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Winter Distribution of Juvenile Coho Salmon (*Oncorhynchus kisutch*) Before and After Logging in Carnation Creek, British Columbia, and Some Implications for Overwinter Survival

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Numbers of juvenile coho salmon (*Oncorhynchus kisutch*) in streams are reduced substantially in winter compared to those that occur in summer. Most of this reduction occurs early in autumn with the onset of the first seasonal freshets. Stream sections containing adequate winter habitat in the form of deep pools, log jams, and undercut banks with tree roots and debris lost fewer fish during freshets and maintained higher numbers of coho in winter than sections without these habitat characteristics. These features provide shelter and reduce stream velocities. Microhabitats occupied by coho juveniles in winter after logging were unchanged from those described before logging — all microhabitats were characterized by low water velocities (≤0.3 m/s). Up to 48% of the coho population inhabiting stream sections with adequate shelter remained there by midwinter (Jan. 3). This percentage was typical of stream sections where at least some trees remained after logging. Streamside trees stabilized the banks and prevented their collapse. In contrast, two of three study sections that had been clear-cut logged had unstable banks which collapsed during winter freshets. Almost no coho remained in these sections in winter. Many coho emigrate from the main stream to seek the shelter of low-velocity tributaries and valley sloughs concurrent with the decline of coho populations in Carnation Creek during autumn and early winter. This seasonal shift in distribution reverses in the spring when large numbers of coho reenter the main stream. Fish overwintering in these sites have a high apparent survival rate. Before logging a 4-yr mean of 169 ± 44 coho entered one tributary (a slough called 750-m site) in autumn. Of these numbers entering, 72.2% came out in spring. During and after logging, an annual mean of 288 coho entered the same site. The apparent survival rate during and after logging was 67.4%, essentially unchanged from the prelogging value. Logging has neither reduced the numbers of coho juveniles that enter such sites in autumn to overwinter, nor reduced the numbers leaving these sites to reenter Carnation Creek in spring.

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Le nombre de jeunes saumons coho (*Oncorhynchus kisutch*) dans le cours d'eau diminue substantiellement en hiver comparativement à ce qui se produit en été. Cette diminution survient surtout à l'automne, avec le début des premières crues saisonnières. Les sections du cours d'eau contenant des habitats hivernaux adéquats, tels que fosses profondes, embâcles de buches et berges sapées avec racines d'arbres et débris, perdent moins de poissons durant les crues et maintiennent plus de saumons coho en hiver que les sections dépourvues de ces caractéristiques d'habitat. Ces dernières fournissent des abris et ralentissent les courants. Les microhabitats occupés par les saumoneaux en hiver après exploitation forestière ne diffèrent pas de ceux décrits avant l'exploitation — tous les microhabitats sont caractérisés par de faibles vitesses de courants (≤ 0,3 m/s). Jusqu'à 48 % de la population de saumons coho habitant les secteurs munis d'abris adéquats y sont encore à la mi-hiver (3 janvier). Ce pourcentage est typique des secteurs du cours d'eau où au moins quelques arbres sont encore présents après l'exploitation forestière. Les arbres stabilisent les berges et empêchent leur affaissement. Par contre, deux des trois secteurs étudiés qui avaient été coupés à blanc avaient des berges instables qui se sont affaissées lors des crues hivernales. À cette saison, très peu de saumons y demeurent. Plusieurs sujets émigrent hors du cours d'eau principal et cherchent un abri dans les tributaires à courant moins rapide et munis de dépressions, en même temps que se produit un déclin des populations de saumons coho dans le ruisseau Carnation en automne et au début de l'hiver. Ce glissement saisonnier de la distribution s'inverse au printemps alors qu'un grand nombre de sujets pénètrent de nouveau dans le cours d'eau principal. Le taux de survie apparent des poissons hivernant à ces endroits est élevé. Avant l'exploitation forestière, une moyenne de 169 ± 44 saumons pénétrèrent dans un tributaire (une fondrière dénommée site 750 m) en automne. Sur ces nombres, 72,2 % en sortirent au printemps. Pendant et après l'exploitation forestière, une moyenne annuelle de 288 saumons pénétrèrent dans le même site. Le taux de survie apparent pendant et après l'exploitation a été de 67,4 %, essentiellement le même qu'avant l'exploitation. Cette dernière n'a donc pas réduit le nombre de juvéniles pénétrant à ces endroits en automne afin d'y hiverner, non plus que réduit le nombre qui en sortent pour pénétrer de nouveau dans le ruisseau Carnation au printemps.

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JUVENILE coho salmon (*Oncorhynchus kisutch*) occupy a wide variety of stream habitats in summer. Areas occupied include pools (with or without bank cover), slow-moving riffles and side channels, midstream locations, locations under or near banks, and areas jammed with logs and other large debris (Hartman 1965; Ruggles 1966). Several investigators have documented that stream-dwelling coho undergo seasonal shifts in distribution (Bustard and Narver 1975a, b; Mason 1976). Spatial requirements in winter differ from those in summer (Mason 1976). Mason (1966) reported that during winter when water temperatures were low (5–8°C in Oregon), coho fry aggregated near the bottoms of pools in the main stream, remained close to each other, and were quiescent. Bustard and Narver (1975a) demonstrated that young coho in autumn move into deep, slow-moving water as stream temperatures decline and discharge volumes increase. These investigators concluded that coho in winter must avoid (a) downstream displacement and physical injury during freshets (floods), and (b) predation by birds and mammals. They determined that important overwintering sites are (1) under banks, along stream margins where water movement is slow (≤0.15 m/s), (2) flooded sloughs in the stream valley that contain rooted vegetation, and (3) low-velocity side channels and small tributaries that sometimes contain flowing water only in winter. Coho also seek the shelter provided by large masses of debris (e.g. tree roots and logs) as seasonal water temperatures fall (Bustard and Narver 1975a).

Logging may affect the overwinter survival of coho in several ways. For example, Toews and Moore (1982) have shown that logging operations along stream sections in which (1) all trees are removed to the banks, and (2) felled trees are removed from the stream, eventually result in less debris accumulating in the stream and also cause debris masses to be less stable compared to stream sections not subjected to such logging practices. Winter freshets may thus remove debris cover and erode banks more readily in such logged areas than in unlogged locations.

Because banks and debris cover provide overwintering habitats important to juvenile coho (Bustard and Narver 1975a), and because some logging practices may eliminate or alter this cover (Toews and Moore 1982), logging can potentially reduce populations of stream-dwelling coho in winter. Therefore, one major objective of this research was to describe the numbers and distribution of coho juveniles overwintering in selected sections of a British Columbia coastal stream in relation to (1) the distribution of freshets, and (2) different logging practices applied in each stream section.

Bustard and Narver (1975a) demonstrated that large numbers of juvenile coho salmon leave the main stream in autumn to enter side channels, sloughs, and tributaries to overwinter. The same coho then reenter the main stream in spring. Bustard and Narver (1975a) reported that coho that moved into these sheltered habitats in autumn survived the winter at twice the rate as those which remained in the main stream. The second objective of this paper was to compare the numbers of coho entering sloughs and tributaries in autumn with numbers reentering the main stream in spring for several years both before and during logging.

Study Area

Carnation Creek is a small stream, about 7.8 km long, flowing into Barkley Sound on the west coast of Vancouver Island. The stream drains an area ~10 km^2 in the "Coastal Western Hemlock Biogeoclimatic Zone" of British Columbia (Hartman et al. 1982). Annual precipitation varies from 250 to 380 cm, most of which falls between early September and late March. Discharge volumes fluctuate rapidly and widely during winter from about 0.2 m^3/s up to 46 m^3/s during frequent winter freshets. The area, stream, and fish populations are described by Hartman et al. (1982).

Two areas in the Carnation Creek valley inhabited by many coho fry ["age 0" fish, Bustard and Narver (1975a, b)] and yearlings ["age 1+" fish, Bustard and Narver (1975a, b)] are a slough (called "750-m site") located 750 m upstream from the mean summer high-tide mark, and a low-velocity tributary at 1600 m (called 1600 Tributary). These sites are as described by Bustard and Narver (1975a) except that clear-cut logging has since removed all trees from both areas and left

TABLE 1. Data for the Carnation Creek study sections used to enumerate overwintering coho. Two values for area and volume (plus seasonal mean values in parentheses) are given for "cover" in section VI due to the midwinter addition of new cover when a large root mass fell into the stream.

		Cover available for coho		Logging method used	
Study section	Length (m)	Area (m^2)	Debris vol (m^3)	Streamside strip of trees (% of bank covered)	Log hauling across the stream
B (at "B-weir")	38	26.0	46.0	100	None
III	62	41.0	37.0	80	None
VI	77	5.0–8.0 (6.5)	2.5–5.0 (3.8)	0	Yes (limited)
VIa	8	2.5	3.0	0	None
VII	27	2.0	2.0	0	None

debris in 1600 Tributary. The 750-m site consists of seasonally flooded channels (usually filled with water during autumn, winter, and spring) that meander through areas thick with rooted vegetation (sedges and grasses). Both sites also contain small shrubs that provide cover over the flooded channels (see Bustard and Narver 1975a).

Materials and Methods

ENUMERATION OF POPULATIONS OVERWINTERING IN CARNATION CREEK

Visual counts of coho fry and yearlings overwintering in five selected sections in the Carnation Creek main channel were made from October 3, 1980 to March 20, 1981. The lengths of the study sections, the amount of cover available to overwintering coho, and the logging practices conducted at each site are summarized in Table 1. Cover was defined to comprise (a) the area of bank that overhung the stream, in addition to (b) the area of woody debris that occurred in the stream. Both types of cover were measured in the field using 30-m tapes. The total volume of this cover was determined by measuring the lengths, widths, and depths of such habitat that would be available to coho juveniles during periods of high discharge volumes (i.e. $\geq 10\ m^3/s$).

Counts were made in stream sections that represented two different methods of logging. Section III and the site ~25 m upstream from the "B" hydrographic weir (Section B) were at least partly "forested." Logging was conducted along both sides of the stream in these sections but streamside strips of trees were left in both areas. These strips, which varied from 5 to 40 m wide, consisted of trees that either could not be felled away from the stream or could not be hauled up over the crests of steep cliffs that bordered the stream valley. No logging-related activity occurred within the stream channel, and all large, woody debris in the stream was left undisturbed. Section B contained shallow pools overhung by grassy banks at its lower end. The upstream portion was comprised entirely of a large pool with deeply undercut banks, large tree roots, and much debris in the form of jammed logs. The pool was 3 m deep in its center. Section III contained a long riffle about 20 m in length. This section had deep pools with fallen logs and tree roots at its upstream end.

Three sections, VI, VIa, and VII, were located in a large clear-cut area where all trees had been removed up to the stream banks. No overhead cover from vegetation was present. These sections were located in a part of the stream valley where logging practices included: (a) falling all trees up to the stream bank, (b) hauling some felled trees across or out of the stream, (c) dragging out from the stream commercially valuable trees that had fallen into it before logging, and (d) killing non-commercial tree species (especially red alder, *Alnus rubra*) by girdling bark from the trunks and by applying herbicide. This type of logging resulted in changes in the morphology of the stream channel. Section VI was essentially a straight channel (77 m long) which contained rapidly flowing water when the discharge volume was $>0.5\ m^3/s$. This section contained little shelter in the form of pools or cover provided by undercut banks. Two small (often isolated) pools along the south side of the stream always contained coho juveniles. These pools contained tree roots and debris. In contrast to these sites, sections VIa (immediately upstream from VI) and VII contained large debris and large root masses located in deep pools. The pools in section VIa also contained deeply undercut banks in which fish could take refuge.

Ten visual counts of resident fry and yearlings were made in each section during the course of the study. Observations were made by snorkeling in the stream, and a handheld flashlight aided in locating fish residing under banks and in other poorly lit areas. Data were recorded by a field assistant, and all sections were enumerated on the same day. All counts were made between freshet periods when the discharge volumes ranged from 0.12 to 1.10 m^3/s. Four counts were made immediately after a major freshet to observe any resulting changes in population numbers.

Visual counts were confirmed by estimates made of the sizes of the coho populations. The Seber-LeCren (1967) removal method was used to calculate population sizes, and fish in Carnation Creek were sampled using electrofishing and pole-seine equipment. Comparison of results from visual counts with those from population estimates indicated that thorough visual enumeration using flashlights produced data that agreed with those of the alternate method. Population estimates were made in sections III and VI on September 16–17, 1980 and again on October 9, 1980. "Fry" (fish <1 yr old) and yearlings were distinguished visually. All fish ≥ 75 mm long were considered to be yearlings. Water velocity measurements were taken in March with a Gurley "Pygmy" current meter in areas where fish had overwintered.

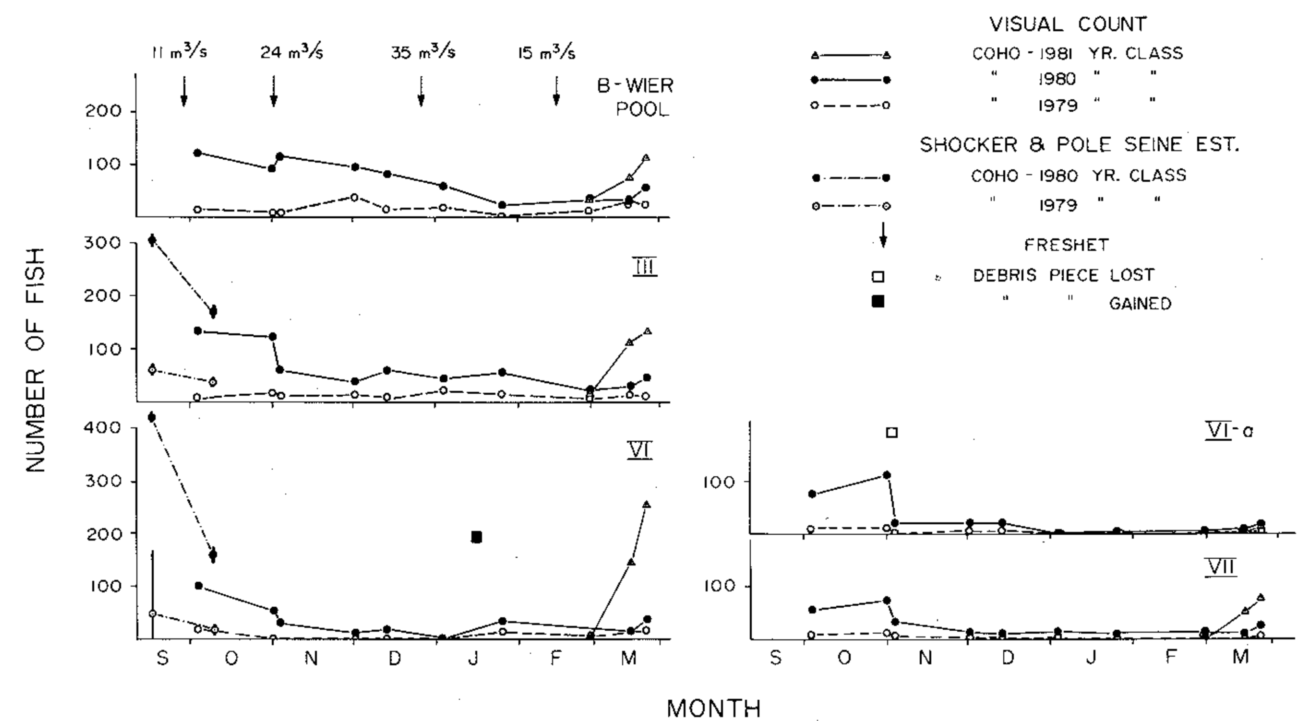

FIG. 1. Numbers of juvenile coho (1979, 1980 year-classes) overwintering in five selected sections of Carnation Creek during the autumn–winter of 1980–81. In late winter, all sections included some new coho fry (1981 year-class). Coho population sizes estimated by the Seber-LeCren (1967) removal method (sections III and VI, Sept. and Oct.) are given with 95% confidence limits (vertical lines). Arrows indicate freshet maxima.

ENUMERATION OF COHO OVERWINTERING IN SLOUGH AND TRIBUTARY HABITATS

Screen weirs, as described by Bustard and Narver (1975a), containing both "upstream" and "downstream" traps were constructed at the confluences of two side-channel sites with Carnation Creek. The traps at the 750-m site were checked from September to June each year from 1972 to 1981 except for March–June 1979 and January–June 1980, when no traps were operated. Traps at 1600 Tributary were operated only in 1972–73, 1973–74, and 1980–81. Observations were made daily except when flood conditions made observations impossible or when periods of drought occurred and the traps were thus dry. In several instances, trapping was suspended for a number of days when the weirs and traps needed repair.

The daily numbers of coho fry and yearlings entering the 750-m site and 1600 Tributary from Carnation Creek, and those leaving these areas, were recorded for each observation. Fish were removed from the traps and then anesthetized in a 1:4000 aqueous solution of 2-phenoxyethanol. Fork length of each fish was measured (from the tip of the snout to the tail fork), and scale samples were occasionally collected from fish >65 mm long to confirm the age of larger individuals. Simultaneously, water depths at each weir were read directly from staff gauges, and water temperatures in both sites and in Carnation Creek were taken with simple mercury thermometers.

Results and Discussion

MICROHABITATS OF COHO JUVENILES OVERWINTERING IN THE MAIN CHANNEL OF CARNATION CREEK

Observations made while enumerating coho revealed that microhabitats selected by coho fry and yearlings in winter were unchanged from those described qualitatively before logging by Bustard and Narver (1975a, b). Areas jammed with logs, undercut banks, and deep pools filled with upturned tree roots and other forest debris contained almost all the coho salmon that remained in the main channel of Carnation Creek during the winter. During winter (Nov.–Feb.) no coho were observed in midstream locations in any section, and coho did not inhabit areas under banks unless these sites contained tree roots and (or) lodged debris.

Consistent with the observations of Bustard and Narver (1975a) yearlings were often found deeper under banks than were fry. The former also occupied the deepest parts of pools (e.g. water depths ≥ 45 cm) more frequently than the younger coho.

All microhabitats occupied by fry and yearlings were characterized by low water velocities. Water velocity measurements taken at sites inhabited by coho juveniles revealed that all fish were found in water velocities <0.3 m/s. These largely qualitative findings are consistent with those reported in detail by Bustard and Narver (1975a, b).

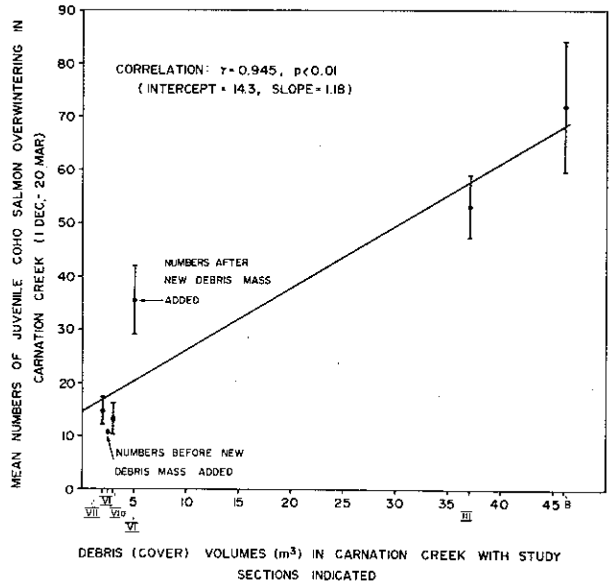

FIG. 2. Relationship between debris (cover) volumes and mean numbers of coho overwintering in five selected sections of Carnation Creek. Each mean (except those for section VI) represents seven individual enumerations from December 1 to March 20 when population numbers were relatively stable. Two means are given for section VI. One represents fish numbers before the addition of new cover in the form of a large root mass (Dec. 1–Jan. 3). This value results from only three enumerations and thus contains no ± standard error bars. The second value represents fish numbers after the root mass fell into the stream section.

Seasonal Reductions in the Numbers of Coho Inhabiting the Main Channel

Coho population numbers in Carnation Creek are reduced substantially in winter compared with numbers inhabiting the same mainstream areas in summer (Fig. 1). Population estimates in sections III and VI revealed that most of this seasonal reduction occurs early in autumn (late Sept. and Oct.), coincident with the onset of freshets and low water temperatures (Fig. 1). For example, numbers of fry after the 11 m^3/s freshet of September 28 were reduced by about 63% in section VI and 45% in section III. Similarly, numbers of yearlings in the same sections were reduced, respectively, by 74 and 40%. Losses of fish in the clear-cut section VI, which contained little cover volume (Table 1), were much higher than in the partly forested section III, which contained high cover volume (Table 1).

Four major freshets occurred during the season studied. The first one (Sept. 28) was the least in magnitude but resulted in the largest declines in coho numbers in the two sections enumerated (Fig. 1, sections III and VI). Extreme discharge volumes such as those which occurred later in the season (Fig. 1) are thus not required to produce large numerical changes in the stream population early in the season. Subsequent freshets removed successively lower absolute numbers of fish from most study sections (Fig. 1); however, large declines in coho numbers continued to occur during the second seasonal freshet on November 1 (24 m^3/s). For example, the loss of most of one large root mass during the latter storm coincided with a decline in coho numbers from 122 to 23 in section VIa. Following the freshet of November 1, visual counts showed that coho populations in all sections fluctuated at low numbers (Fig. 1).

Relation Between Coho Numbers and Habitat Structure in Mainstream Sections

Sections containing winter habitat in the form of deep pools and undercut banks, both in association with tree roots and debris, lost fewer fish during freshets and maintained higher numbers of coho than sections without these features. For example, between the census of October 3, 1980, and the third (and most severe) seasonal freshet on December 26, 1980, coho juveniles were almost eliminated from two clear-cut sections of stream. No coho fry were observed in section VI. This section of shallow, relatively swift water contained almost no shelter of the form described above. Coho numbers in the adjacent section VIa (immediately upstream) were similarly reduced to one yearling. The freshet that occurred on December 26 eroded large areas of bank and caused its collapse in this section. Although section VII also occurred in the clear-cut zone of Carnation Creek, about 27% of the fry numbers and 29% of the yearlings counted on October 3 remained over the same time period. A stable debris mass located in a deep pool provided shelter for overwintering juveniles.

Sections III and B contained all of the features described above that gave shelter to overwintering coho. These sections contained streamside strips of trees, and most of the banks within these areas were stable. In addition, both sites contained stable debris in the form of submerged logs. Forty-eight and 32% of the fry numbers observed on October 3 in sections III and B, respectively, remained there on January 3, 1981.

Stream sections containing stable habitat and deep pools might have provided a refuge for fish displaced downstream from areas (e.g. section VI) where adequate habitat and cover were lacking. For example, section III contained over 4 times more yearlings on January 3 than were observed on October 3. Both sections III and B contained substantially more yearlings during winter than did any clear-cut section. Between-section movements of fish were also important in reestablishing at least low numbers of coho in sections VI and VIa by mid-to-late winter. Fish had virtually disappeared from both areas earlier in the season. The addition of a new root mass into section VI after a bank had collapsed coincided with an increase in population numbers, which stabilized at low levels from mid-January to late winter (Fig. 1).

During "mid-winter" (Dec. 1–March 20) when populations were relatively stable, the numbers of coho in each section were positively and linearly correlated ($r = 0.945$, $P < 0.01$) to the volume of debris present (Fig. 2). This relationship is based on limited data (only five study sections with numbers of fish in each section derived from seven enumerations); however, the data suggest that further investigation be undertaken. Future investigations must include a complete range of cover volumes in different study areas to establish a more detailed and precise relationship. Coho numbers were also correlated significantly to area of bank and debris cover ($r = 0.811$ and $P < 0.05$); however, the lower correlation coefficient for cover area demonstrates that much

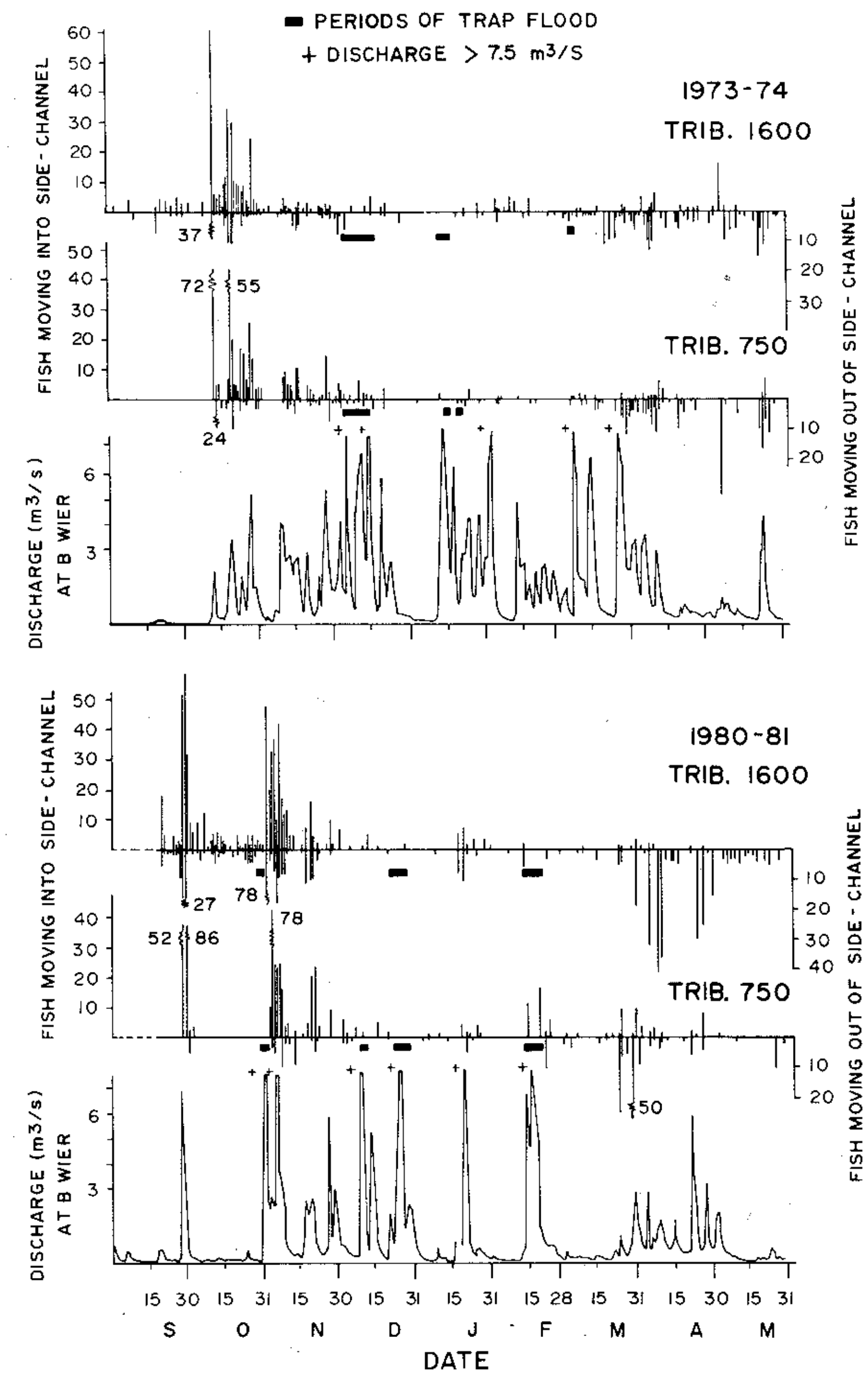

FIG. 3. Daily movements of coho juveniles (all ages combined) before logging (1973–74, top) and after logging (1980–81, bottom) between Carnation Creek and the overwintering sites at the 750-m slough and 1600 Tributary. Stream discharge volumes are also plotted (m^3/s). Traps could not always be checked during periods of heavy flooding. The symbol "+" is given when discharge volumes exceeded 7.5 m^3/s. Heavy solid bars indicate periods when traps were completely under water and thus not functioning properly.

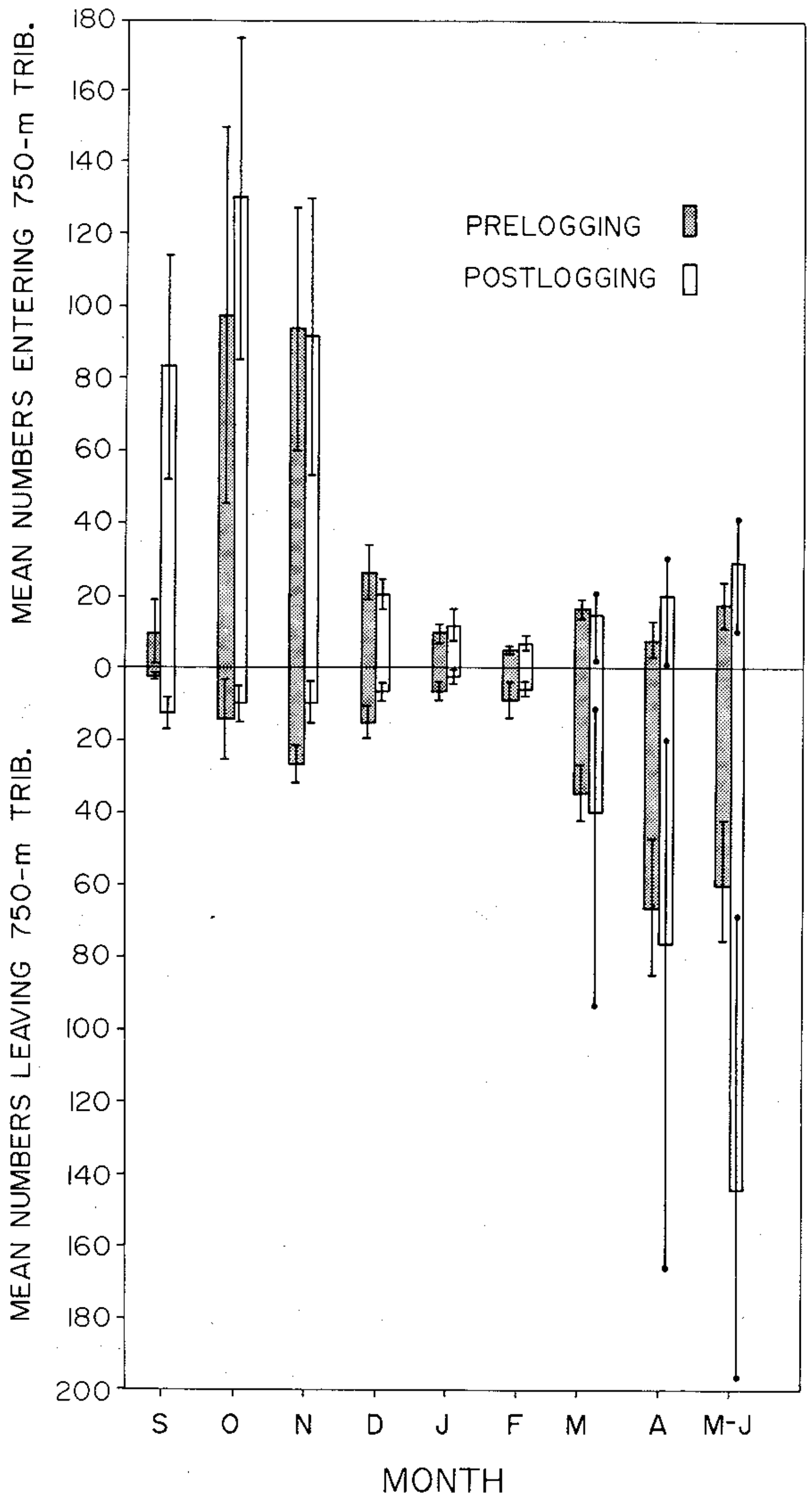

FIG. 4. Numbers of coho juveniles (all ages combined) entering and leaving the overwintering area at the 750-m site. Histograms depict mean movements into and out from the 750-m slough. Shaded histograms represent prelogging years (1972–75). Clear histograms represent postlogging years (1976–81). For September to December, means (with ± standard error) represent 4-yr prelogging and usually 5 yr when logging occurred. For January and February after logging, mean values (with ± standard error) represent only 4 yr of data because traps were not operated in 1979–80. For March, April, and May–June after logging, mean values represent only 3 yr because traps were not operated in 1978–79 and in 1979–80. The latter mean values are bounded by ranges.

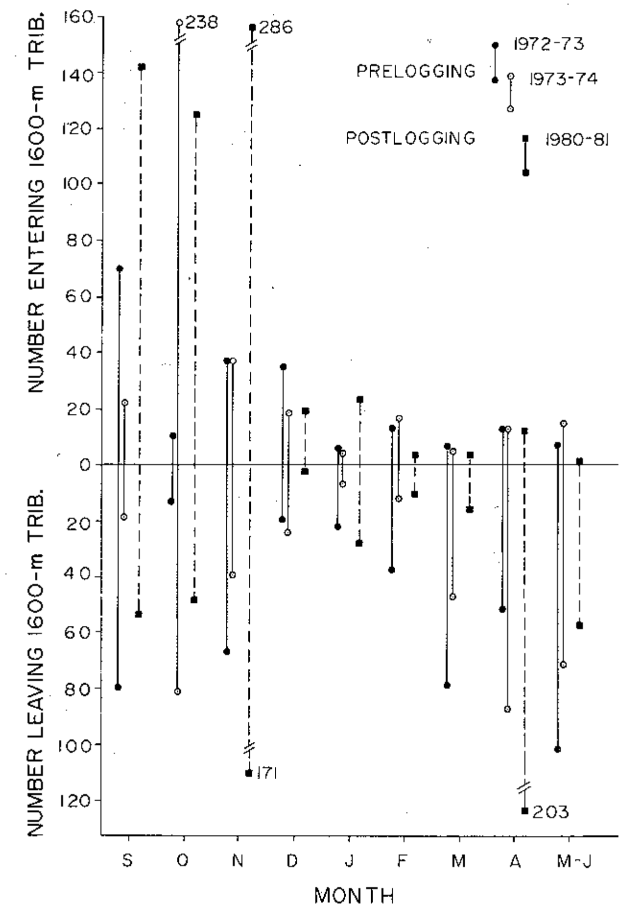

FIG. 5. Numbers of coho juveniles (all ages combined) overwintering in 1600 Tributary. Years before logging (1972–73, 1973–74) are represented by solid bars. A broken line represents 1980–81. Data are given as discrete annual values.

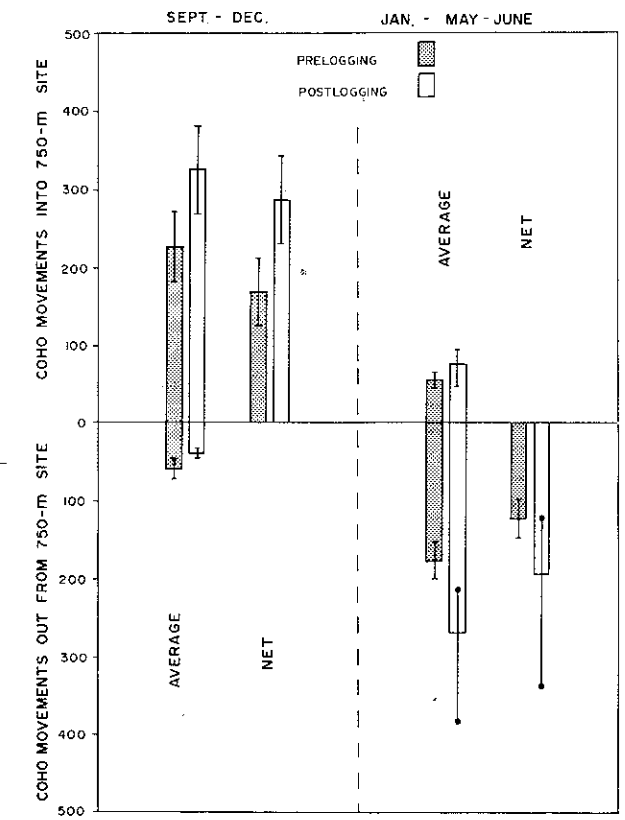

FIG. 6. Seasonal average and net mean movements of coho juveniles (all ages combined) into and out from the 750-m site. Shaded histograms represent prelogging years (1972–75). Clear histograms represent postlogging years (1976–81). Values are bounded by ± standard error bars except for January–May–June after logging. The latter means are bounded by their ranges because only 3 yr of complete seasonal data are available.

more of the variance in coho numbers and distribution is accounted for by cover volume than by cover area.

Immigration of Overwintering Coho into Valley Sloughs and Tributaries

Three factors could account for the large reductions in coho numbers from the study sections in autumn: (1) mortality due to physical injury caused by freshets, (2) displacement of fish to locations downstream, and (3) immigration into valley sloughs and tributaries. The large reductions in the mainstream population in autumn coincided with the largest movements of fry and yearlings into the side-channel slough at 750 m and into 1600 Tributary (Fig. 3). Coho that left the main stream to overwinter in these sheltered habitats thus accounted partly for the low numbers inhabiting Carnation Creek during winter. However, the proportion of the total population that entered these areas is unknown because (a) not all sloughs and tributaries were studied, and (b) actual fish movements from one mainstream site to another could not be determined because fish were not marked for individual identification.

A general pattern exists in the seasonal movements of coho juveniles between Carnation Creek and its tributaries at 750 m and 1600 m: fish entered the tributaries in autumn and left them to reenter Carnation Creek in spring (Fig. 3). The largest movements of fish were generally coincident with peaks in discharge volumes in both spring and autumn

(Fig. 3). No qualitative differences in the patterns of fish movements were detectable between the prelogging year of 1973–74 and the last year of logging (1980–81). The large daily movements into these side-channel sites in autumn occurred with the onset of the first seasonal freshets. These early peaks in stream discharge were usually much lower than those that occurred in midwinter. This phenomenon indicates that the autumn increase in discharge volumes may be a seasonal cue for coho to seek shelter before the extreme discharge volumes occur later in the year. Daily movements from December to February were generally low. From February to May, large movements out from the side-channel sites occurred (see monthly and seasonal data, Fig. 4, 5, and 6).

Large numbers of coho moved into the 750-m site from September to December during both prelogging and postlogging years (Fig. 4). Movements were bidirectional but far fewer fish reentered the main stream of Carnation Creek in this season. Large net movements of fish into the 750-m site occurred during autumn–early winter (Fig. 6).

In January and February, low numbers of fish moved in either direction between Carnation Creek and the slough at 750 m. Coho juveniles are relatively inactive in midwinter (Bustard and Narver 1975a; Hartman 1965). From late winter to spring, the net movements were reversed from those shown in autumn (Fig. 6). Overwintering coho left the 750-m site in large numbers and reentered Carnation Creek (Fig. 4 and 6). These seasonal shifts in distribution, first reported by Bustard and Narver (1975a) for early prelogging years, remained unchanged 5 yr after the first logging operations began in 1976.

When prelogging (1972–75) and postlogging (1976–81) periods are compared on a monthly basis from September to December, no clear differences in fish movements into the 750-m site are distinguishable except for September (Fig. 4). Large increases in coho movements into the site occurred after logging in that month (Fig. 4). This apparent increase may be due in part to sampling errors. Prelogging data were not collected for September in 1972 and 1974, and are incomplete for September 1973. Sampling problems notwithstanding, high between-year variation in the numbers of fish entering the 750-m site occurred for all months and thus renders prelogging and postlogging (including during logging) mean movements to be statistically the same (by analysis of variance) for October, November, and December (see ± standard errors, Fig. 4).

When monthly movements are combined to compare seasonal (autumn–early winter) net movements for prelogging and logging periods, new trends are shown (Fig. 6). The absolute numbers entering and leaving the 750-m site are statistically equal for both periods; however, a trend toward higher net movement of coho into the overwintering site occurred after logging began in 1976 (Fig. 6). However, this increase is not statistically significant ($P > 0.05$, by analysis of variance).

Similar relationships are shown for the January–June monthly and seasonal movements. Because traps were not operated in 1978–79 and in 1979–80, only 3 yr of data are available for March, April, and May–June after logging (Fig. 4). Prelogging and postlogging periods thus cannot be treated statistically for the latter months. However, monthly averages for movements both into the 750-m site and out from it were virtually the same except for May–June. Despite high between-year variation, a trend toward higher numbers of coho leaving the 750-m site after logging occurred for March and April and became more pronounced in May–June (Fig. 4). This trend resulted in higher seasonal (January–June) net movements of coho out of the 750-m site after logging began (Fig. 6). Although statistical comparisons (by analysis of variance) are not possible for this season, it is clear that logging has neither reduced the numbers of coho fry and yearlings that enter the 750-m slough in September–December to overwinter, nor reduced the numbers leaving the site to reenter Carnation Creek from January to June. In contrast, trends toward higher numbers of fish using the overwintering site are suggested.

An annual mean of about 169 ± 44 coho entered the 750-m site from September to December to overwinter before logging occurred in Carnation Creek. On the average, 122 ± 15 coho reentered Carnation Creek from January to June during the same period of time. If these net seasonal movements can be taken as a rough measure of overwinter "survival," then these values indicate a survival rate of 72.2% for coho using the site during prelogging years. From 1976 to 1981, annual numbers of coho entering the same site in "autumn" and then leaving in the "spring" were about 288 and 194, respectively. The survivorship rate for the postlogging period was 67.4%; little changed from the prelogging value. Although logging had removed the forest cover at the 750-m site, it appears that the quality of the coho overwintering habitat was not altered to the degree that overwinter survival of the fish was affected adversely.

The monthly and seasonal patterns of coho movements shown by the data for the tributary slough at 750 m are repeated at 1600 Tributary (Fig. 5). Only 3 yr of data are available for coho movements in 1600 Tributary (2 yr prelogging and 1 yr postlogging); however, these data are presented to illustrate that coho juveniles used similarly two different types of tributaries to overwinter. In contrast to 750 Tributary, which is frequently dry during spring and summer, 1600 Tributary is a more stable stream and has higher discharge volumes. No between-year differences can be distinguished in coho movements in 1600 Tributary (Fig. 5); therefore, no obvious logging-induced changes have occurred in the numbers of juvenile coho overwintering in the latter site (Fig. 5).

The seasonal movements of young coho described in this paper are consistent with those shown by Peterson (1980). He observed that many coho were displaced downstream during freshets in autumn. Some of these fish were able to enter tributaries, sloughs, and side channels to overwinter. These fish returned to the main stream in spring, during (or before) the period when stream-dwelling coho transform into seagoing smolts. Peterson (1980) documented that the downstream movement of coho in autumn can occur over long distances (hundreds of metres). The coho he studied overwintered in large, spring-fed ponds.

Implications Concerning Logging and Coho Salmon Habitat

This work and that of others (Bustard and Narver 1975a, b; Peterson 1980) show clearly that valley tributaries and sloughs are essential for the winter survival of many young coho salmon. Conservation of these features is essential in habitat management efforts. These habitats should also be protected by forest-harvest planners and road-construction engineers. Forest-harvest planners and fisheries-protection specialists should also ensure that large, stable, debris masses (e.g. logs, tree roots), which occur normally in such streams as Carnation Creek, remain both during and after logging. Leaving a streamside buffer strip of trees after logging is important in the continued production of such debris. Streamside trees and other vegetation maintain the prelogging rate of bank erosion and reduce the potential for bank collapse.

Before logging, small numbers of adult coho and cutthroat trout (*Salmo clarki*) reproduced in 1600 Tributary. After logging, the channel became unsuitable for spawning because it had been filled with sediment and small debris (e.g. wood chips, tree bark). Given that adult fish spawn in such tributaries and that juveniles find refuge in them, forest-industry managers must ensure that they do not become obstructed by roads or blocked by undesirable materials.

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