Introduction

The effects of forestry practices on watershed processes and fish populations have been studied for 35 years at Carnation Creek. This intensive, single-watershed case study has generated the longest series of continuous data on fish-forestry interactions anywhere. The study was initiated in 1970 by Fisheries and Oceans Canada in cooperation with MacMillan Bloedel Ltd. (now Weyerhaeuser Co.) and other partners. It rapidly expanded into a multi-agency and multi-disciplinary study that is responsible for much of our present understanding of how small coastal watersheds function and how forestry practices affect their functions.

The comprehensive, long-term research and monitoring approach implemented at Carnation Creek has made landmark contributions to the scientific basis for sound watershed stewardship.

Purpose and Objectives

Historically, the three principal objectives were:

• to provide an understanding of the physical and biological processes operating within a coastal British Columbia watershed;
• to reveal how the forest harvesting practices employed in the 1970s and early 1980s changed these processes; and
• to apply the results of the study to make reasonable and useful decisions concerning land-use management, fish populations, and aquatic habitat protection.

Research is presently documenting the mid-term post-harvest responses to logging practices from studies focused on the hydrologic regime, hillslopes, stream channel network, riparian forest, aquatic habitats, water temperatures, and fish populations.

An important objective is to determine the mechanisms, rates, and levels of natural resource recovery by quantifying the long-term changes in biological and physical watershed processes as the second forest grows.
Study Components
Data collected historically included comprehensive information on:

- climate,
- stream temperatures and discharge,
- groundwater levels,
- air chemistry,
- water chemistry,
- terrain stability,
- stream channel morphology,
- large woody debris (LWD),
- streamed sediment composition,
- suspended sediment generation and transport,
- streambed scour and deposition,
- forestry-related ground disturbance,
- post-harvest revegetation,
- biomass of aquatic algae, and
- fish habitats and populations.

Many historic study components continue today, and several new ones have been added. A basin-scale approach is used to describe and model the sequential linkages among hillslope, drainage network, and floodplain processes; develop watershed sediment and debris budgets; and document and predict the consequences of these processes for stream channel morphology and aquatic habitats. Research on fish populations and habitats continues to be a key project component.

Core study components and activities include:

1. Hydrology and meteorology – water temperatures, depths, and discharge are monitored at four stream weirs; data on air temperature, precipitation, relative humidity, and wind speed and direction are collected at six climate stations.

2. Hydrologic recovery – rain gauges, stem-flow sampling, and run-off troughs in both mature forests and second-growth stands are used to determine the proportion of rainfall intercepted by the forest vegetation and channelled to the ground.

3. Channel morphology and sediment dynamics – determining channel and fish habitat changes, including LWD, streamed textures, and erosion and deposition processes.

4. Ground-based and aerial photographic surveys of riparian areas and steep terrain – quantifying the rate of second-growth canopy closure and changes in channel structure; documenting the location, frequency, and size of hill-slope (landslides, debris flows) and riparian sediment and debris sources.

5. Salmonid migration assessments – monitoring juvenile coho and chum salmon, and cutthroat and steelhead trout migrating seaward from the creek, and adults returning to spawn.

6. Resident salmon rearing in fresh water – abundance, distribution, age structure, growth, and survival.

7. Winter habitats – assessing the relative importance of low-order tributaries vs. main-channel habitats for overwinter survival and production of juvenile salmon.
Some Long-term Research Results

The Carnation Creek study has been carried out over pre-logging (1970–1975), during-logging (1976–1981), and post-logging (1981–present) periods. Two broad and interrelated categories of forestry-related effects have had a dominant influence on fish and aquatic habitats:

1. Structural Habitat Alterations – The main effects of forest harvesting on the stream were bank erosion, loss of LWD, and movement of sand and pea gravel to the lower reaches of the stream and estuary. Some of these changes were a consequence of riparian clearcutting; however, longer-term changes to the stream channel resulted from increased frequencies of landslides and debris torrents after logging. Forestry practices reduced egg and alevin survival by about one-half in both chum and coho salmon. Chum survival declined due to elevated sedimentation of their spawning beds. Coho survival declined due to reduced channel stability and increased bedload. Juvenile coho were further affected by reduced rearing-habitat complexity in both the careful and intensive clearcut treatments. Loss of pool habitat, reductions in the amount, size, and stability of functional LWD within the stream channel, and increased lateral erosion and bedload volumes all contributed to declining habitat quality and availability.

2. Temperature-related Shifts – Riparian clearcutting has increased stream temperatures in all seasons. Increments during autumn and winter accelerated egg and alevin development, which caused sequential changes in emergence timing, growth, survival, and seaward migration timing in both chum and coho salmon. These effects still persist and will likely continue for several years until a new riparian forest canopy is established over the stream. Elevated stream temperatures due to logging have increased the growth and survival of coho fry so that the lower numbers of fry inhabiting the creek after logging have been able to produce more smolts than before—a clear example of the complexity of fish-forestry interactions.

Chum salmon numbers have declined in the post-logging period to about 27% of their pre-logging levels. Analyses have shown that 26% of this decline is due to forestry-related causes, mainly sedimentation of chum spawning beds.

Large volumes of sediment and debris generated by this hillslope failure in 1984 have caused major channel and fish habitat impacts that persist today.

Most existing logjams and heavy sediment accumulations are the ultimate consequences of hillslope failures that occurred in Carnation Creek over 20 years ago.

Late-summer Coho Populations in Carnation Creek 1971–2003

The numbers of young coho the stream can support during summer have declined by about one-half up to the mid-1990s. Some of the decline is due to channel habitat changes due to riparian harvesting, but most habitat change has been caused by debris and sediment from landslides. Higher numbers in recent years are related to increased numbers of adult spawners resulting from fishery closures and restrictions.
Application of Carnation Creek Results

The Carnation Creek project has made outstanding contributions to our knowledge of the effects of forestry practices on watershed processes, with more than 200 publications generated from over 35 years of study. Project results have been widely used to develop forest management practices, regulations, and guidelines in British Columbia and elsewhere in the Pacific Northwest. Examples include the B.C. Coastal Fisheries-Forestry Guidelines (CFFG) (1987–1995), the hillslope, stream, and riparian management provisions of the B.C. Forest Practices Code (1995–2004), and similar environmental standards presently continued under the current British Columbia Forest and Range Practices Act.

Future Directions

Carnation Creek’s long-term research approach has shown that key forestry-related changes continue to occur more than two decades after harvesting concluded, in spite of tree regeneration and growth throughout the watershed that is contributing to hydrologic recovery.

Further declines in the quantity and quality of aquatic habitats are anticipated within the next several years due to (1) increased riparian canopy closure over the stream channel (resulting in reduced salmonid growth, survival, and smolt abundance due to declining water temperatures and aquatic primary production), and (2) downstream cumulative progression of impacts of landslide-generated sediment and debris into the part of Carnation Creek historically protected by riparian buffers and that contains the last remaining high-quality anadromous fish habitats. This demonstrates the long duration of some harvest-related alterations, and the vulnerability of streams to hillslope failures and debris flows regardless of riparian reserves.

Continued research on these prolonged alterations and recovery processes is a priority. Important outcomes include refined descriptions of hydrologic responses to harvesting, hydrologic recovery in second-growth stands, landslide risk and prediction for different forestry practices, sediment supply and transfer processes (hillslopes to channels), and the long-term consequences for channel morphology, aquatic habitats, and fish populations.

Hydrologic monitoring (stream flows and water temperatures) occurs at weirs such as Station B on the main channel.

Monitoring post-logging forest growth and watershed hydrology responses.

Landslide-generated sediment and debris from roads in steep terrain can enter headwater stream channels.

Downstream progression of logjams and excess bedload are continuing to cause channel and fish habitat impacts. These changes are now beginning to affect the part of the creek protected by the riparian buffer treatment. The riparian vegetation has not yet recovered to provide canopy closure in most clearcut portions of the creek.

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