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# Impacts of Forestry Practices on a Coastal Stream Ecosystem, Carnation Creek, British Columbia

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## Abstract

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Results from the first 17 yr of a multi-disciplinary study about the effects of logging activities on a small stream ecosystem in the coastal rainforest of British Columbia have been reviewed. The main hydrological, fluvial-geomorphological, thermal, and production relationships are integrated in four schematic illustrations. The study has revealed that each activity conducted within an overall forest management plan may affect the physical components of an ecosystem differently. Whether these effects had positive or negative impacts on fish and other stream biota depends upon the specific activity conducted, the species present, and the life stage of each species of fish.

In Carnation Creek forest practices that increased stream insolation, water temperature and nutrient levels increased the numbers, growth period and size of coho salmon fry (*Oncorhynchus kisutch*), but reduced the marine survival of chum fry (*O. keta*). They also increased the growth period and growth rate of trout fry (*O. mykiss* and *O. clarki*), but growth decreased among the older age groups of both coho salmon and trout. The positive effects of these changes were simultaneous with the commencement of logging and burning of slash.

Stream-side logging activities also decreased the stability of the stream channel and its large organic debris. These changes and changes in the composition of spawning gravel reduced fish survival and numbers. The negative effects required more time to manifest themselves than the positive effects. Influences of the negative and positive freshwater impacts continued into the marine life history stages of both chum and coho salmon.

Applications of results to land use planning are also discussed. Logging-related changes in a drainage can occur over decades of time. Although coastal streams in British Columbia are diverse, the common features that must be considered in fisheries-forestry planning are high rainfall, high hydrological energy, physical instability, low nutrient levels and cool temperatures. Long-term case history studies such as the one reported here reveal ecosystem processes permitting researchers to partition climatic variability from man induced impacts. Resource managers must be able to understand and apply such process information to other stream systems in the light of their own experience and site specific information.

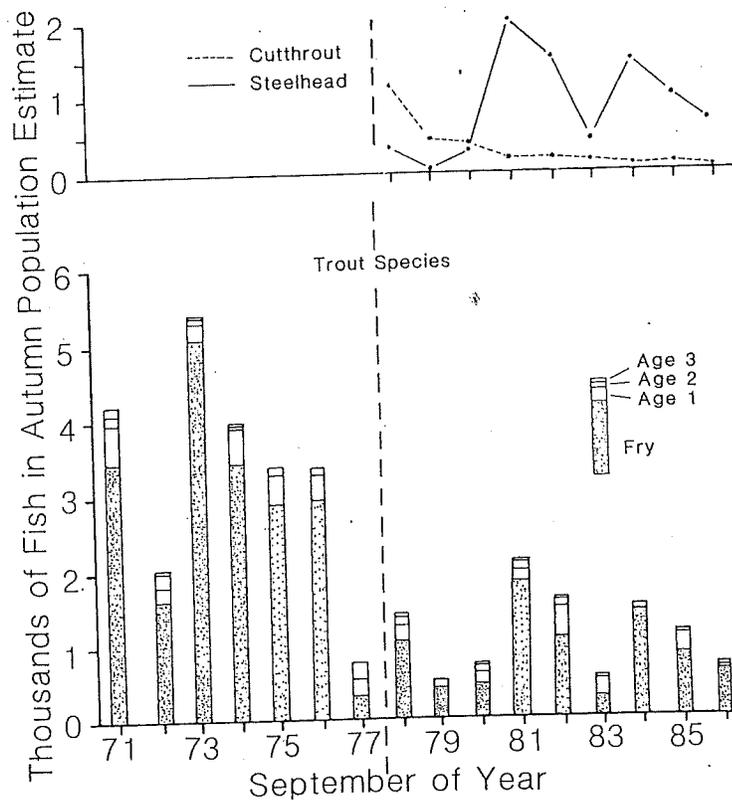


FIG. 67. Numbers of trout in the lower 3.1 km of Carnation Creek during autumn from 1971 to 1986. Numbers of cutthroat and steelhead trout were combined until 1978 and separated thereafter.

#### *Survival of coho during summer*

Multiple regression models were used to determine the relative influences of stream flow, fish density, stream temperature, and streambank vegetation on the survival of juvenile coho during the summer. The proportion of stream bank vegetated, July density of coho fry, number of 5-d periods when minimum daily stream flow exceeded  $2.8 \text{ m}^3 \cdot \text{s}^{-1}$ , and maximum temperature on the date of minimum annual flow accounted for 95 % ( $R^2$ ) of the summer loss rates of age 0+ coho (Holtby and Hartman 1982). Streambank vegetation accounted for 39.8 %, density accounted for 23.6 %, flows exceeding  $2.8 \text{ m}^3 \cdot \text{s}^{-1}$  accounted for 16.3 %, and maximum temperature accounted for 15.1 % of the variation. Stream-side logging affected vegetation cover, fish density (Fig. 62 ; Table 11), and stream temperatures (Fig. 27).

Loss rates of age 1+ coho in summer were affected most by stream discharge, at B-weir. The number of days when minimum daily flow exceeded  $2.8 \text{ m}^3 \cdot \text{s}^{-1}$  accounted for 44.1 % of the variation in numbers during September ; and the proportion of time that stream flow was less than  $0.028 \text{ m}^3 \cdot \text{s}^{-1}$  accounted for a further 12 % of the variation (Holtby and Hartman 1982).

#### *Coho and trout sizes and growth*

The size of coho salmon and trout in the autumn was greater following logging. Comparisons between years were possible after mean fork lengths (FL) of coho salmon

and trout were adjusted to a uniform date, September 30, by using the average daily size increments (growth rate) between July and September. The FL of age 0+ coho were significantly greater following logging (1977-86) than before logging (1970-76; Mann-Whitney *U*-test,  $P < 0.001$ ), despite their smaller size during 1978 and 1980 (Fig. 68). Age 0+ trout in the lower 3.1 km of the main channel were also larger following logging (Mann-Whitney,  $P < 0.001$ ), despite their smaller size during 1985 (Fig. 69). The older age-groups of both coho (Fig. 68) and trout (Fig. 69) were also larger in size following logging, but most of the 11 mm increase for coho and 18 mm increase for trout had been attained by the end of their first summer.

The size of age 0+ coho in autumn was dependent upon the length of the spring/summer growth period and the rate of growth. Regression models indicated the relative importance of various physical and biological influences on these two factors (Holtby and Hartman 1982; Holtby 1988). The duration of the period of summer growth, which was extended by earlier emergence of fry, had the greatest positive effect on fry FL and weight in the autumn. Day-of-the-year when 50 % of the fry had emerged was strongly correlated with their size in autumn ( $r = -0.96$ ,  $n = 16$ ,  $P < .001$ ). Day-of-the-year of 50 % emergence was also correlated with stream temperature during egg incubation, e.g., thermal summation of daily means of stream temperature (Hartman et al. 1984; Scrivener and Andersen 1984). Warmer winters led to earlier emergence and a longer growing season. The growth rate of coho fry was negatively density dependent (FL,  $r = -0.56$ ,  $n = 16$ ,  $P < 0.05$ ; weight,  $r = -0.83$ ,  $n = 16$ ,  $P < 0.001$ ; Holtby 1988) for the whole stream, and for each study section (Scrivener and Andersen 1984). The number of days with stream flow  $< 0.028 \text{ m}^3 \cdot \text{s}^{-1}$  also affected growth of coho fry, i.e., the greater the duration of low summer flow periods the smaller the growth rate (Holtby and Hartman 1982). Finally, stream temperature during the summer, thermal summation of mean daily temperatures at B-weir, was positively correlated with fry FL and weight in the autumn (Holtby 1988). All of these factors were affected by clearcut logging.

An apparent discrepancy appeared when the mean FL of age 1+ coho in autumn was greater following logging (Fig. 68), but the growth rates were smaller during the second summer for age 1+ coho (Holtby and Hartman 1982). The apparent discrepancy was

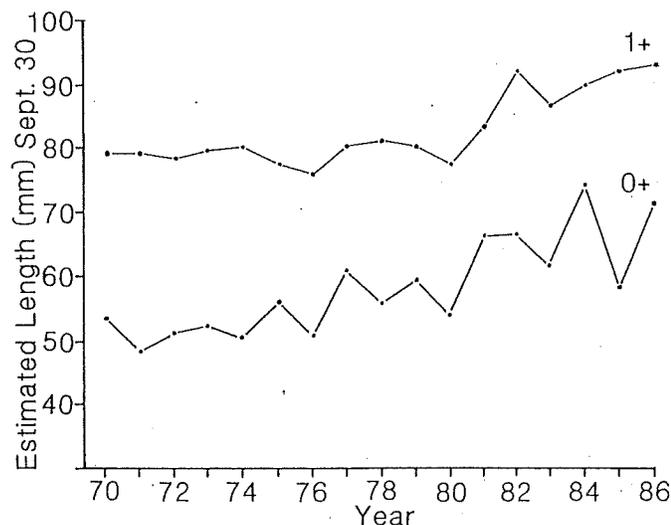


FIG. 68. Mean length (FL) of age 0+ and 1+ coho salmon on September 30 from 1970 to 1986.

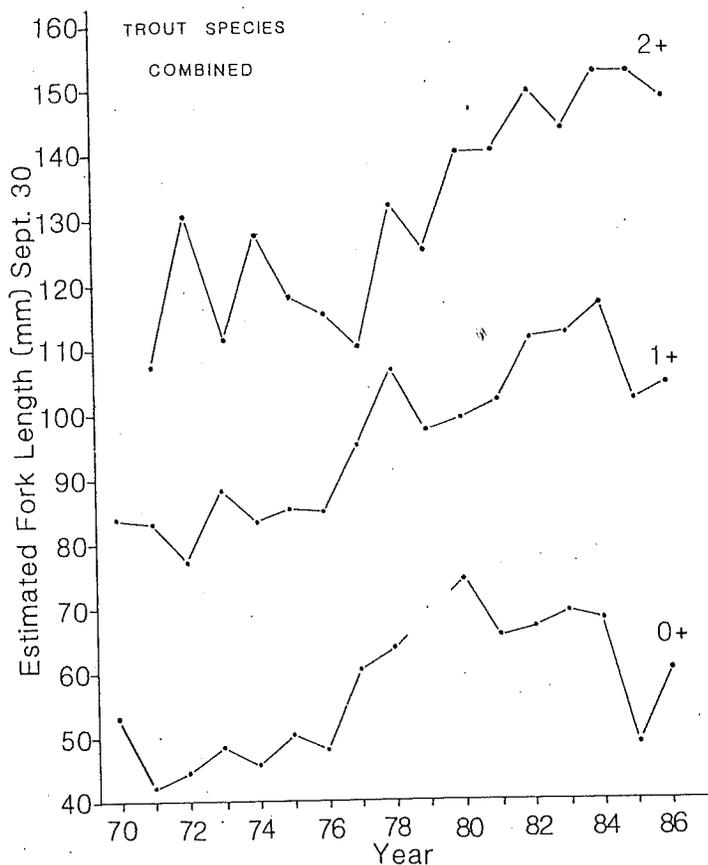


FIG. 69. Estimated mean lengths on September 30, of age 0+, 1+ and 2+ trout in the main stream (data for steelhead and cutthroat trout combined) from 1970 to 1986. No steelhead fry were caught during September 1979.

clarified when five results were evaluated :

1. Size (FL) of age 1+ coho salmon in autumn depended upon their size during the previous autumn at age 0+ ( $r = 0.65$ ,  $n = 17$ ,  $P < 0.01$ ).
2. Size and growth rate of age 1+ coho were independent of the density of age 0+ or 1+ coho during the summer, unlike the situation with age 0+ coho (Holtby 1988).
3. The growth rate of age 1+ coho was negatively correlated with thermal summation during summer in contrast with age 0+ coho (Holtby 1988).
4. The growth rate of age 1+ coho during the summer was positively correlated with the proportion of stream side that was vegetated. This was not the case with age 0+ coho (Holtby and Hartman 1982).
5. The growth rate of age 1+ coho during the summer was negatively correlated with the duration of stream flows  $< 0.028 \text{ m}^3 \cdot \text{s}^{-1}$ , as was the case with age 0+ coho.

We speculate that food supply was reduced following logging when stream-side vegetation was removed (reduced - leaf litter, Fig. 53, and terrestrial food) and when low flows prevented transport of food from riffles to coho in the pools. Stream temperatures were also higher and the food required for growth and maintenance was greater than during the prelogging period. A multiple regression model indicated that the proportion

of the stream bank that was vegetated explained 46 % of the reduction of summer growth rate for age 1+ coho, while the duration of low stream flow (no. of  $<0.028 \text{ m}^3 \cdot \text{s}^{-1}$  days) explained another 19 % of the reduction (Holtby and Hartman 1982).

Increasing stream temperature and decreasing trout density in the lower 3.1 km of Carnation Creek caused trout size to increase following logging (Fig. 69). As with coho fry, the size of age 0+ trout in autumn was dependent upon stream temperature during the incubation period (spring ; Table 14) and density of trout during the summer (Fig. 70).

TABLE 14. Mean size (FL) of age 0+, 1+, and 2+ trout (steelhead and cutthroat) on September 30 regressed against thermal history at B-weir (thermal summation of mean daily stream temperatures) and against trout numbers during July in the lower 3.1 km of Carnation Creek. Periods of summed stream temperature included the egg incubation or spring growth periods (Mar. 1 - May 31), the summer growth period (June 1 - Sept. 30) and the total thermal history (TTH) for age 0+ (Mar. 1 - Sept. 30), for age 1+ (Mar. 1 - Sept. 30 yr + 1), and for age 2+ (Mar. 1 - Sept. 30 yr + 2).

| Thermal history      | No. of years | r     | P      | Equation                                   |
|----------------------|--------------|-------|--------|--|
| <b>Age 0+</b>        |              |       |        |  |
| Mar.-May             | 16           | 0.88  | <0.001 | FL = 0.072*(°C) + 11.89                    |
| June-Sept.           | 16           | 0.74  | <0.001 | FL = 0.042*(°C) - 3.30                     |
| TTH                  | 16           | 0.82  | <0.001 | FL = 0.028*(°C) - 2.74                     |
| <b>Age 1+</b>        |              |       |        |  |
| Mar.-May             | 17           | 0.85  | <0.001 | FL = 0.081*(°C) + 45.21                    |
| June-Sept.           | 17           | 0.85  | <0.001 | FL = 0.056*(°C) + 14.09                    |
| TTH                  | 16           | 0.88  | <0.001 | FL = 0.016*(°C) + 17.54                    |
| <b>Age 2+</b>        |              |       |        |  |
| Mar.-May             | 17           | 0.60  | 0.01   | FL = 0.069*(°C) + 89.37                    |
| June-Sept.           | 17           | 0.75  | <0.001 | FL = 0.066*(°C) + 33.60                    |
| TTH                  | 15           | 0.84  | <0.001 | FL = 0.011*(°C) + 39.07                    |
| <b>Trout numbers</b> |              |       |        |  |
| Age 0+               | 16           | -0.86 | <0.001 | FL = -19.59Log <sub>10</sub> (No.) + 123.0 |
| Age 1+               | 17           | -0.66 | 0.004  | FL = -18.62Log <sub>10</sub> (No.) + 158.2 |
| Age 2+               | 17           | 0.38  | 0.12   |  |

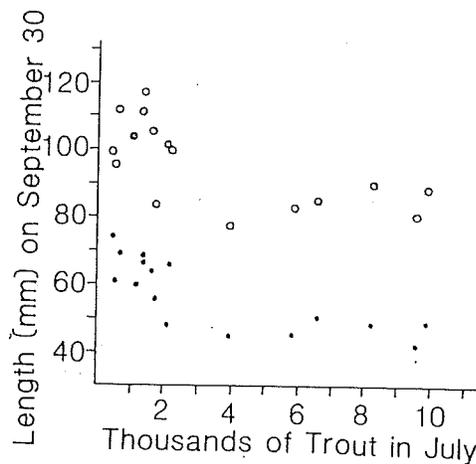


FIG. 70. Relationships between mean lengths (FL) of age 0+ (dots) and 1+ (circles) trout on September 30 (1971-87) and density during July. A population estimate was not obtained in the stream during July 1986.