of variance from the ANOVA used in Ryan's Q test should not be used to calculate the standard error of comparisons when the treatment variances are heterogeneous (Day and Quinn 1989). The GH test resolved this problem by calculating an appropriate standard error for each comparison.

To examine the influence of maximum depth on density of juvenile coho salmon during the winter, we used correlation analysis (Sokal and Rohlf 1969).

Results and Discussion

Seasonal Habitat Use

We found highly significant differences in mean density among habitat types in all seasons (ANOVAs on transformed data, $P \leq 0.001$). Juvenile coho salmon were most abundant in pool habitat throughout the year (Fig. 2). However, the type of pool with the highest density varied by season.

During spring, the mean density of coho salmon fry in backwater pools was more than twice that of any other habitat type (Ryan's Q test, $P \leq 0.05$), and mean density in dammed pools, glides, and scour pools was greater than that in rapids (Ryan's Q test, $P \leq 0.05$, Fig. 2). Lister and Genoe (1970) also found that coho salmon fry prefer backwater areas, and Peterson and Reid (1984) found coho salmon fry moving from the mainstem Clearwater River, Washington, into off-channel, slack-water areas (i.e. wall-base channels and ponds). Although we found fry to be most abundant in backwater pools, they were common in all habitat types, even riffles and rapids, where they used the stream margins (Mundie 1969; Lister and Genoe 1970).

During summer, there was no difference in mean density of juvenile coho salmon among pool types (GH test, $P > 0.05$, Fig. 2), although backwater pools had the lowest mean density of all pool types. We also found that riffle habitat supported the lowest density of juvenile coho salmon during summer and that glides were intermediate in density between riffles and pools (GH test, $P \leq 0.05$). These results are similar to those found by Ruggles (1966) in an artificial stream channel. In Washington streams, Bisson et al. (1988) found that abundance of juvenile coho salmon was greater in pools than in riffles and rapids. However, they found that abundance of juvenile coho salmon in glides was similar to that in riffles and rapids, although their sample size for glides was small (n = 4).

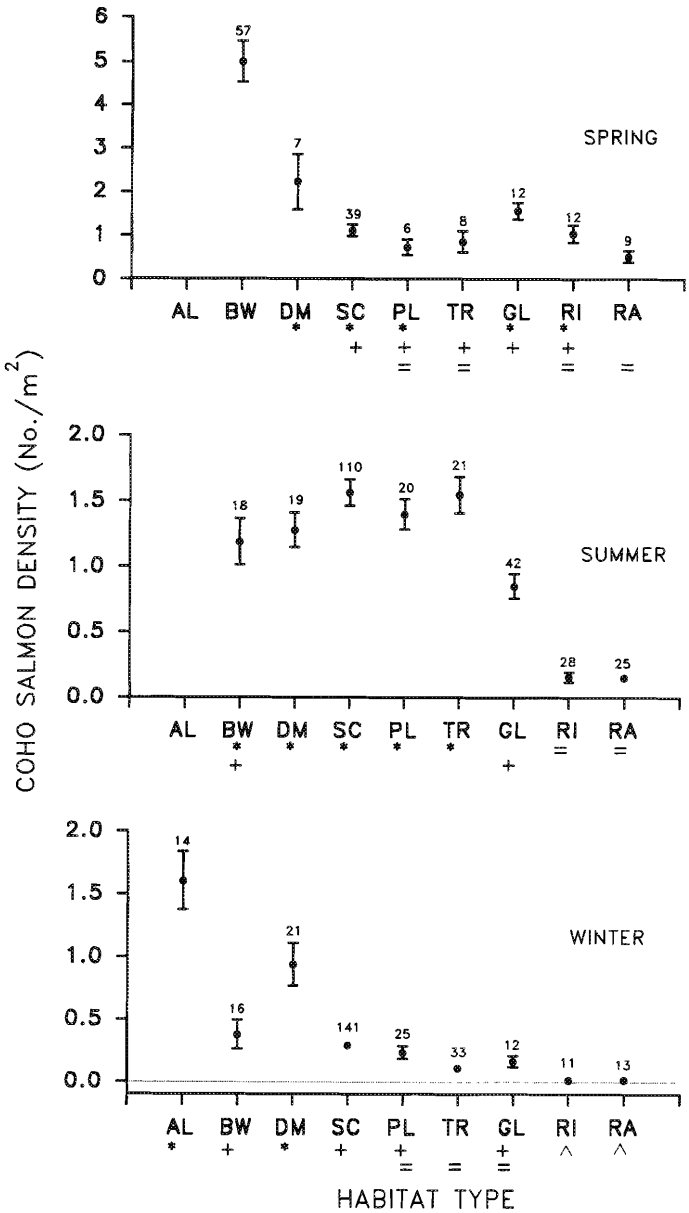

FIG. 2. Mean and standard error for density of juvenile coho salmon by habitat type during spring, summer, and winter. Some standard errors are smaller than the points. Habitat types are arranged from slowest to fastest water velocities after Bisson et al. (1988). AL = alcove; BW = backwater pool; DM = dammed pool; SC = scour pool; PL = plunge pool; TR = trench pool; GL = glide; RI = riffle; RA = rapid. Like symbols below these abbreviations indicate habitat types that had mean densities not significantly different from one another ($P > 0.05$). Sample size is shown above each datum.

During winter the mean density of juvenile coho salmon in alcoves and in dammed pools, habitats with low current velocity and little turbulence during freshets, was greater than that in all other habitat types (GH test, $P \leq 0.05$, Fig. 2). As in summer, mean salmon density in riffles and in rapids was significantly lower than that in all other habitat types (GH test, $P < 0.05$).

Of the 21 dammed pools sampled during winter, 12 were beaver ponds. The distinction between beaver ponds and other dammed pools during winter is an important one. Compared with other dammed pools, beaver ponds supported more fish (mean = 456/pond versus 96/pool; ANOVA, $P \leq 0.01$) at a

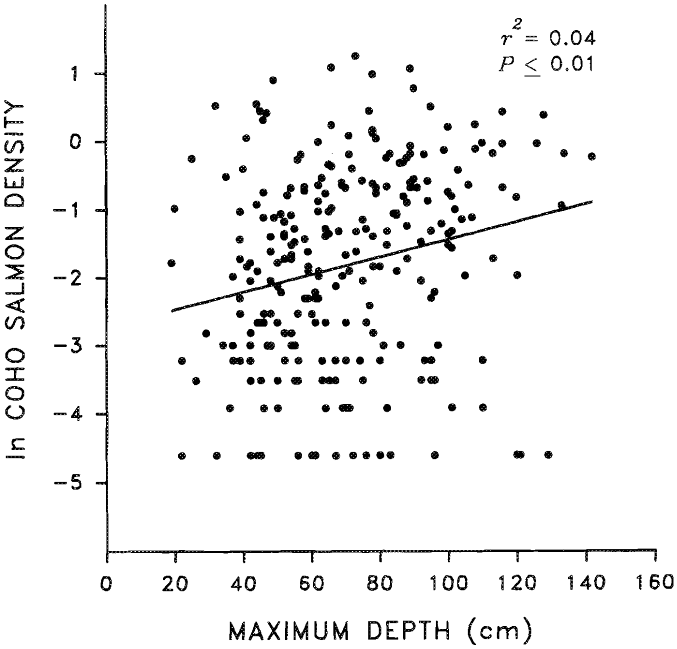

FIG. 3. Relationship between density of juvenile coho salmon during winter and maximum pool depth.

TABLE 2. Correlation coefficients (*r*), sample size (*n*), and probability (*P*) for relationships between density of juvenile coho salmon during winter (after natural logarithm transformation) and maximum depth of pools.

Pool type	Average maximum depth (cm)	*r*	*n*	*P*
All pools	70	0.21	250	<0.01
Alcove	63	0.12	14	0.69
Backwater	56	−0.43	16	0.10
Dammed	92	0.45	21	0.04
Scour	66	0.41	141	<0.01
Plunge	79	−0.28	25	0.18
Trench	72	0.31	33	0.08

higher density (1.28 versus 0.49 fish/m^2; ANOVA, $P \leq 0.01$). The beaver ponds were also larger (450 versus 150 m^2; ANOVA, $P \leq 0.01$) and deeper (103 versus 77 cm; ANOVA, $P \leq 0.01$) than the other dammed pools. Dammed pools tend to be an area of deposition, and thus fill in through time. Beavers maintain depth in their ponds by continually increasing the height of their dams and by creating channels of deeper water (Naiman et al. 1988).

Maximum pool depth during winter was significantly correlated ($P \leq 0.01$) with density of juvenile coho salmon when all pools types were analyzed collectively. However, this relationship was highly variable, and maximum depth explained only 4% of the variation in density of juvenile coho salmon (Fig. 3). Except for alcoves, the individual correlation coefficients were higher when the density – maximum depth relationship was analyzed by pool type (Table 2). Maximum pool depth was positively correlated with density of juvenile coho salmon in scour pools ($P \leq 0.01$), dammed pools ($P = 0.04$), and trench pools ($P = 0.08$). In these pool types, depth may be a factor that reduces current velocity and turbulence. Maximum pool depth was negatively correlated with density of juvenile coho salmon in plunge pools and backwater pools. During high flow, these pools undergo a downward scouring action. Greater depth may be an index of greater velocity and turbulence in backwater and plunge pools during freshets. Depth is not an important factor influencing the density of juvenile coho salmon found in alcoves. Alcoves are located out of the main channel and thus have low current velocity regardless of depth.

Winter habitat of coho salmon in Oregon coastal streams is similar to that reported by investigators elsewhere. Bustard and Narver (1975a, 1975b) found that during winter, juvenile coho salmon prefer natural or artificial "sidepools," similar to the habitat we classified as alcoves. They also found that beaver ponds were important overwintering habitat. Everest et al. (1986) sampled beaver ponds on an Oregon Cascade Mountain stream and found densities similar to those we report. Bustard and Narver (1975a), Tschaplinski and Hartman (1983), and Hartman and Brown (1987) observed movement of juvenile coho salmon from Carnation Creek, British Columbia, into slow off-channel habitats during September–December. The use of off-channel ponds and lakes during winter has been observed in Washington (Peterson 1982b; Peterson and Reid 1984) and British Columbia (Swales et al. 1986, 1988; Swales and Levings 1989).

We observed definite seasonal shifts in habitat use by juvenile coho salmon. Between spring and summer the shift was primarily from the riffles, glides, and backwater pools to other types of pools. This movement was likely the result of reduced velocities in main-channel pools as a result of lower streamflows during summer and a shift to deeper water as the fish grew (Lister and Genoe 1970). The shift in habitat use was most dramatic from summer to winter, probably a response to increased streamflows and decreased water temperature (Bustard and Narver 1975a; Tschaplinski and Hartman 1983). Many scour, trench, and plunge pools that supported large numbers of coho salmon during summer supported few, if any, during winter. Alcoves and beaver ponds composed only 9% of the total number of habitat units and 31% of the area sampled during winter, but accounted for 66% of the coho salmon sampled.

The types of habitat used by juvenile coho salmon during winter were once quite common in Oregon coastal streams (Sedell and Luchessa 1982). During the nineteenth century, coastal streams and rivers were choked with wood and beaver ponds that provided varied and complex habitat for anadromous salmonids, including numerous marshes, sidechannels, and sloughs. Most of this diversity has been lost as a result of clearing, splash-damming, diking, and channelizing streams associated with timber harvest, log transport, and agriculture (Sedell and Luchessa 1982). Today, alcoves and beaver ponds are rare in Oregon coastal streams during winter (Table 3), leading us to believe that given adequate seeding, production of coho salmon smolts in many Oregon coastal streams is probably limited by the availability of winter habitat.

Estimating Production Potentials and Limiting Factors for Coho Salmon

An understanding of the habitat associations of anadromous salmonids throughout the year is necessary to identify factors limiting smolt production and to assess the capacity of a stream or basin to produce smolts. Identification of limiting factors is a critical element in the planning of stream habitat rehabilitation projects (Hall and Baker 1982). This element is often missing because of the lack of analytical methods to identify limiting factors. Lack of information on the density of salmonids in

TABLE 3. Occurrence of winter habitat classified as prime (alcoves and beaver ponds), fair (dammed, backwater, and scour pools), or poor (plunge and trench pools, glides, riffles, and rapids) for production of coho salmon in 14 Oregon Coast Range streams as determined from stream inventories conducted at winter base-flow.

Stream	Length (km)	Percent of winter habitat by area		
		Prime	Fair	Poor
Moon Cr.	4.4	0.1	21.4	78.5
East Cr.	5.0	0.0	24.6	75.4
E. F. Lobster Cr.	3.4	2.3	25.7	72.0
S. F. Lobster Cr.	3.8	0.1	23.9	76.0
Benson Cr.	16.4	12.4	11.3	76.3
Schooner Cr.	4.7	0.0	24.8	75.2
Carcus Cr.	5.1	0.3	19.0	80.7
Hortil Cr.	0.6	0.0	36.3	63.7
Klickitat Cr.	0.3	0.0	30.1	69.9
Staveboldt Cr.	1.3	0.0	23.0	77.0
Speelyai Cr.	0.9	0.0	38.6	61.4
Little Cr.	4.3	0.5	23.4	76.1
Raymond Cr.	3.5	0.1	15.8	84.1
Walford-Johnson Cr.	0.9	11.9	8.2	79.9

TABLE 4. Potential populations of coho salmon supported seasonally as estimated from stream inventories and habitat-specific mean densities (see text).

Stream	Estimated potential population			
	Eggs	Spring	Summer	Winter
Moon Cr.	448 400	22 500	13 700	2 400
East Cr.	1 961 600	39 900	15 900	4 400
E. F. Lobster Cr.	1 330 000	28 100	12 900	3 900
S. F. Lobster Cr.	1 335 000	32 600	15 900	3 800
Benson Cr.	1 615 600	139 900	57 000	30 200
Schooner Cr.	801 600	28 600	13 800	3 200
Carcus Cr.	414 200	40 600	9 000	3 100
Hortil Cr.	91 600	2 200	1 100	300
Klickitat Cr.	5 000	2 500	1 500	100
Staveboldt Cr.	120 000	5 200	5 100	400
Speelyai Cr.	5 000	6 200	2 100	800
Little Cr.	570 000	23 500	8 500	2 400
Raymond Cr.	82 600	13 200	4 700	800
Walford-Johnson Cr.	51 600	13 100	4 900	2 100

various types of habitat during different times of the year has impeded the development of such methods.

Results from this study can be used to interpret stream habitat inventories in terms of the capacity of the habitat to produce coho salmon smolts and to develop methods to identify factors that limit production of coho salmon smolts. The Bisson et al. (1982) habitat classification system is useful for accomplishing these products because it is detailed enough to differentiate among preferences of coho salmon, yet can easily be used by a field crew conducting basinwide surveys.

Because of the substantial seasonal changes in habitat use by juvenile coho salmon, it is difficult, if not impossible, to predict the smolt production potential of a stream based only on an inventory of summer habitat, as is the common practice today, or to reliably determine the habitat limiting production. Provided that water quality is adequate, habitat potential during summer is largely dependent on the amount of pool habitat available. Habitat capacity during winter, however, is dependent on the amount of alcoves and dammed pools (especially beaver ponds) available, much of which cannot be adequately estimated from a summer inventory because alcoves are generally dry at low summer flow and many beaver dams present in summer are washed out by the first fall freshet. We therefore recommend that stream habitat be inventoried during the summer low-flow period and again during a winter base-flow period. From this information, a stream's production potential and the habitats limiting production can more accurately be determined.

The capacity of a stream to support coho salmon during a particular season is the sum of the potential number of fish supported by each of the individual habitat units comprising the stream. This can be estimated by multiplying the average density of coho salmon that we observed for each habitat type by the area of that habitat as estimated from summer and winter stream habitat inventories. We recommend using the winter base-flow inventory to also estimate the potential of spawning habitat and of spring habitat. Table 4 provides an example of this approach applied to the same streams as shown in Table 3. In this case, we have estimated the egg potential by multiplying the estimated area of spawning gravel by 833 eggs/m^2 (Reeves et al. 1989).

We have used this basic approach of comparing the habitat needs of coho salmon for spawning, spring rearing, summer rearing, and winter rearing combined with survival rates between successive life stages to address the question of identification of limiting factors. A preliminary method, in the form of a key, has been developed to identify limiting factors (Reeves et al. 1989). We are currently testing and refining this method.

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