The amounts and size distributions of litter and organic material in the bottom substrate were estimated. Samples were collected by forcing metal cylinders, 10 cm in diameter, into the bottom, capping the upper end with a tight plastic cap, carefully withdrawing the cylinder and sealing the bottom with another cap as it was withdrawn from the substrate. In the lab the substrate samples were washed through a graded series of sieves with nominal mesh sizes of 8. 4. 2. 1. 0.5. 0.25. 0.106, and 0.053 mm. After sieving, invertebrates were picked from each subfraction and preserved in formaldehyde for later enumeration and identification. Material retained on each sieve was oven dried at approximately 70°C for 24-48 hours, cooled and weighed to the nearest 0.05 g. Samples were taken in the summers of 1984-1986 from the heads of pools in the main-stem at 1600M and 2600M and in two tributaries, 1600T and 2600T (Fig. 1).

Litter decomposition rates were estimated by observing the rate at which alder leaves disappeared from small mesh bags placed in the stream. Leaf-pack studies have been extensively used by stream ecologists to study litter decomposition in streams. Immediately before starting an experimental series, fresh leaves were collected from the lower branches of alder trees around the Carnation Creek camp. After the herbicide application, leaves were collected from areas known not to have been over-sprayed. The leaves were dried for 24 h at 70°C, cooled in a desiccator and weighed to within 5 mg. Known weights of leaves (approx. 5-7 g) were then carefully placed in 15x20 cm packs made of plastic screening (mesh size approx. 3 mm). The packs were identified with numbered plastic disks enclosed with the leaves. The packs were then carefully carried to the four sites (Fig. 1), placed underwater in protected areas of pools, and tied to a strong line that extended across the channel. The packs were held on the bottom of the channel by placing rocks or debris on their attachment cords. Experimental series were run for 2-3 months in the summers of 1984-1986 and for 2-6 months in the winters of 1984/85 and 1985/86.

Periodically, individual packs were removed by carefully cutting the attachment string and sliding the pack into a 1 L container that had been filled with water at the site. The can was sealed with a tight fitting plastic lid and transported to the lab. At the time of collection, temperature and dissolved O₂ measurements were made with a YSI Model 57 oxygen meter at each site. The meter was calibrated in saturated water of known temperature using tables supplied with the instrument. In the lab, oxygen and temperature measurements were periodically made over a 4-8 h period following collection of the packs. Measurements of dissolved oxygen were made by first carefully inverting each can to mix the water and then replacing the plastic lid of a can with a lid through which the oxygen probe protruded. Although there was undoubtedly some gas exchange during the measurements, comparisons between samples should be valid. Measurements made on water samples without packs showed little change in dissolved O₂ levels after 8 h, even when initial O₂ values were well below saturation. Oxygen measurements were made only during the series that included the herbicide application and the following winter. After the 4-8 h period, the packs were opened and their contents placed in shallow, white trays. All of the leaves and leaf fragments were removed, gently washed, dried for 24 h at 70°C, cooled in a desiccator and weighed to within 5 mg. The contents of the pans, which included all of the invertebrates, were then screened through a 0.1 mm screen, and preserved in formaldehyde. Leaf-pack decomposition rates were estimated by fitting negative exponential curves to the proportion of dry leaf weight remaining over time (Peterson and Cummins 1974).

Invertebrates from the leaf packs and substrate samples were subsequently identified and enumerated. Most insects and other large organisms were identified to genus. Dipteran midges, copepods, worms, mollusks and water mites were identified as far as was practical for non-specialists, usually to family. Variation in the numbers of dominant taxa, those present in at least 30% of all samples, was summarized using principal components analysis (PCA). This technique enables the variation in community composition over time to be succinctly displayed on a
graph. We used the PCA analysis to determine whether the herbicide application was associated with changes in community composition at the affected sites, both immediately after spraying and one and two years later. The role of macro-invertebrates in litter decomposition was assessed by comparing the number of animals in individual taxa and in the shredder functional group (Cummins 1974) with the rate of leaf-pack decomposition.

The sizes and densities of coho fingerlings in Carnation Creek during September from 1981-1986 were obtained from Andersen (1984,1985,1987). A fish fork-length - density relationship (log-log) was used to estimate fingerling densities at 28 sites within Carnation Creek during September 1983 from fork-length data (Andersen 1985). The variation in fish densities in the stream in relation to the outlet of the two major tributaries (1600T and 2600T) is used in the speculative discussion of the role of valley-bottom tributaries in the energy budget of the Carnation Creek ecosystem.

RESULTS

Before the herbicide application, annual deciduous litter-fall ranged from 90 g.m² in the relatively open areas at 2600M to 350 g.m² under the dense alder canopy in the lower sections of 1600T (Fig. 2A). Coniferous litter-fall was one to two orders of magnitude less (Fig. 2B). These values are similar to those obtained by Neaves (1978) for similarly vegetated areas prior to logging.

The seasonal pattern of litter-fall indicates peak deposition in September-October, with the fall senescence and fall of deciduous leaves, virtually no litter-fall during the winter, and gradually increasing rates of deposition during the summer (Fig. 3). The yearly pattern of litter-fall at Carnation Creek is no different from those observed in other sites dominated by deciduous trees in the northern hemisphere (Dixon 1976), but is quite different from the patterns observed by Culp and Davies (1982) at the same sites several years earlier.

The herbicide had a pronounced effect on litter-fall at 1600T beginning in the early summer of 1985, the year after application (Fig. 2A). Deciduous litter-fall in the year after application fell to 30 g.m², less than 10% of the previous year. Total litter-fall at the other sites was similar in 1984 and 1985. The litter that did fall in 1985 at 1600T was largely from herbaceous plants growing near the ground that toppled, rather than fell, into the litter traps. Coniferous litter-fall at 1600T was similar in 1984 and 1985 (Fig. 2B). At two of the other three sites coniferous litter-fall increased substantially in 1985 (Fig. 2B). The reason for that increase is uncertain. There was no obvious increase in the height or number of conifers at any site and trap placement was not different in 1985 compared to 1984.

The size distribution of organic particles found in the substrate of 1600T appears to have changed in response to defoliation of the riparian alder (Fig. 4A). In the particle size spectra of Figure 4, leaves and leaf fragments predominate the size categories from 0.4-2 mm. Larger particles and especially those retained by the 8-mm sieve were woody debris, which is very resistant to fragmentation and decay. In the two summers following herbicide application there was a progressive decrease in the total weight of particles between 0.4 and 2 mm, probably a result of decreasing leaf deposition into 1600T. There was little change in the number of particles above 4 mm and no consistent change in smaller particles. Organic matter in the substrate of the main channel at 1600M was considerably less abundant than in the tributary (Fig. 4B), and there was a notable absence of particles > 2 mm. The reasons why small particles were comparatively rare in 1985 compared to 1984 and 1986 are uncertain. The bottom samples from those years had comparatively large amounts of sand, and it is possible that the between-year differences are due to changes in the particle size composition of the gravels.
Figure 2. A) Deciduous and B) coniferous litter-fall at the main-stem and tributary sites from Aug. 1984 - Feb. 1986.
Figure 3. Comparison of total yearly litter-fall in 1984 and 1985 at the two tributary sites.

Differences in the decomposition rates between sites were probably related to differences in the invertebrate communities of the four sites. Decomposition rates (Table 1) and the patterns of decomposition (Fig. 5) in the two main-stem sites were very similar. At both of the main-stem sites decomposition appears to proceed in two stages which are related to the colonization of the leaf-packs by invertebrates in the shredder functional group (Fig. 6). Large-bodied shredders, in particular the gammarid amphipod Antisogammarus, were abundant in 1600T and the highest decomposition rates were observed there (Table 1). The timing of decomposition curves in this tributary is described very well by a negative exponential function (Fig. 5C). Decomposition rates in 2600T were slightly lower than those in the main-stem sites (Table 1), but the time patterns of decomposition (Fig. 5D) and the abundances of shredders (Fig. 6D) were similar to the main-stem sites.

The between-season and between-year differences in decomposition rate are largely attributable to temperature (Fig. 7). The relationship between decomposition rate and temperature is the same for the two main-stem sites and for 2600T, but a different relationship applies to 1600T (Fig. 7) where the rate of increase in the decomposition rate with temperature was greater than at the other sites.
Figure 4. Size distributions of organic particles in the substrates of A) 1600T and B) 1600M during the summers of 1984-1986.
Table 1. Exponential rates of decomposition for leaf packs at four sites in Carnation Creek and tributaries. Mean temperatures during the experimental series are shown in brackets. Fall/winter measurements during 1984 could not be obtained from the main-stem sites due to high water levels.

<table>
<thead>
<tr>
<th>Site</th>
<th>summer 1984</th>
<th>fall/winter 1984</th>
<th>summer 1985</th>
<th>fall/winter 1985</th>
<th>summer 1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>1600T</td>
<td>-0.0477</td>
<td>0.0138</td>
<td>-0.0498</td>
<td>-0.0207</td>
<td>-0.125</td>
</tr>
<tr>
<td></td>
<td>(10.6)</td>
<td>(6.1)</td>
<td>(11.3)</td>
<td>(7.0)</td>
<td>(11.5)</td>
</tr>
<tr>
<td>2600T</td>
<td>-0.0136</td>
<td>0.0071</td>
<td>-0.0179</td>
<td>-0.0051</td>
<td>-0.0223</td>
</tr>
<tr>
<td></td>
<td>(12.0)</td>
<td>(4.9)</td>
<td>(13.0)</td>
<td>(6.2)</td>
<td>(14.2)</td>
</tr>
<tr>
<td>1600M</td>
<td>-0.0212</td>
<td>n/a</td>
<td>-0.0369</td>
<td>-0.02044</td>
<td>-0.0244</td>
</tr>
<tr>
<td></td>
<td>(11.9)</td>
<td>(5.0)</td>
<td>(11.3)</td>
<td>(6.5)</td>
<td>(13.3)</td>
</tr>
<tr>
<td>2600M</td>
<td>-0.0217</td>
<td>n/a</td>
<td>-0.0229</td>
<td>-0.0185</td>
<td>-0.0278</td>
</tr>
<tr>
<td></td>
<td>(11.7)</td>
<td>(4.9)</td>
<td>(11.5)</td>
<td>(6.2)</td>
<td>(13.5)</td>
</tr>
</tbody>
</table>

An indirect effect of the herbicide application is perhaps revealed by the anomalous decomposition rate observed in 1600T during the summer of 1986 (Fig. 7). The temperatures in 1600T were lower than they had been in 1985 (Holby 1989) and the numbers of shredders and other invertebrates were similar to numbers in 1984 and 1985. In a study of the impacts of logging on litter decomposition, Webster and Waide (1982) observed a similar increase in decomposition rates that could not be accounted for by higher temperatures. They noted that their leaf-packs had become islands of high-quality food that were rapidly colonized and processed. The observed declines in both litter-fall (Fig. 3) and the amount of coarse particulate detritus (Fig. 4) in 1600T probably resulted in a similar "oasis-desert" situation existing in 1600T during the summer of 1986.

Oxygen consumption rates of the leaf-packs and the associated organisms were similar at all sites (Fig. 8). Consumption rates rose rapidly after introduction of the leaf-packs and had reached maximum values after 2-3 wk. Thereafter consumption rates declined exponentially. The rate of decline was inversely related to the decomposition rate. There was no change in oxygen consumption immediately after the application of the herbicide in 1600T (Fig. 8). If the herbicide had an effect on the respiration of the leaf-pack community then that effect was not measurable the day after application.

The principal component analysis indicated that there were three macro-invertebrate communities, which could be distinguished by the relative abundances of the 20 common taxa found in the leaf packs. The communities found at both main-stem sites were similar to each other, but different from the communities found in the tributaries. The two main-stem sites were characterized by an absence of the sand-flea *Anisogammarus*, the isopod *Asellus*, a snail (Planorbidae).
Leaf-pack Decomposition

Figure 5. Proportion of dry weight remaining in the leaf packs at the four sites during the summers of 1984-1986, as functions of immersion time.
Macroinvertebrate shredders

A - 1600M

B - 2600M

C - 1600T

D - 2600T

Figure 6. Numbers of invertebrates in the shredder functional groups collected from the leaf packs at the four sites during the summers of 1984-1986 as functions of immersion time.
Figure 7. Instantaneous decomposition rates in the leaf packs from 1984-1986 as functions of mean temperature during immersion.
Figure 8. Oxygen consumption rates of leaf packs during the summer of 1984 as functions of immersion time of the leaf packs. The date of herbicide application at 1600T is indicated.
and a caddis fly of the family Polycentropodidae, and by the relative scarcity of the mayfly Paraleptophlebia, all of which were abundant in the tributaries. Taxa abundant in the main-stem but absent or rare in the tributaries included the mayfly Baetis, a caddis fly of the family Lepidostomatidae and the stonefly, Capnia (Table 2). The two tributary sites were distinguished by the relative abundances of Anisogammarus and Asellus, which were abundant in 1600T and ostracods, oligochaetes, and gastropods, which were abundant in 2600T. Some taxa such as chironomid midges and cyclopoid and harpactacoid copepods were abundant at all sites. In functional terms, the communities of the main-stem were dominated by animals that collect suspended particles or scrape particles off solid substrates. The community of 1600T was dominated by shredders, animals that fragment and ingest large particles. The community of 2600T included several taxa that feed in rich organic ooze.

The PCA scores summarize patterns of variation in community composition and when PCA scores from the same sites are arrayed over time, time-dependent changes in community composition should be revealed. The time tracks of the leaf-pack communities (Fig. 9) show gradual development of the communities characteristic of the four sites, but there is no indication of large changes in community composition or changes in the abundance of dominant taxa around the time of spraying (Fig. 9). Although macro-invertebrate abundances were lower at all sites in 1985 and 1986 (Fig. 6), projection of the taxa abundances in those years into the component space defined by abundances in 1984, indicated that no change in community composition had occurred (Fig. 9).

**DISCUSSION**

The application of herbicide to the riparian vegetation surrounding a small, valley-bottom tributary of Carnation Creek greatly reduced the amount of litter that fell into the tributary in the following year. As a result of the decrease in leaf litter input, the number of detrital particles 0.5-2 mm in size decreased in the two summers following herbicide application. Detrital processing rates were dependent on water temperature and on site-specific assemblages of macro-invertebrates. Detrital processing rates were consistently higher at the site where the macro-invertebrate community was dominated by large-bodied taxa in the shredder functional group (Cummins and Klug 1979). In general, between-year differences in processing rates could be accounted for by variations in temperatures. In the summer of 1986, two years after the herbicide application, detrital processing rates in the over-sprayed tributary were much greater than expected, even after correcting for temperature. Such a result might be expected in a system where high quality food particles have become scarce and the experimenter artificially introduces packets of high quality food (Webster and Waide 1982).

Current conceptual models of stream ecosystems (Boling et al. 1975; Vannote et al. 1980) clearly indicate the importance of detrital inputs as the major energy source of small woodland streams. The utilization of detrital inputs is critically dependent on mechanisms that enhance the capture and retention of litter (Cummins et al. 1980; Petersen and Cummins 1974; Reice 1980). In coastal streams in the Pacific northwest, the highest stream flows, and presumably the fastest flushing of small debris, occurs in October-December, immediately after leaf-fall. Any structural characteristics of streams in this region that promote the retention of debris should be important modifiers of stream energy budgets. Small, valley-bottom tributaries typified by 1600T at Carnation Creek, because of their small size and low discharges, the large amount of woody debris they contain and their relatively high sinuosity, promote the retention of small debris such as leaves. The dense growth of alder along these water courses insures significant litter inputs.
Table 2. Spearman rank correlations between abundances of macro-invertebrate taxa and the first two principal components derived from the summer 1984 leaf-pack experiment. The functional group assigned to each taxon are shown: SH-shredder; FP-fine particle feeder; CO-gathering or filtering collector; P-predator; U-unknown.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Functional group</th>
<th>Spearman rank correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 27.9% of total variance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- characterizes communities dominated by fine particle feeders</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ostracods</td>
<td>FP</td>
<td>0.722 ***</td>
</tr>
<tr>
<td>cyclopoid copepods</td>
<td>FP</td>
<td>0.682 ***</td>
</tr>
<tr>
<td>Polycentropodidae (caddisfly)</td>
<td>U</td>
<td>0.662 ***</td>
</tr>
<tr>
<td>Oligochaeta (worm)</td>
<td>FP</td>
<td>0.691 ***</td>
</tr>
<tr>
<td>Paraleptophlebia (mayfly)</td>
<td>CO</td>
<td>0.606 ***</td>
</tr>
<tr>
<td>Planorbidae (snails)</td>
<td>FP</td>
<td>0.594 ***</td>
</tr>
<tr>
<td>harpactacoid copepods</td>
<td>FP</td>
<td>0.578 ***</td>
</tr>
<tr>
<td>Nemoura (stonefly)</td>
<td>SH</td>
<td>0.544 **</td>
</tr>
<tr>
<td>Ceratopogonidae (no-see-um)</td>
<td>CO/FP</td>
<td>0.490 **</td>
</tr>
<tr>
<td>chironomid midges</td>
<td>CO/FP</td>
<td>0.422 *</td>
</tr>
<tr>
<td>water mites</td>
<td>P</td>
<td>-0.351 *</td>
</tr>
<tr>
<td>Ameletus (mayfly)</td>
<td>SH</td>
<td>-0.422 *</td>
</tr>
<tr>
<td><strong>Factor 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 25.2% of total variance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- collectors +ve loadings, large-bodied shredders -ve loadings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ephemerella (mayfly)</td>
<td>CO</td>
<td>0.859 ***</td>
</tr>
<tr>
<td>Lepidostomtidae (caddisfly)</td>
<td>SH</td>
<td>0.778 ***</td>
</tr>
<tr>
<td>Baetis (mayfly)</td>
<td>CO</td>
<td>0.766 ***</td>
</tr>
<tr>
<td>Alloperla (stonefly)</td>
<td>P</td>
<td>0.760 ***</td>
</tr>
<tr>
<td>Capnia (stonefly)</td>
<td>SH</td>
<td>0.758 ***</td>
</tr>
<tr>
<td>chironomid midges</td>
<td>CO/FP</td>
<td>0.745 ***</td>
</tr>
<tr>
<td>Empididae (dance-flyys)</td>
<td>U</td>
<td>0.691 ***</td>
</tr>
<tr>
<td>Nemoura (stonefly)</td>
<td>SH</td>
<td>0.605 ***</td>
</tr>
<tr>
<td>Asellus (isopod)</td>
<td>SH</td>
<td>-0.752 ***</td>
</tr>
<tr>
<td>Anisogammarus (amphipod)</td>
<td>SH</td>
<td>-0.780 ***</td>
</tr>
</tbody>
</table>

* p < 0.05; ** p < 0.01; *** p < 0.001
Figure 9. PCA analysis of taxonomic composition of leaf pack invertebrates during the summer of 1984. The 1 wk period that includes the application of herbicide at 1600T is indicated.

In comparison, features that would retain fine detritus in the main-stem, deep pools, debris jams, and complex channel form, are deteriorating rapidly in the aftermath of clear-cut logging, probably significantly reducing the capacity of the main-stem to capture and process detritus, and increasing the relative importance of the valley-bottom tributaries as sites of energy capture.

In Carnation Creek there are indications that detrital processing in valley-bottom tributaries does serve as an important energy source for the main-stem animal community. Water flowing out of the tributaries is considerably richer in fine particulate organic matter than water in the main-stem (Holby and Ballie, unpubl. data). Those particles are undoubtedly collected by the numerous invertebrates in the main-stem adapted to the collection of fine particles. The probable importance of this detrital input to the fish community is suggested by the concentrations of subyearling coho immediately downstream of the tributary inflows (Fig. 10) where densities can be as much as 2.5 times higher than in areas far removed from tributary influences.
Figure 10. The variation of estimated fish densities down the length of Carnation Creek in Sept. 1983. The locations of the confluences of the main-stem with important valley-bottom tributaries are indicated.

We were unable to detect any changes in the either the invertebrate community of the tributary or the salmonids in the tributary after herbicide application (Holby and Baillie 1989). However, we did observe large decreases in detrital inputs to the tributary and changes in the composition of detrital particles in the tributary sediments. Those changes, coupled with the probable significance of the tributary to the energy budget of the entire system, recommend caution in future modifications to the riparian vegetation of valley-bottom tributaries.

ACKNOWLEDGEMENTS

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DRIFT OF AQUATIC INVERTEBRATES IN A GLYPHOSATE CONTAMINATED WATERSHED

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ABSTRACT

Short-term effects on stream invertebrates of glyphosate applications to parts of the Carnation Creek watershed were determined by measuring drift response. Drift densities of most invertebrates did not increase in response to the glyphosate applications. Post-spray mean drift values were not significantly higher (ANOVA $p > 0.05$) than pre-spray mean densities. A non-significant but measurable alteration in drift patterns of *Paraleptophlebia* sp. (Ephemeroptera) suggested a slight and ephemeral drift response to glyphosate contamination by this specific mayfly genus. A small post-spray increase in the numbers of drifting *Gammarus* sp. (Amphipoda) was less conclusive.

INTRODUCTION

As part of research activities (Reynolds et al. 1989) conducted to investigate the fate and effects of a glyphosate application to the Carnation Creek valley, we examined the short-term effects on aquatic invertebrates by measuring drift response. A program to determine the fate and persistence of the herbicide in stream water was jointly conducted with this project, but results from residue analyses are presented elsewhere (Feng et al. 1989).

Three sites were selected for sampling invertebrate drift: 1) in the main channel of Carnation Creek approximately 30 m below B-Weir and downstream of most treated portions of the valley, 2) in C-Creek, a 1000 m ephemeral tributary buffered from the applications, and 3) in 1600 tributary, a 800 m stream directly oversprayed (Fig. 1). Samples from the tributaries were collected approximately 10 m upstream from their confluences with the main channel. The drift site below B-weir was typical of most of lower Carnation Creek, with a section of riffle approximately 4 m wide comprising scoured gravel with small amounts of sand and silt. Water velocity ranged from 0.55 to 1.15 m/sec during sample collection. Water levels in C-Creek fluctuated drastically throughout the sampling period such that the drift site varied from 0.5 m wide with almost no flow to 2 m wide with a water velocity of 0.97 m/sec. The stream bottom at the C-Creek sampling site and through most of the 100 m section bordering the spray blocks consisted of small rubble and gravel with patches of sand and silt in quieter areas. Although riparian vegetation was dense in certain sections, C-Creek contained little organic debris. The 1600 tributary drained a swampy portion of the valley south of the main channel with a number of small pools and sections of moderate flow in constricted areas. In contrast to the other two sampling sites, this tributary contained a large amount of organic debris with a bottom type mostly consisting of silt, detritus, sand and small sections of fine gravel. The drift sampling site in 1600 tributary was approximately 0.5 m wide with a flow rate that varied much less (0.33 to 0.58 m/sec) than the main channel or C-Creek.
Figure 1. Glyphosate treatment blocks and drift sampling sites in the Carnation Creek watershed, September 1984.
A specific drift net location was established at each site and used throughout the sampling period. Drifting invertebrates were collected in 0.47 x 0.32 m nets with a 363 µm mesh positioned midstream to sample a water column from the surface to the stream bottom, or to the net bottom when water levels exceeded the height of the net opening. Current velocity and depth of water at the net opening were measured with each sample, and the collected invertebrates were subsequently quantified as number per 10 m$^3$ of water flowing through the drift net. Drift samples of 5 to 15 min duration were taken hourly during sunset and sunrise periods on collection dates, corresponding to the times when stream invertebrate drift normally peaks and declines (Waters 1972). Additional samples were collected at hourly intervals immediately following the applications of herbicide.

Differences in drift levels between sample periods were tested with ANOVA (p < 0.05). Because of the small size of the creeks, especially C-Creek and 1600 tributary, spatial replication of drift nets was impossible. The values tested were mean drift numbers from collections over equal periods of time (i.e. means from morning or evening drift periods). Mean values were tested for statistical significance, but peak drift numbers provided a clearer indication of drift magnitude, and are presented.

Glyphosate was applied as ROUNDUP (30.5% active ingredient) at a concentration of 2.0 kg a.i./ha in a total volume of 258 L/ha using a MICROFOIL BOOM with 1.5 mm hayrack nozzles, mounted on a Bell G-47 helicopter (Reynolds et al. 1989). Glyphosate was applied to 11 spray blocks (Fig. 1) at various times over four separate days. Only those with potential for contaminating the portion of the watershed above drift sampling sites are discussed. On the evening of 6 September 1984, between 1940 and 2005 h, a spray block immediately adjacent to the east edge of C-Creek was treated with herbicide (Fig. 1). Most of the remaining creek valley, including the portion on the west side of C-Creek, was sprayed between 1425 and 1945 h on 14 September. The main channel of Carnation Creek and C-Creek were buffered by a 10 m no-spray zone, while 1600 tributary was intentionally oversprayed.

RESULTS AND DISCUSSION

Drift densities of most aquatic invertebrates did not increase in response to the glyphosate applications. None of the post-spray mean drift values for total invertebrate catches were significantly higher than pre-spray mean densities (p > 0.05). Since many of the organisms in the drift samples were collected in low numbers, only the more frequently collected taxa are listed with their peak drift levels (Table 1). High water conditions at both the beginning (from heavy rains on 4 September) and end (from heavy rains on evening of 15 September) of the sampling period probably accounted for most of the variations in total drift density. Some groups, such as Baetis sp. at B-Weir and Capnia sp. in C-Creek, demonstrated increases in drift rate after an application, but the levels were comparable to previous pre-spray evening drifts. Several other taxa, including Lepidostoma sp. at B-Weir and early instar limnephilid caddisflies in 1600 tributary, showed an increase in drift density at the end of the sampling period that corresponded to heavy rainfall and an approximately five-fold increase in stream discharge. However, elevated drift levels of these same groups were found in high water conditions at the beginning of the study period (September 4), suggesting that the post-spray increases resulted from the increased discharge rather than glyphosate contamination.

Although the drift patterns of most invertebrates were not measurably affected by the herbicide treatment, the drift response of Gammarus sp. and Paraleptophlebia sp. suggests some disturbance of these genera by the glyphosate contamination. None of the mean post-spray drift densities of these two taxa were significantly higher than mean pre-spray densities (p > 0.05), but a measurable alteration in drift patterns, especially of Paraleptophlebia, was demonstrated. These drift increases may have resulted from natural causes, but were coincident with glyphosate contamination and therefore cannot be dismissed as being unrelated to the herbicide applications.
**Gammarus** sp. in 1600 tributary drifted in numbers approximately twice as high on the evening of the overspray as they were in pre-spray evening drifts (Table 1). This amphipod is commonly found in stream drift but is not particularly susceptible to glyphosate. Folmar et al. (1979) reported a 48 h EC_{50} of 43,000 µg/L for **Gammarus** exposed to ROUNDUP contaminated water. The highest glyphosate concentration measured in 1600 tributary was 162 µg/L (Feng et al., 1989).

Although the magnitude of the drift increase was little more than measurable and the duration was less than two hours, the elevated drift on the evening of the application represents a disruption of the previously established evening drift pattern and may indicate a disturbance of **Gammarus** sp. by glyphosate contamination in 1600 tributary. Definite indications of a toxic or behavioral response of **Gammarus** sp. to the herbicide application are precluded by the minimal drift increase.

Immediately following the herbicide treatment to the eastern periphery of C-Creek on 6 September, the numbers of drifting **Paraleptophlebia** sp. distinctly increased (Table 1). The mean number of these mayflies on the evening of the adjacent application was not significantly different from the previous evening (p > 0.05), but as illustrated in Figure 2, the drift rate attained a higher level (approximately 10x the pre-spray peak) than at any other time in C-Creek.

**Paraleptophlebia** sp. drift rates in C-Creek did not increase with treatment of the other adjacent spray block on 14 September. A 10 m buffer on both sides of C-Creek was observed for both applications adjacent to the creek, but recorded field observations suggested that the helicopter flew closer to the creek on the evening of 6 September than during the 1600 tributary overspray on 14 September. During the first application adjacent to C-Creek, the aircraft flew a spray pattern roughly parallel to the stream and given the circuitous nature of the creek, the likelihood of inadvertently overspraying parts of C-Creek was greater than when flight patterns approached the creek at right angles during the application on 14 September. The greater opportunity for contamination of the stream during the first peripheral application may account for the differential response of **Paraleptophlebia** sp. to the two applications adjacent to C-Creek. Since no residue samples were collected from C-Creek, the contamination cannot be substantiated.

This mayfly also demonstrated an increased drift rate in 1600 tributary and B-Weir in evening drift samples 30 h after the overspray of 1600 tributary (Fig. 2). The increases were less than 9x the pre-spray peak and may simply have been a response to the increase in stream discharge resulting from heavy rainfall during the evening sampling period. However, elevated drift levels of **Paraleptophlebia** sp. at these two sites were not previously associated with the high water conditions at the beginning of the study period 4-5 September (Fig. 2). The post-spray drift increases following the rain storm indicate a response to glyphosate contamination from runoff. Shortly after rain began on 15 September, concentrations of glyphosate in stream water increased at both B-Weir and 1600 tributary (Feng et al., 1989). The occurrence of glyphosate residues may have combined with the effects of increasing discharge to produce these slightly elevated drift levels of **Paraleptophlebia** sp.

The apparent response of **Paraleptophlebia** mayflies to the glyphosate applications suggests a particular susceptibility of this genus to the herbicide. If the drift response in C-Creek was attributable to the herbicide treatment, the impact was limited to **Paraleptophlebia** sp. since none of the other groups demonstrated a similar increase. The indications of a slight post-spray increase in drifting **Gammarus** sp. were inconclusive. In summary, glyphosate was applied at operational rates on or near Pacific salmon nursery streams and resulted in, at most, slight and ephemeral drift increases of one mayfly genus.
Table 1. Drift of selected aquatic invertebrates (no. per 10 m$^3$) collected in Carnation Creek. Values for each taxon represent peak numbers collected in morning or evening drift samples. Totals represent the total numbers of all taxa in the largest of hourly samples from morning or evening sample period.

<table>
<thead>
<tr>
<th>Date (September)</th>
<th>5 PM</th>
<th>6 AM</th>
<th>6 PM</th>
<th>6 AM</th>
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<th>7 AM</th>
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<th>12 AM</th>
<th>13 PM</th>
<th>14 AM</th>
<th>14 PM</th>
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* East periphery sprayed at 1940 h to 2000 h on 6 September and west periphery sprayed at 1515 h to 1535 h on 14 September 1984.

** Oversprayed at 1425 h to 1510 h on 14 September 1984.
Figure 2. *Paralepiophlebia* sp. drift densities in Carnation Creek and two tributaries during evening sampling hours. Arrows indicated time of glyphosate applications.
ACKNOWLEDGEMENTS

The contributions to this study by P. Reynolds, Project Coordinator, are greatly appreciated. The cooperation, assistance, and provision of equipment and facilities by the Pacific Biological Station, Nanaimo, B.C. were vital to the operations of the program and are gratefully acknowledged. A major portion of this research was funded by the B.C. Ministry of Forests.

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Feng, J.C., D.G. Thompson and P.E. Reynolds. 1987. Fate of glyphosate in a forest stream ecosystem. This proceedings.


SALMONID TOXICITY STUDIES WITH ROUNDUP

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V7P 2R4

ABSTRACT

Laboratory toxicity studies were conducted to assess acute lethal toxicity of ROUNDUP herbicide to three salmonid species (rainbow trout, chinook and coho salmon), and acute sublethal toxicity to coho salmon in seawater challenge tests. The results of this testing indicate that, during the course of normal usage at the manufacturer's recommended use-rates, ROUNDUP poses no acute toxicity hazard to salmonids nor will it affect seawater adaptation of coho salmon.

INTRODUCTION

This manuscript summarizes published (Mitchell et al. 1987a: b) and unpublished research into the acute toxicity of ROUNDUP herbicide. Unlike most of the other studies reported in these Proceedings, the present research was not part of work done at Carnation Creek. Rather, this research was funded by Monsanto (St. Louis, U.S.A.) to answer specific questions concerning the aquatic toxicity of ROUNDUP.

The results of this research were the subject of an invited platform presentation at the Carnation Creek Workshop in 1987 and are published here due to their relevance to the Carnation Creek Project. Two separate studies were conducted: determinations of acute lethality using standard 96-h LC50 bioassay testing, and seawater challenge testing to determine whether ROUNDUP has an effect on seawater adaptation of anadromous salmonids.

MATERIALS AND METHODS

Full details of the materials and methods used are provided in Mitchell et al. (1987a, b) and are briefly summarized below.

Acute Lethality

Acute lethality (96-h LC50) static bioassay testing was conducted in accordance with procedures outlined by APHA (1985) using three different salmonid species: rainbow trout (Salmo gairdneri), chinook salmon (Oncorhynchus tshawytscha) and coho salmon (O. kisutch). Three different waters were used in testing: dechlorinated North Vancouver City drinking water, dechlorinated reconstituted North Vancouver City drinking water, and water collected from Cultus Lake, B.C.

Test conditions were: ten fish per concentration, loading densities below 1.0 g/L, 200 L fiberglass tanks for the coho and chinook, 20 L glass tanks for the trout, 11 ± 10°C, a 16 h light: 8 h dark photoperiod regime, and dissolved oxygen maintained at greater than 60% saturation.
Tests were conducted by directly diluting ROUNDUP to obtain the desired exposure concentrations. Exposure concentrations were confirmed by selective HPLC analyses of the bioassay waters. Median lethal values (96-h LC₅₀) and 95% confidence limits were calculated from survival data using probit, moving-average of binomial probability analysis, and were confirmed by graphical log-probit analysis.

Seawater Challenge

Coho salmon smolts were exposed to three sublethal concentrations of ROUNDUP following the experimental design shown in Figure 1. Seawater challenge testing was conducted on half of the test fish immediately after the 10-d test exposure; the remaining fish were kept in clean water for 10-d prior to seawater challenge to allow detection of any delayed results. At the end of both sets of seawater challenge testing, the fish were sacrificed for Na⁺ analysis.

Test conditions were: flow-through systems, dechlorinated North Vancouver City drinking water; 200 L fiberglass tanks; water flow rates of 1.0 L/min (95% molecular replacement time of 9 h); fish fed ad libitum: 11 ±1°C; 16 h light: 8 h dark photoperiod with 1 h gradual dawn/dusk simulation. Na⁺ was measured using atomic emission spectrophotometry with appropriate quality assurance/quality control procedures. The length, weight, hematocrit values (percent blood cells by volume), and condition factor (100 times weight divided by length cubed) of each fish was also determined.

Tests were conducted by directly diluting ROUNDUP to obtain the desired exposure concentrations. Exposure concentrations were confirmed by selective HPLC analyses of the bioassay waters. Mean results for herbicide-exposed fish for Na⁺, hematocrit, condition factor, length and weight were statistically compared with the mean results for control fish using a one-way analysis of variance with specific differences determined using Dunnett's method (Miller 1966).

RESULTS AND DISCUSSION

Acute Lethality

The results of acute lethality testing are presented in Table 1 in terms of both the total ROUNDUP formulation and the IPA salt of glyphosate. Test concentrations were confirmed by glyphosate analysis. After 24 h, 70-87% of target levels remained in the fiberglass tanks while only 21-63% remained in the glass tanks. The reason(s) for this difference are unknown but may relate to different rates of herbicide absorption on fiberglass as compared to glass. However, since there were no significant differences in toxicity related to the differences in remaining glyphosate levels, it appears that the majority of the lethal dose was absorbed by the fish prior to any major loss from solution.

As is apparent from Table 1, there were no significant differences in toxicity to 0.37 g trout, 4.6 g chinook and 11.8 g coho. Similarly, there was no significant difference in toxicity with dilution water type. These results contrast with those of Folmar et al. (1979), who reported large, significant differences in toxicity when testing was done at pH 6.5 as compared to pH 7.5, and with trout weighing 2.0 g as compared to trout weighing 1.0 g. Folmar et al.'s (1979) results are unexpected given the small changes in test pH and fish size and are not supported by the present study or by work done by Hildebrand et al. (1982). These latter authors found that differing water type and conductivity did not affect toxicity.
FIGURE 1. SCHEMATIC REPRESENTATION OF SEAWATER CHALLENGE TESTING.

10-d Roundup herbicide exposure concentration: 2.78 mg/L 0.289 mg/L 0.029 mg/L Control

50 fish 50 fish 50 fish 50 fish

Post-herbicide exposure 24-h seawater challenge

25 fish @ 30 ppt salinity
plasma Na

10-d recovery, clean freshwater

Post-recover 24-h seawater challenge

25 fish

25 fish @ 30 ppt salinity
plasma Na

Figure 1. Schematic representation of seawater challenge testing.
Table 1. Results of acute lethality testing.

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Water type&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Total formulation&lt;sup&gt;b&lt;/sup&gt; (mg/L)</th>
<th>IPA salt of glyphosate&lt;sup&gt;b&lt;/sup&gt; (mg/L)</th>
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<sup>a</sup> Dechl. = dechlorinated, recons. = reconstituted  
<sup>b</sup> Values in parentheses are 95% confidence limits  
n.d. = no data

Seawater Challenge

The purpose of seawater challenge testing was to evaluate the potential sublethal toxicity of ROUNDUP. Sublethal toxicity was tested by using the sensitive seawater entry phase of the anadromous salmonid life-cycle. Seawater entry is a sensitive time when high natural mortality occurs due to the physiological stress imposed by adjusting from fresh to salt water (Clarke 1982). Since additional stress would be expected to increase mortalities, the question was asked: is seawater adaptation affected by ROUNDUP?

The adaptive process of smoltification is complex. The main adaptation provided is an active increase in salt excretion capacity. The efficiency of salt regulation can be measured by seawater challenge testing, which determines the concentration of Na+ in fish plasma following a 24-h seawater exposure. Fish with plasma levels greater than 170 meq/L grow more slowly, have reduced locomotor performance, and increased susceptibility to predation (Wedemeyer et al. 1980).

The results of seawater challenge testing are presented in Table 2. There was no effect on seawater adaptation of coho salmon due to ROUNDUP. Plasma sodium values were all less than 170 meq/L and were not significantly different from the controls. Survival values were between 95 and 100%. There were no significant differences between test and control values for hematocrit, condition factor, length and weight. There were no apparent behavioral abnormalities: the fish fed normally and gained weight during the test.
Table 2. Results of seawater challenge testing.

<table>
<thead>
<tr>
<th>Herbicide treatment (mg/L)</th>
<th>Plasma Na⁺ (mg/L)</th>
<th>Hematocrit[^a] (%)</th>
<th>Condition factor[^b]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-herbicide</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.029-2.78[^c]</td>
<td>24-25</td>
<td>155-158</td>
<td>36-39</td>
</tr>
<tr>
<td>Control</td>
<td>23</td>
<td>159</td>
<td>40</td>
</tr>
<tr>
<td>Post-recovery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.029-2.78</td>
<td>22-24</td>
<td>160-162</td>
<td>42-47</td>
</tr>
<tr>
<td>Control</td>
<td>25</td>
<td>160</td>
<td>45</td>
</tr>
</tbody>
</table>

[^a]: Hematocrit values = percent red blood cells by volume.
[^b]: Condition Factor = 100 x weight/length cubed.
[^c]: The range of values obtained for three test concentrations (0.029, 0.289 and 2.78 mg/L) are shown.

As summarized by Mitchell et al. (1987b), disruption of seawater adaptation has been shown to occur following sublethal toxicant exposure to heavy metals, low pH, contaminated sediments and fish disease therapeutic agents. Previous studies with other herbicides have shown no effects on seawater adaptation at concentrations of up to 0.16X the 96-h LC₅₀ value.

**CONCLUSIONS**

**Acute Lethality**

The toxicity values derived in the present study are generally within the range of previously determined values; the full range of values for 96-h LC₅₀ s to salmonids (Table 1) is from 15 to 55 mg/L based on the total formulation. Since the Maximum Environmental Concentration of the total formulation measured following aerial application at the manufacturer's recommended use-rates is 0.27 mg/L (Newton et al. 1984), no acute ROUNDPUP toxicity hazard to salmonids is expected during the course of this product's normal usage.

**Seawater Challenge**

The maximum exposure concentration of ROUNDPUP used in seawater challenge testing was 2.78 mg/L, based on the total formulation. No sublethal effects were observed at this level. Since this concentration is 10x the Maximum Environmental Concentration measured following aerial application at the manufacturer's recommended use-rates (Newton et al. 1984), this study indicates that chronic exposure to concentrations of ROUNDPUP of up to 10x the maximum concentrations encountered in the environment immediately following aerial application at the manufacturer's recommended use-rates will not affect subsequent seawater adaptation and survival of coho salmon.
ACKNOWLEDGEMENTS

This work was conducted under contract to Monsanto Co., St. Louis, Missouri, and I expressly thank Monsanto for permission to publish this information. I gratefully acknowledge Dave Mitchell (E.V.S. Consultants) and Tim Long (Monsanto) for their assistance in the studies which form the basis of this paper.

LITERATURE CITED


CHANGES IN THE INVERTEBRATE POPULATIONS OF THE MAIN STREAM AND BACK CHANNELS OF CARNATION CREEK, BRITISH COLUMBIA FOLLOWING SPRAYING WITH THE HERBICIDE ROUNDUP (glyphosate).

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Nanaimo, British Columbia V9R 5K6

ABSTRACT

Populations of macroinvertebrates were monitored at two sites in the main stream and at sites with bare mud and mud with rooted vegetation substrates in four tributary swamps. Three tributary swamps (750-trib, 1500-trib, 1600-trib) and one site in the main stream were influenced by the herbicide ROUNDUP (glyphosate) after aerial application. Any impacts from the herbicide were not easily detectable because macroinvertebrate densities varied with substrate types, with the seasons and with previous hydrological conditions. In the main stream, a negative relationship between density and stream flow indicated that after frequent freshets macroinvertebrate densities were 42% lower at the treated versus untreated site, although the difference was not statistically significant (p = 0.09). In the swamps, density of organisms on the surface of the substrate was related to stream flow with a cubic polynomial (R^2 = 0.45). Density maxima occurred during median flows, while density minima occurred during periods with extremes of flow. During periods of freshet, densities in the treated swamp were half those of the untreated swamp.

INTRODUCTION AND METHODS

This paper describes changes in the populations of benthic invertebrates at two sites in the main stream and in four tributary swamps between 1983 and 1986. Three of these tributary swamps (trib.750; trib.1500; trib.1600) and most of their drainage basins were sprayed with ROUNDUP (glyphosate) during September 6-15, 1984 (Reynolds et al. 1989). A treatment of 2.12 kg/ha was applied with a Bell-47 helicopter and 7.9m long MICROFOIL BOOM. In the main stream one site was above (2350m) and one site was below (630m) the confluences with these treated tributaries. Tributary 2600 was an untreated control. The areas that were adjacent to all sites had been logged and the logging slash burned between January 1976 and September 1981. Details of the design and forestry plan of the Carnation Creek Watershed Project were reported earlier (Dryburgh 1982; Scrivener 1988).

Between November 1982 and June 1986, paired samples were collected from two main stream riffles monthly during the summer and every 2 months during the winter. A cylinder (0.144 m^2) with a surrounding 200 µm mesh net was pushed into the streambed and the enclosed substrate was agitated to a depth of 15 cm. All dislodged invertebrates and detritus were washed by the current into a net that formed the downstream end of the cylinder. The samples were preserved in 5% formalin. In the laboratory, the samples were split with a plankton splitter and a proportion sorted under 50x magnification. Benthic invertebrates were identified to species when possible and the density of mayflies, stoneflies, dipteran larvae, and caddisflies (fish-food organisms) were expressed in no./m^2.
At 2-month intervals between May 1984 and June 1986, two or three replicate samples of macroinvertebrates were also collected in the swamps from sites with substrates of bare-mud and of mud and rooted vegetation. A 10 x 10-cm sled was rapidly pulled a measured distance over the bottom and the organisms on the surface of the substrate and grassy vegetation were caught in the trailing 200 µm net (Sibert et al. 1977). Comparable samples were also obtained from tributaries 750 and 1500 on May 11 and September 6 of 1984. No samples were obtained when the sites were dry between July and October 1985. Swamp and main stream samples were processed in the same manner. This sampling technique does not provide accurate estimates of total macroinvertebrate densities in the swamps (Edmondson and Winberg 1971), but it does provide comparable data of the component that is useful as salmonid food (Sibert et al. 1977). Occasionally organisms that lived in the mud were caught when the sled dug into the substrate. These animals were excluded from the analysis (eg. bivalves, nematodes, worms).

Water levels were continuously recorded at B-weir and C-weir. Stage/discharge curves that were updated at least five times a year were used to compute stream flow (cubic feet/sec., cfs) from water level. Mean stream flow during the 60-day period prior to each sampling of macroinvertebrates was used as an indicator of previous hydrological conditions. Flows at B-weir were used for main stream samples, while C-weir flows were used for swamp samples. Tributary C separates the watersheds of tributary 1600 and 2600.

RESULTS AND DISCUSSION

Differences in Density Among the Sites

Macroinvertebrates in the main stream and tributary swamps consisted of different communities of organisms. In the main stream, most organisms were adapted to living in fast flowing riffles. Mayflies, stoneflies and dipteran larvae dominated the community (Culp and Davies 1983). Mayflies such as Cinygmula sp. and Epeorus sp. that have flattened body forms were most common, but Baeis sp. was also present in large numbers. Species of Alloperla, Capnia, Kathoperla, and Nemoura were the most common stoneflies. Dipterans were mainly represented by midges (chironomids) of the Tanypodinae and Orthocladiinae subfamilies. In the swamps, the fish-food organisms consisted mainly of dipteran larvae, copepods, ostracods, mayflies, amphipods, and caddisflies. Stoneflies were occasionally represented by Paraleuctra sp. Mayflies such as Amelorus sp. and Paraleptophlebia sp. were found at sites with rooted vegetation. Dipteran larvae were represented by midges, biting-midges (Ceratopogonids, no-see-ums), and black flies (Simulids).

In tributary swamps, greater numbers of fish-food organisms were found at sites with rooted vegetation than at sites with bare-mud substrates (Table 1). At rooted sites, mean densities were 4 times greater in tributary 750, while they were 10 times greater in tributary 1500. Therefore data from sites with different substrates were analyzed separately so that any impacts from the herbicide could be detected.

Seasonal Variation

Seasonal variation of densities made interpretation of herbicide impacts difficult. In the main stream, the density of the benthos changed from 7-fold to 14-fold annually between November 1982 and June 1986 (Fig. 1). An annual peak occurred each summer when water levels were near the minimum, but when surface water still flowed in the stream (Fig. 1). Annual minima occurred when winter freshets were frequent. The minimum density was observed on January 15, 1984 (375/m²; Fig. 1). 10 days after the largest freshet occurred during the study (64 m³/s; Scrivener 1988).
Table 1. Mean densities observed in samples of fish-food organisms from tributaries 750, 1500, 1600, and 2600 between May 1984 and April 1986. Densities where Scirpus grasses predominated are shown, but they were also included within the rooted-vegetation type.

<table>
<thead>
<tr>
<th>Site</th>
<th>Substrate type</th>
<th>Number of samples</th>
<th>Mean density no/m²</th>
<th>Comparisons by Mann-Whitney U tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>trib. 750</td>
<td>bare-mud</td>
<td>2</td>
<td>50.0</td>
<td>U = 1 p = 0.056</td>
</tr>
<tr>
<td></td>
<td>rooted-vegetation</td>
<td>7</td>
<td>202.0</td>
<td></td>
</tr>
<tr>
<td>trib. 1500</td>
<td>bare-mud</td>
<td>2</td>
<td>45.0</td>
<td>U = 0 p &lt; 0.05</td>
</tr>
<tr>
<td></td>
<td>rooted-vegetation</td>
<td>5</td>
<td>484.9</td>
<td></td>
</tr>
<tr>
<td>trib. 1600</td>
<td>bare-mud</td>
<td>20</td>
<td>80.6</td>
<td>U = 33 p &lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>rooted-vegetation</td>
<td>24</td>
<td>540.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>scirpus</td>
<td>13</td>
<td>732.1</td>
<td>U = 106 p = 0.45</td>
</tr>
<tr>
<td>trib. 2600</td>
<td>bare-mud</td>
<td>19</td>
<td>249.5</td>
<td>U = 96 p = 0.002</td>
</tr>
<tr>
<td></td>
<td>rooted-vegetation</td>
<td>28</td>
<td>687.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>scirpus</td>
<td>15</td>
<td>1081.0</td>
<td>U = 103 p = 0.037</td>
</tr>
</tbody>
</table>

Changes of water level in the ephemeral tributaries have forced swamp macroinvertebrates to develop life cycles with a different seasonal pattern. Peak densities occurred during spring, when water levels were moderate and prior to the emergence of adults from the swamps (Fig. 2). Annual lows occurred during summer and autumn, when the swamps were either dry or nearly dry and when macroinvertebrates often entered resting stages (eggs, pupae; Williams and Hynes 1976).

Densities usually varied from 100/m² to 2400/m² annually. This 24-fold change also made any herbicide impacts difficult to detect. The magnitude of annual variation was similar at sites with substrates of bare-mud, but the densities were lower (Fig. 3).

Stream Flow Influences on Density

In the main stream, the density of benthic fish-food organisms was negatively correlated with mean stream flow during the 60-day period prior to sampling (Fig. 4). Relationships were also obtained between density of macroinvertebrates and stream flow during shorter and longer time periods, but this 60-day mean produced the most consistent results. Stream flow explained 47% of the variability at 630m (r²) and 29% of the variability at 2350m in these densities (Fig. 4). Densities were low after frequent freshetting, while they were high during periods of stable low flows. Deviations from the correlations tended to be positive during the spring sampling period just prior to emergence of adults from the stream (Fig. 4, triangles). During the summer, very high
Figure 1. Mean densities of macroinvertebrates obtained for paired samples from station 2350 between November 1982 and June 1986 (winter = W, spring = S, summer = S, autumn = A). This site is 2350m upstream of the estuary in the main stream of Carnation Creek, British Columbia.

Figure 2. Mean densities of fish-food organisms observed on mud substrates with rooted vegetation in two tributary swamps during the 12 sampling periods between May 1984 and June 1986 (spring = S, summer = S, autumn = A, winter = W). Tributary 1600 (solid-bars) was sprayed with herbicide, while tributary 2600 (clear-bars) was not treated.
densities probably occurred because the organisms were forced into a smaller wetted area as stream flow declined, and because new recruits from hatching eggs were becoming big enough to be retained by the net of the sampler. During the winter, they dispersed into a greater wetted area and many organisms were scourred from the streambed and transported downstream during freshets (Culp and Davies 1983).

In the tributary swamps density of fish-food organisms was related to stream flow, but the relationship was of a different manner. Unlike the main stream, densities that were obtained with the benthic sled were not linearly correlated with stream flows at either tributary 1600 ($r = -0.08$) or tributary 2600 ($r = -0.04$). When the data were grouped into periods with different ranges of stream flow (0-1cfs, 1-2cfs, 2-3cfs, 3-4cfs, 4-6cfs, and >6cfs) mean densities were significantly different among periods at both tributary 1600 ($F = 5.3$, $p < 0.01$) and tributary 2600 ($F = 3.6$, $p < 0.05$). High densities occurred during periods with moderate stream flows, while low densities occurred during periods with extremes of flow. A cubic polynomial explained 45% of the density variation in tributary 1600 and 32% of the density variation at 2600 (Fig. 5). Significant improvements of fit were obtained for each step of the polynomial calculation. Most of the aquatic insects appeared to emerge from the swamps as adults before the summer dry period, while other organisms entered resting stages within the substrate mud. Low densities during the winter probably occurred because organisms dispersed or were lost during freshets.
Figure 4. Relationships observed between mean stream flow (previous 60-d period) and the density of benthic organisms in samples from stations 2350m (A.) and 630m (B.) in Carnation Creek. Dots indicate densities from pre-herbicide samples, while squares indicate post-herbicide densities. Solid squares show densities of the first three sampling periods following herbicide application. Triangles indicate densities prior to adult emergence during the spring of 1983, 1984 (solid = pre-herbicide), 1985 and 1986 (open = post-herbicide).
Figure 5. The relationship observed between stream flow at C-weir and the density of fish-food organisms on substrates of mud and rooted vegetation in two tributary swamps at Carnation Creek, British Columbia. The watershed of tributary 2600 (A.) was an untreated control, while 1600 tributary (B.) was sprayed with herbicide.
Apparent Impacts of the Herbicide

In the main channel, the relationship between density of benthic organisms and stream flow was improved by using the logarithm of stream flow (Table 2), indicating that the relationship is probably not just a simple linear one. Explained variability increased at 630m from 47 to 60%, but it was unchanged at 2350m (30%). No difference was observed between the pre-herbicide and post-herbicide relationships at 2350m, the control site, but there appeared to be a difference at 630m, the treated site, although it was not statistically significant (Table 2; steeper slope, slightly greater intercept). After the herbicide treatment, densities tended to be much smaller at high flows (-54% at 60 cfs), whereas they tended to be greater at low flows (+30% at 3 cfs). Any negative impact appeared to manifest itself only after freshets of the first post-herbicide winter (Fig.4; solid squares). Probable mechanisms for any loss of organisms were either the compounding influence of the herbicide in the water with scour, or the compounding influence of increased sediment transport with high water velocities during storms. Loss of streamside vegetation can make more sediments available for transport (Bormann and Likens 1979). Sediments that saltate downstream during freshets have increased since logging (Scriver and Brownlee 1989), and they are known to be an effective scouring agent of benthic organisms (Culp and Davies 1983).

Table 2. Relationships observed between stream flow at B-weir (60-d mean) and the density of benthic fish-food organisms at stations 630 and 2350 before and after the herbicide ROUND UP was used at Carnation Creek, British Columbia. Stream flow is the independent variable X, while density is dependent variable Y.

<table>
<thead>
<tr>
<th>Station and scenarios</th>
<th>Relationship</th>
<th>corr. coeff.</th>
<th>Number of sampling periods</th>
<th>Prob.</th>
<th>Comparison of intercepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2350m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>all yrs</td>
<td>$Y = \log(X) \times -1803.4 + 4499.5$</td>
<td>-0.54</td>
<td>28</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>pre-herb.</td>
<td>$Y = \log(X) \times -2104.8 + 5072.4$</td>
<td>-0.60</td>
<td>15</td>
<td>0.02</td>
<td>F = 0.16</td>
</tr>
<tr>
<td>post-herb.</td>
<td>$Y = \log(X) \times -0.45$</td>
<td>-0.45</td>
<td>13</td>
<td>0.12</td>
<td>p = 0.85</td>
</tr>
<tr>
<td>630m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>all yrs</td>
<td>$Y = \log(X) \times -4259.1 + 9909.8$</td>
<td>-0.78</td>
<td>28</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>pre-herb.</td>
<td>$Y = \log(X) \times -2963.3 + 7931.1$</td>
<td>-0.70</td>
<td>15</td>
<td>&lt;0.01</td>
<td>F = 2.65</td>
</tr>
<tr>
<td>post-herb.</td>
<td>$Y = \log(X) \times -0.86$</td>
<td>-0.86</td>
<td>13</td>
<td>&lt;0.001</td>
<td>p = 0.09</td>
</tr>
</tbody>
</table>

In the tributary swamps densities of fish-food organisms in relation to stream flow were similar for 1600 and 2600 at low flows, but they became progressively greater in tributary 2600 at higher flows. Peak densities were 8% greater in tributary 2600 when flows were 2 cfs (983/m
versus 1073/m²), while they became 2-times greater when densities were lower and flows were 4.5 cfs (160 versus 360/m², Fig. 5). These differences could be entirely due to spatial variation between sites, but this is unlikely because consistent differences between the swamps did not appear until the spring and summer of 1985 (Figs. 2 and 3). Enough samples were not obtained from the swamps before the herbicide treatment (four sampling periods) to compare pre and post treatment times as was done for the main stream. If some of these differences between the swamps represent a real herbicide impact, results would be consistent with those from the main stream. Any impacts seemed to be more pronounced after periods of freshet.

**MANAGEMENT IMPLICATIONS AND CONCLUSIONS**

The densities of fish-food organisms vary with the seasons in response to a very dynamic environment. During summer and early autumn, if stream flows are adequate, numbers peak as the next generation enters the larval aquatic stage, as growth and food resources peak (detritus, epiphyton), and when sediments and the bed are stable (Culp and Davies 1983). During the late autumn and winter, numbers decline as organisms disperse or when storm flows with accompanying sediments scour them from the substrate. Numbers also vary with substrate composition and hydrological regime.

Superimposed on these variations were influences from logging and silvicultural activities. Logging impacts were most pronounced during the winter at sites with logging to the stream bank. After logging, benthic organisms were reduced during the winter by 24% at 630m and by 41% at sites with logging to the stream banks (Culp and Davies 1983). The stream banks of all of our sites except 630m were logged. Our results indicated that any herbicide impacts could be similar in magnitude to those obtained after logging, and that they would also be most pronounced after periods of freshet. The organisms were scoured from the bed and transported down stream. They would be lost to the stream ecosystem if adequate habitat could not be reached.

**ACKNOWLEDGEMENTS**

Assistance in the field from Messrs. B.C. Andersen, S.G. Baillie, T.G. Brown, A. Langston, and R. Leahy was gratefully accepted. Partial funding for the processing of samples was provided by the B.C. Ministry of Forests. The manuscript was reviewed by H. Mundie, B. Holtby and C. Levings.

**REFERENCES**


EFFECTS OF THE HERBICIDE ROUNDUP\textsuperscript{1} ON COHO SALMON FINGERLINGS IN AN OVER-SPRAYED TRIBUTARY OF CARNATION CREEK, BRITISH COLUMBIA

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ABSTRACT

The responses of coho salmon fingerlings to the over-spraying of a tributary of Carnation Creek with the herbicide ROUNDUP are described. Qualitative observations of caged coho fingerlings at exposed sites in the over-sprayed tributary indicated some stress 2 h after application and within 24 h of application some mortality (2.6\%) of those fish was observed. Caged fish at other sites showed no similar signs of stress and no mortality immediately after application. We observed no unusual mortality of the approximately 120 coho fingerlings estimated to be resident in the tributary at the time of the herbicide application. In comparison with unaffected sites, catch per unit effort in the tributary declined immediately after the application but recovered within 3 weeks, suggesting that coho fingerlings had been stressed by some component of the herbicide spray. In comparison with 1-3 years of pre-spray data, in the two years following application no changes in over-winter mortality, growth rates, probabilities of entering and leaving the tributary or timing of spring emigration were observed that could be unambiguously attributed to the herbicide.

INTRODUCTION

Many studies of the impacts of agricultural and silvicultural chemicals on fish are extrapolations of short-term toxicological effects (e.g. 96-h $L_C_{50}$ concentrations), done in the laboratory on standard test organisms under tightly controlled conditions. There are very few studies that examine possible sub-lethal effects that could exist for several years after the application of a toxic chemical. In this study we examine several aspects of the responses of coho salmon ($Oncorhynchus kisutch$) juveniles after a tributary of Carnation Creek used by the fish as winter habitat was intentionally over-sprayed with the herbicide ROUNDUP (glyphosate).

The specific objectives of this study were to: 1) document short-term toxicity of the herbicide formulation on a native salmonid in a natural habitat; 2) document any changes in the way coho salmon exploited the tributary as a winter refuge; and 3) to document long-term (1-2 yr) effects of the herbicide on population parameters of the coho salmon such as mortality and growth rates.

\textsuperscript{1} Registered trademark, Monsanto Corporation, St. Louis, MO.
METHODS

Details of the site and the herbicide application are extensively documented elsewhere (Reynolds et al. 1989). The over-sprayed tributary 1600T is largely contained in an 8.9-ha plot that was sprayed in the mid-afternoon of September 14, 1984. Nominal application rate of ROUNDUP was 2.11 kg glyphosate/ha. The application rate achieved was 1.88 kg/ha (Feng et al. 1989). The water temperature ranged between 9.8°-13.1°C. Discharge was approximately 0.01 m³/s at the outlet of the tributary. In most of the middle section of the tributary there was no flow, but rather a series of shallow, isolated pools (Fig. 1). The upper section was mostly dry. The conductivity and pH were not measured but had ranged in the past between 40-60 µmho/cm², and 5.5-6.5 respectively at similar flow levels.

HERBICIDE FISH STUDY

![Map of the study area showing location of fish cages and an indication of canopy over 1600T prior to the herbicide spray.]

Figure 1. Sketch map of the study area showing location of fish cages and an indication of canopy over 1600T prior to the herbicide spray.

The riparian vegetation in the lower 200 m of the tributary was dominated by alder 4-6 m tall, which had formed a nearly complete canopy over the stream (Fig. 1). In the middle section of the tributary there were scattered alder and little canopy closure while in the upper sections there was little alder and no canopy. In most of the ecological studies described below comparisons are drawn between the over-sprayed tributary (1600T) and an unsprayed tributary approximately 1 km further up the stream (2600T). Although 2600T is similar in size to 1600T, the riparian vegetation there is less well developed and throughout most of its length there is no canopy and only scattered alders. Winter temperatures in 2600T were generally 1-2°C colder than in 1600T. Both of the tributaries have extensive areas in their upper reaches comprised of ephemeral shallow ponds and channels (Fig. 1). These areas are largely dry in the summer, but are extensively used by coho during winter floods (Brown 1987). Our studies were generally restricted to areas that were permanently wet.
In order to document short-term toxicity, a total of 430 coho fingerlings were placed in 28 mesh cages at six sites in the stream (Fig. 1). Each cage had a volume of approximately 0.2 m$^3$ and was covered on three sides with 3 mesh/cm hardware cloth. Eight of the cages were located in the main-stem below the confluence with the over-sprayed tributary. The fish were caught with a pole seine in a side-channel of the nearby Sarita River and transported to Carnation Creek in twelve 25 L plastic containers. All fish were caught, transported and caged (15-17/cage) within a 2-h period on August 31. One fish died during transportation, probably from injuries sustained during the capture. The remainder of the fish appeared to be vigorous. Several hours after being caged, at which time the fish were first observed as unobtrusively as possible, there were no overt behavioral signs of distress. After a small storm on September 5, all of the cages at 1600M were displaced downstream and lodged in a debris jam causing the death of 16 of the 60 fish and probably severely stressing the remaining fish. The cages were returned to a more protected location. The remaining fish appeared to have recovered by September 14, but the stress of the storm probably compromises using mortality in those cages as an indication of herbicide toxicity. All caged fish were carefully observed every other day until the application date. On September 14 the cages were observed in the morning prior to the spray, within 2 h of the spray, and thereafter in the morning of each day until the fish were removed from the cages on September 21, individually weighed and returned to the Sarita River side-channel.

In order to monitor fish movements into and out of the two tributaries, small, two-way fences at the mouths of 1600T and 2600T were monitored daily throughout the winters of 1981/82 (or 1982/83 at 2600T) through 1985/86. Fish moving into or out of the tributaries were identified and their fork-lengths determined. The numbers entering and leaving a tributary were subsequently used in the estimation of population mortality rates within the tributaries. The number of fish entering each tributary was compared to the number of coho salmon in the main-stem in order to determine whether the likelihood of a fish entering 1600T was diminished in either 1984/85 or 1985/86. The ratio of the numbers of fish entering/numbers of fish leaving were used to determine if probabilities of emigration from 1600T increased after the herbicide application. In the spring of each year, pre-smolt coho salmon leave the tributaries and eventually enter the ocean as smolts. A relationship between the timing of smolt emigration and spring temperatures has been observed in the main-stem (Holby 1988a). We examined the timing of emigration from the tributary in order to determine if it had been affected by herbicide-related temperature changes (Holby 1989).

At various times during the winter we estimated the numbers of coho salmon in the two tributaries using Peterson mark-recapture estimates (Ricker 1975) on fish trapped in small Gee-minnow traps baited with canned sardines. The capture and re-capture runs were always done over-night. The locations of all traps and the numbers of fish caught in each trap were recorded. After the capture run of each estimate, all of the fish were measured to the nearest mm weighed to the nearest 0.05 g, and cold-branded (Everest and Edmundson 1967) with a mark specific for the tributary and particular estimate date. After 1-2 weeks the recapture run was conducted using similar numbers of traps and trap locations. All of the fish captured during these runs were carefully examined for brands and measured to the nearest millimetre.

**RESULTS**

The cages in the upper section of the over-sprayed tributary were placed in the middle of a large pool, with no canopy cover (Fig. 1). The tops of those cages were thoroughly soaked with herbicide spray. Two cages were placed in a small pool in the lower part of the tributary that had a dense canopy cover. Very little spray penetrated to the water surface at that point and the tops of the cages were dry. The remaining two cages were placed in the pool immediately below the
fence, where the canopy cover was approximately 40%. Some spray reached the water surface and while the tops of the cages were wet, they had not been soaked as thoroughly as in the upper section. Two hours after spraying, the caged fish in the upper section of 1600T showed exaggerated opercular movements at elevated rates compared to fish in the untreated areas. In the opinion of the observers, the fish in that one section were stressed. Fish in other areas, including the lower section of 1600T appeared normal and showed no behavioral changes. All of the fish were behaving normally the next day and remained so until the end of the experiment.

Some mortality occurred in the caged fish in 1600T the day of the spraying (Table 1). Two fish in the upper section of the tributary (3.4%) and one fish at the fence (3.3%) died between Sept. 14, 2 h after spraying and the morning of September 15. No fish had died in 1600T until that time. No fish died at the other sites immediately after spraying (Table 1). If we had completed the experiment on September 20 rather than September 21 then the only deaths that would have been observed would have been in the exposed sites in 1600T. However, on September 21 six fish in one of the four cages in 2600T and one fish in 1600M died (Table 1). While the death at 1600M was possibly the result of injuries sustained in the earlier flood, there is no explanation for the deaths at 2600T. However, the timing of the deaths in 1600T and their occurrence only in the two areas directly exposed to the herbicide does suggest a causal connection with the herbicide application.

Table 1. Summary of short-term toxicity in caged coho fingerlings

<table>
<thead>
<tr>
<th>Site</th>
<th>No. cages</th>
<th>Date 1</th>
<th>Date 2</th>
<th>Date 3</th>
<th>Date 4</th>
<th>Date 5</th>
<th>% Mortality after spraying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main stem below spray</td>
<td>4</td>
<td>8/31a</td>
<td>9/12</td>
<td>9/14b</td>
<td>9/15</td>
<td>9/21</td>
<td>3.4</td>
</tr>
<tr>
<td>1600M</td>
<td>4</td>
<td>60</td>
<td>33</td>
<td>29</td>
<td>29</td>
<td>28</td>
<td>3.4</td>
</tr>
<tr>
<td>Main stem above spray</td>
<td>4</td>
<td>64</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2600M</td>
<td>4</td>
<td>60</td>
<td>33</td>
<td>29</td>
<td>29</td>
<td>28</td>
<td>3.3</td>
</tr>
<tr>
<td>Over-sprayed tributary</td>
<td>2</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>29</td>
<td>29</td>
<td>3.3</td>
</tr>
<tr>
<td>1600T-fence</td>
<td>2</td>
<td>30</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1600T-mid</td>
<td>2</td>
<td>59</td>
<td>59</td>
<td>59</td>
<td>57</td>
<td>57</td>
<td>3.4</td>
</tr>
<tr>
<td>1600T-upper</td>
<td>4</td>
<td>119</td>
<td>117</td>
<td>117</td>
<td>114</td>
<td>114</td>
<td>2.6</td>
</tr>
<tr>
<td>Overall</td>
<td>8</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>62</td>
<td>8.8</td>
</tr>
</tbody>
</table>

a Experiment started.
b Herbicide applied mid-day, cages examined before spraying.

We attempted to detect sub-lethal stress by comparing the weights of caged fish among sites using ANOVA with the co-variate of fork-length. We have assumed that the initial distribution of fish was random with respect to fish weight. The fork-length-weight relationship was shown to be the same for all sites. When the fish from 1600M were included, significant between site differences were detected (Table 2). Since the fish from 1600M had been severely stressed by the flood 9 days before the herbicide application, and that stress was clearly shown by their low weights (after standardizing for fork-length), those fish were excluded, and the analysis repeated. There were no significant differences between the standardized weights among the remaining five sites (Table 2). The absence of measurable weight loss is consistent with the observational data from the over-sprayed tributary which suggested that any stressed caused by the herbicide was short-lived.
Table 2. Comparison of weights of caged fish at 6 test sites on termination of the experiment, 1 wk after the spray. "p" values indicate probabilities that the mean weights being compared are not different.

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
<th>mean weight (g)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1600M</td>
<td>28</td>
<td>2.325</td>
<td>all sites: p &lt; 0.005</td>
</tr>
<tr>
<td>1600T-fence</td>
<td>29</td>
<td>2.198</td>
<td>1600 &amp; 2600 sites: p = 0.08</td>
</tr>
<tr>
<td>1600T-mid</td>
<td>28</td>
<td>2.757</td>
<td></td>
</tr>
<tr>
<td>1600T-upper</td>
<td>57</td>
<td>2.552</td>
<td></td>
</tr>
<tr>
<td>1600T-overall</td>
<td>114</td>
<td>2.512</td>
<td>1600 overall &amp; 2600 overall: p &gt; 0.1</td>
</tr>
<tr>
<td>2600M</td>
<td>62</td>
<td>2.650</td>
<td></td>
</tr>
<tr>
<td>2600T</td>
<td>62</td>
<td>2.355</td>
<td></td>
</tr>
<tr>
<td>2600 - overall</td>
<td>124</td>
<td>2.502</td>
<td></td>
</tr>
</tbody>
</table>

* a 1 fish escaped to Carnation Creek prior to measurement.

Another indication of a short-lived stress on the fish in 1600T was the observed decrease in catch per unit effort (CPUE) in 1600T just after the spray (Fig. 2A). One unit of effort was a single Gee minnow trap. Two weeks after the spray, CPUE in 1600T had recovered to pre-spray levels. CPUE in both tributaries was correlated with water temperatures (Fig. 2B), and the observed decline in CPUE over the winter (Fig. 2A) was associated with decreasing water temperatures. The sample point for 1600T immediately after the spray is outside the 1% confidence limits of the temperature-CPUE relationship (Fig. 2B).

There were no significant changes in the abundance of either coho salmon or cutthroat trout (*Salmo gairdneri*) in 1600T when mark-recapture estimates of abundance made 6 days, 2, 4 and 6 weeks after the spray are compared with estimates made 3 weeks before the spray (Table 3). Since there was no measurable mortality resulting from the spraying, the decreased value of CPUE in 1600T after the spraying was probably due to reduced activity of the fish, which might be an indication of stress.

Early winter survival (October-January) was compared in both side-channels for three winters: 1983/84, 1984/85 and 1985/86 (Table 4). The observed survival rates in both 1600T and 2600T are comparable to the overall population survival rates which ranged from 73-92% during this period (Holtby 1988a). The estimated survival rates in the tributaries are similar to those observed in the tributaries before logging (Bustard and Narver 1975). With the exception of cutthroat trout in 2600T, survival rates in the two tributaries were notably constant in the three years. There is nothing to suggest that the survival of coho salmon or cutthroat trout in 1600T was affected by the herbicide, either directly in 1984/85 or indirectly in 1985/86.
Figure 2. A: Catch per unit effort in 1600T and 2600T for early winter 1984, following herbicide spray in 1600T. B: Relationship between catch per unit effort and temperature in 1600T and 2600T over the same period.
Table 3. Estimated numbers of coho salmon and cutthroat trout in 1600T and 2600T around the time of herbicide application. The estimated population sizes have been corrected for movements through the fences on each of the tributaries. Approximate 95% confidence intervals are shown for each estimate.

<table>
<thead>
<tr>
<th>Date of Estimate</th>
<th>Aug. 23/25</th>
<th>Sept. 19/20</th>
<th>Sept. 27/28</th>
<th>Oct. 4/5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days after Spray</td>
<td>-21</td>
<td>+7</td>
<td>+14</td>
<td>+21</td>
</tr>
</tbody>
</table>

Coho salmon
- 1600T: 142 (96-227) 110 (76-180) 156 (101-241) 116 (87-171)
- 2600T: 176 (125-264) 232 (160-369) 201 (149-298) 185 (129-227)

Cutthroat trout
- 1600T: 54 (31-112) 59 (35-118) 58 (37-120) 50 (27-104)
- 2600T: 72 (45-128) 119 (77-210) 124 (80-212) 103 (74-154)

Table 4. Over-winter survival of coho salmon and cutthroat trout fingerlings in two permanent tributaries.

<table>
<thead>
<tr>
<th>Year</th>
<th>1600T (treated)</th>
<th>Population estimate</th>
<th>% Survival</th>
<th>2600T (untreated)</th>
<th>Population estimate</th>
<th>% Survival</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coho salmon</td>
<td>83/84</td>
<td>353  298</td>
<td>84.4</td>
<td>355  303</td>
<td>355  303</td>
<td>85.4</td>
</tr>
<tr>
<td></td>
<td>84/85</td>
<td>118  108</td>
<td>91.5</td>
<td>147  118</td>
<td>147  118</td>
<td>80.3</td>
</tr>
<tr>
<td></td>
<td>85/86</td>
<td>324  325</td>
<td>100.3</td>
<td>415  323</td>
<td>415  323</td>
<td>77.8</td>
</tr>
<tr>
<td>Cutthroat trout</td>
<td>83/84</td>
<td>133  134</td>
<td>100.8</td>
<td>89   49</td>
<td>89   49</td>
<td>55.1</td>
</tr>
<tr>
<td></td>
<td>84/85</td>
<td>49  47</td>
<td>95.9</td>
<td>103  84</td>
<td>103  84</td>
<td>81.6</td>
</tr>
<tr>
<td></td>
<td>85/86</td>
<td>44  48</td>
<td>109.1</td>
<td>134  58</td>
<td>134  58</td>
<td>43.3</td>
</tr>
</tbody>
</table>

The growth rate data for coho salmon in the tributaries over the same early winter period gives no indication of any adverse effect of the herbicide in either 1984/85 or 1985/86 (Table 5). In 1600T, growth rates were higher in 1984/85 than growth rates in 1983/84 and 1985/86, but in 2600T the converse was true. However, none of the differences were statistically significant. The higher growth rates in 1600T during 1984/85 could have been associated with the small numbers of fish in that year, but density dependent growth rates during the winter have not been previously observed in Carnation Creek (Holby 1988b) and no increase in growth in 2600T was seen with similar low numbers of fish in that same year (Table 5). The differences in fish numbers between the years are clearly reflected however, by the differences in size at the start of the winter (Fig. 3). Summer rearing densities have been shown to be strongly correlated with the size of coho fingerlings in the fall (Holby 1988b).
Table 5. Over-winter growth rates of coho fingerlings in two permanent tributaries. Both instantaneous and arithmetic growth rates were calculated, although arithmetic rates generally fit the data better.

<table>
<thead>
<tr>
<th>Year</th>
<th>1600T (treated)</th>
<th>2600T (untreated)</th>
<th>Ratio 1600/2600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>arithmetic rates (mm.day$^{-1}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>83/84</td>
<td>0.0497</td>
<td>0.0695</td>
<td>0.715</td>
</tr>
<tr>
<td>84/85</td>
<td>0.0614</td>
<td>0.0605</td>
<td>1.015</td>
</tr>
<tr>
<td>85/86</td>
<td>0.0554</td>
<td>0.0693</td>
<td>0.799</td>
</tr>
<tr>
<td></td>
<td>instantaneous rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>83/84</td>
<td>0.000724</td>
<td>0.00102</td>
<td>0.711</td>
</tr>
<tr>
<td>84/85</td>
<td>0.000806</td>
<td>0.000815</td>
<td>0.989</td>
</tr>
<tr>
<td>85/86</td>
<td>0.000827</td>
<td>0.000976</td>
<td>0.847</td>
</tr>
</tbody>
</table>

In addition to simple measurements of mortality and growth in the over-sprayed tributary we considered whether coho salmon were more or less likely to enter the tributary after it had been over-sprayed, and whether fish were more likely to leave it. Five years of fence data were available for 1600T and four years of data for 2600T. For 1600T, coho salmon appear to have been less likely to enter the 1600 tributary in the two winters after spraying compared with the three years before spraying for which we have data (Table 6). The decline in the two post-spraying years was marginally significant at the 10% level ($p=0.09$; two-tailed t-test, adjacent stream section). Although comparisons of 1600T with 2600T are hampered by the lack of data from 2600T for 1981, the numbers of fish entering 2600T in relation to potential immigrants, did not decline in 1984/85 or 1985/86 (Table 6).

Table 6. Numbers of coho salmon fingerlings entering the tributaries during the September-December as proportions ($p$) of total main-stem populations and numbers in adjacent main-stem reaches.

<table>
<thead>
<tr>
<th>Year</th>
<th>1600T (treated)</th>
<th>2600T (untreated)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no. in stream</td>
<td>no. entering</td>
<td>no. stream</td>
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Figure 3. Size of coho salmon in early winter in A) 1600T and B) 2600T.
The number of fish leaving 1600T compared to the number entering the tributary appears to have fallen in the two years after spraying (Table 7). Whether the decreased probability of leaving the tributary was an effect of the herbicide or a continuation of a trend that was in evidence the year before spraying (Table 7) is uncertain, but the changes are statistically significant ($p=0.041$). However, a similar increase in the probability of remaining in a tributary was observed in 2600T (Table 7).

Table 7. Ratios of numbers of coho entering tributaries to numbers leaving during September-December

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There was a strong relationship between water temperatures in late spring (February-March) in 1600T and the median emigration date for pre-smolt coho (Fig. 4). Spring temperatures were not significantly affected by the herbicide application however (Holmy 1989), and consequently the herbicide had no indirect effect on the emigration timing of pre-smolts in 1600T.

**1600 emigration timing**

![Figure 4. Emigration timing of coho salmon pre-smolts leaving 1600T as function of spring water temperatures in 1600T. The years after the herbicide spray are indicated.](image-url)
DISCUSSION

Subjective observations of fish behavior, low levels of mortality after the herbicide application and a temporary depression in the catch per unit effort, suggest that coho salmon in 1600T were stressed by some component of the ROUNDUP glyphosate formulation or by some factor associated with the application itself. The concentrations of glyphosate and its metabolite reported in the water discharged from 1600T for 96 h after the application did not exceed 170 ppb and were less than 40 ppb for most of that time (Feng et al. 1989). Assuming the deposition rate of glyphosate in this experiment was 1.88 kg/ha (Feng et al. 1989) and that, on average water in 1600T was 0.3 m deep, expected maximum concentrations of glyphosate at the outlet would have been 600 ppb, nearly four times those observed. The greatest penetration of the herbicide to the water would have been in the upper half of the tributary where there was little or no canopy. At the time of application, most of the upper half of 1600T was comprised of small, isolated pools less than 0.5 m deep. Measured concentrations of glyphosate near the outlet are probably a poor indicator of concentrations in the upper section. Estimates of the 96-h LC$_{50}$ of ROUNDUP for rainbow trout range from 8.3 ppm (Folmar et al. 1979) to 28 ppm (Servizi et al. 1987). Approximately 50-150 times greater than observed concentrations at the outlet of 1600T but possibly as little as 12 times greater than concentrations in isolated pools in the upper tributary. Such levels should not have caused mortality, but might have caused some stress, particularly in the upper tributary where stress was, in fact, observed.

Glyphosate is reported to be rapidly degraded in acidic waters with an abundant microflora (Tooby 1985). Rapid degradation of the chemical and the flushing action accompanying a small storm the day after application dramatically reduced glyphosate levels in 1600T and concentrations were less than 40 ppb 8 h after application, and were near the detection limit (0.05-0.1 ppb) 4 days after application (Feng et al. 1989). Rapid removal of the herbicide, and presumably of associated components of the ROUNDUP formulation, are consistent with our observations of rapid restoration of normal fish behavior (within 1 day), and recovery of CPUE in 1600T within no more than 2 weeks. However, our observation of stress appears anomalous. Hildebrand et al. (1982) observed no stress in caged rainbow trout exposed to ROUNDUP at concentrations approximately 10 times those likely to have been experienced by the fish in our study. Tooby (1985) notes that any deleterious effects of ROUNDUP have been observed at near-lethal concentrations, at least 10 times greater than those experienced in this study.

While there were indications that coho salmon avoided entering 1600T in the two years after the herbicide application, those results were not conclusive. Coho salmon enter their winter refugia during the first fall storms in September-November. It is conceivable that during the first fall storms after the application the levels of some component of the ROUNDUP formulation were detected and avoided by coho. Detectable residues did persist for in 1600T effluent for at least 2 months (Feng et al. 1989). Although avoidance reactions have been seen in the laboratory only at much higher levels (Tooby 1985), those tests were not conducted with fish in their natural habitats at a time when the fish were actively seeking winter refuge.

We were unable to detect any deleterious change in mortality rates or growth rates in the over-sprayed tributary, both in before/after comparisons or in paired comparisons with an untreated tributary. Although there were changes in the abundance of some of the invertebrate food organisms in 1600T (Scrivener and Carruthers 1989; Holty and Baillie 1989) few of those changes could be ascribed to herbicide effects and any decreases in the abundance of food were either without consequence to the fish or the consequences were too small to be detected. However, coho salmon are highly opportunistic feeders, which makes the task of linking changes in the abundance of potential food organisms and fish growth very difficult.
We suggest that the results we have presented here can be extrapolated elsewhere only with great caution. The herbicide formulation used in this study was not particularly effective in killing alder, which comprised most of the riparian vegetation around 1600T and at least half of the tributary had no or little riparian canopy anyway. The impacts of using a more effective herbicide in situations where more extensive riparian vegetation is present cannot be anticipated from this study. Carnation Creek is in a cool maritime climate where stream temperatures after canopy removal are not a great concern, even during the summer. Removal of the riparian vegetation in warmer situations would produce much larger temperature changes than were observed here (Holtby 1989) and might be damaging to salmonids.

Demonstrating the sub-lethal effects of any habitat alteration of fish is very difficult because of the generally small magnitude of any effect compared to the usually large magnitude of background variation and the dubious use of different sites as controls. Pella and Myren (1974) suggest that 10-20 years of data are minimal requirements to detect 50% changes in numbers of adult salmon. Some components of this study comprised included data from 2 years before spray and 3 years after spraying, a relatively long study in the context of recent ecological research, but probably not long enough to detect subtle and indirect effects of defoliating the riparian zone, or, viewed from a position of advocacy, not long enough to be certain that our failure to detect effects actually means that there were none.

ACKNOWLEDGEMENTS

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PERSPECTIVE: RISK MANAGEMENT AND THE PUBLIC

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I am here to help you begin to synthesize the information you have heard over the last two days and begin to get an idea of what it means to you, or what you can do with this information when you go home. Whether you’re going to make any changes to your management strategies to make a difference. Or, indeed, can you at all? I am going to offer you about seven perspectives that have come to me in the last couple of days, things that are important to me. I, by the way, am an administrator, so these remarks are things that are important to me. I think they might be important to you. I offer them to you so they may stimulate you to start asking questions both of me and other speakers, and in particular tomorrow. That’s important.

The use of herbicides in B.C. forestry is very important in terms of efficiency. I offer to support that in 1987, this year, we put down about 30,000 ha of herbicides. In 1984 we put down 3,000-6,000 ha. You can see then, in terms of herbicide use in forestry we have made a quantum jump. I don’t want to suggest to you, however, that herbicides are a panacea as seen by B.C. Forestry or that they are deemed to be the only method that is appropriate. Control burns and mechanical treatments have increased as well during this period; in fact, in the last while they have doubled in use. On the whole reforestation business, especially backlog reforestation I might add, the heat has been turned up. I was reminded earlier today that British Columbia is the only western province that uses herbicides in any appreciable way in forestry. From a regulatory point of view that might pose an ominous concern. However, it also might be looked at from the point of view that British Columbia is the only province in western Canada that has a substantial forest industry as well, although that may change as Saskatchewan and others come into the market with aspen.

Now, the use of herbicides in terms of regulations is the other side of the coin. It’s a very regulated business. The product is regulated in registration; the techniques are a great concern and are regulated very closely both in the permits and in the registration. As well, on the forest site where the stuff is going to be used, opportunity is heavily regulated in the permit process. The management is the subject of fishery and forestry discussions which is a heavily integrated and required process. The training of certified applicators is a very formal process that is fairly onerous and time-consuming and carefully undertaken. Public liaison is part of the process. The resulting data are brought in and integrated into the system that we have now. However, I would suggest that in the short term you are not going to see very many significant changes in the regulatory system in British Columbia that come out of this specific work. You will perhaps, in time. An administrative forester, who knows quite well the state of the silvicultural art in British Columbia, told me that in his opinion the pesticide-free zone and the related buffers that are imposed and used by foresters in their herbicide spraying are not so much to protect fisheries, or potable waters but, as a function of risk management, to keep an angry public at bay. They know very well that if they do what they do now, they can meet their objectives and really that’s all they want. I see no data presented here that will significantly
change the regulatory registration of products or the provincial regulatory process in the next couple of years. It might in small ways over time, but I think what we've seen is that, albeit some foresters want to reduce the size of their buffers, it's not inside the system by and large. The regulatory permit system will endure.

The herbicide-use program, and by that I mean both its use and its regulation, has evolved over about the last 15 years, and since the royal commission into pesticides and herbicides in the early 1970s has changed, but has endured as a system. It has changed with research added to it, such as you have heard today; it has, in particular, been modified by public discussion, researchers' discussion, by debate--sometimes quite heated--and by legal challenges. All of these things have changed the system, and in my view, have made it tougher and more resilient. The herbicide system, in general, works. It serves the purposes that everybody intended. Fisheries have their resources protected, by and large. It is possible to come up with an exception, but they're rare. Forestry is doing a dramatic job of increasing its reforestation and the permit system is part of that, and I am sure that the foresters would like it to diminish in bureaucracy. But the system is still allowing them to use herbicides, much more so that other provinces, or say in the western states. The public had direct input; again, you're going to find interest groups that take issue if they don't have enough, but relative to other public interest concerns issues, or areas where the public would be involved, they have a lot of involvement. Wildlife resources also have been looked at more lately, and is being quickly integrated into this regulatory and use process. The system allows the integration of new information such as you have heard and it is very receptive to changes and adaptation in a social evolutionary kind of way. It really does not lend itself at this point to monumental upheaval, e.g., the crossing out of major, basic regulatory requirements or the stopping of the use of herbicides or their use willy-nilly that would otherwise pose a concern to other resources.

So any upheavals, in my opinion, are not in the interest of the province per se. A slow integration of the results is clearly in the interest of the province. It is important that research people continue to explore what glyphosate or other herbicides such as Garlon will possibly do to other resources.
PERSPECTIVE: THE EFFECTS OF FORESTRY USE OF GLYPHOSATE

ON HUMAN HEALTH

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I appreciate this opportunity to spend three days away from my usual work, doing something completely different, and I can accept the fact that a change is as good as a rest. I’ve heard information about fingerlings and stream flows and I have a visual impression of the map of Carnation Creek. So, I’m going to do my best to return the favour and provide you with a change: I heard somebody say earlier that the bottom line is fish, but I’m not entirely convinced about that, as you’ll hear. I am going to try and change things around a bit and ask you to switch momentarily, at least at the beginning, switch brain sides, move over into your right brain. your intuitive synchronous area.

When I was in general practice, over a period of some ten years, it came as a bit of a surprise to me (probably no surprise to you) that when physicians are examining patients, looking at throats day after day, listening to chests, filling out prescriptions, lab reports and whatnot, their minds sometimes wander. Mine used to wander a little bit, and I found it taking refuge in some alternative ideas, so called. One of the things I found very interesting was traditional Chinese medicine. I never became an acupuncturist and I never really practiced it, but I like to read about it and think about it, as a way of understanding health and disease. So I thought I would just share a wee bit of that with you. Traditional Chinese medicine is based on nature, it’s holistic in its approach. It’s a different way of thinking about health and disease; you look at the whole person, not just the body. The emotions, the colour preferences, the smells. All these things are important in this sort of diagnosis of what you see before you as a physician. One thing that’s important is a person’s chosen occupation, where a person may spend their time, the kind of thing they’re attracted to in life. So it may not come as a surprise that the people interested in forestry...(Just to step back a minute, the traditional Chinese medicine, at least one major branch of it is involved with the five element theory, where five elements are in harmony with one another. They nourish one another in a circular, harmonious flow.) It may come as no surprise that if I were a traditional Chinese doctor looking at people in forestry I would be interested in the element wood. You people may well have business with the element wood; you may well have imbalances in that area and that would be something I’d think about if I were working with you as a traditional Chinese physician. If you look at wood and some of its qualities, the upside of wood is growth, strength, flexibility... performing.... I noticed the speaker before me said the process is becoming more flexible and more resilient and these are good qualities of wood. The down side, of course, is “woodness”, in other words being “knot-headed”, as an example.

You may be interested to know that the organs connected with the element wood are the liver and the gall bladder and the function (this is all very strange to Western thinking)... but the function of the liver and the gall bladder in the system is to make decisions and to sort information. The emotions connected with those organs, with the element wood, are the emotions of
anger and frustration; when you can’t sort properly and you can’t make decisions you get bothered and you get angry. People involved in forestry issues, especially as they relate to health and the public, have probably seen some of that anger, probably felt some of it. Think about it again; stretch your right brain a little bit.

The organ. If I asked you which organ was most likely to be involved in detoxifying and processing the chemicals in herbicides, you would probably guess the liver. Correctly. Again, if I was a traditional Chinese public health doctor looking at you people. I would advise you to take very good care of your livers and to be very cautious and careful in the use of things you think might be toxic. From a Western perspective I would offer you the same advice. I’m back into the old cause-and-effect stuff now. I have a slide that shows from the public health point of view, how big an issue forest herbicide toxicity is, related to other things that I’m supposed to be concerned with. I couldn’t print it small enough, to tell you the truth. I have no difficulty at all finding hospitals and morgues and death reports filled as a result of other categories: smoking, family violence, alcohol abuse, motor vehicle accidents, obesity, communicable diseases, etc. No difficulty at all. I would have to look very hard, certainly across Canada, to find one hospital bed filled as a result of forestry use of herbicides. There might be one, I’m not sure. Certainly very few deaths. So why am I interested in it at all? The analogy that comes to my mind is that if I am in general practice and someone who is extremely obese, smokes six packages of cigarettes a day, is hypertensive, drinks a twelve pack very night, beats his wife, etc., comes into the office with a hang-nail or a sore toe, there is nothing I can do about it.

I’m forced to deal with the hang-nail. I have to deal with the guy’s complaint before we can even begin to make some progress on some of these other issues. The public, in my area of Terrace and the Skeena, sees herbicides in the environment, and in some cases forestry use of herbicides, as a health problem and they complain loudly about it as a health problem and I don’t really have any choice but to work through it so we can get on with some of the more important issues. For a minute I want to say a couple of words to get this off the table about ROUNDUP.

I’m an instant expert on ROUNDUP. I got involved in an issue related to some people in Kitimat who had been exposed to ROUNDUP, not in forestry, but around their apartment building, and so I had to very quickly come up with a report for the Kitimat town council as a medical health officer. And so I gathered as quickly as I could what information I could find. What I found was that the acute toxicity, as all of you know, is considered to be very low, that the LD50s for all mammals that have been tested are high. I came to hear that there is something called the Shikamic Acid Pathway in the bio-synthesis of aromatic amines in plants that is a pathway that mammals don’t share, and that is presented as the reason why mammalian toxicity is low. There is evidence apparently from rabbits that there is a mild-to-moderate degree of skin and eye irritation associated with exposure to particularly concentrated solutions of ROUNDUP and from inhalation studies in rats they found that the material was slightly toxic. From what I could gather, those animal models seemed to be fairly accurate with respect to acute toxicity if you extrapolate to humans. There hasn’t been any really well-documented human exposure information but there is a fair amount of anecdotal material around that tends to support those animal models. There is no good evidence at all, looking at animal models over several generations of any carcinogenicity or mutagenicity and so, when you put all that together, you say “well it’s safe isn’t it?”

That really takes us to the end of the registration process and out into the marketplace which is where I, as a person involved in community health, find myself. I suspect most of you, once something hits the registration process, feel your real concerns for safety are over. Now, as I say, unfortunately that’s where mine have to begin. I’d like to try and understand a little bit why it’s so difficult for me to answer the questions that are asked about how safe herbicides
really are. You have to look at the fundamentals of epidemiology, the exposures and outcomes. The idea being that people are exposed to something, for instance a herbicide, after which there is a lag time, and there is an outcome and you try to measure both of those things to make assessments. If we are looking at an acute toxic effect, the outcome occurs very quickly and you can often have an easy time putting the two together. If you are looking at birth defects you are looking at a longer lag time, with late mutations often many years, or generations afterwards.

If we are looking at cancer we look at a lag time of ten to thirty years. So you can see obvious difficulties in working from exposure to outcome, particularly if people are concerned about cancer. There are the cohort studies that people occasionally get to do in industrial settings but they are obviously difficult and expensive, lots of opportunity for loss of follow-up. The other kind of study that gets done is a retrospective study where you look at outcomes. If you think you have a theory about what might be caused by something, for instance a particular kind of cancer, you dig up all the cases you find of that type, compare the exposures back in time for people with that outcome and try to decide whether there is a relationship. There is a whole body of epidemiology related to case control study analysis. The bottom is what I label an ideal experiment where you have a homogeneous population of the exact characteristics of the population you want to generalize to. You randomly allocate samples from that population into two groups. You expose one group and give the other group an identical placebo. Nobody knows who's getting what and at the end you unblind the experiment and see if there are significant differences between the exposed and the placebo group.

I noted that even in your--from my point of view--almost laboratory-like setting at Carnation Creek it was often very difficult to come up with something as clear as that. Certainly in the world of real life and exposure to any number of possible substances we can hardly be expected to approach that. Some of the problems then of course are, as I mentioned, the lag time, the so-called natural experiments that we are forced to look at are poorly designed from any sort of scientific point of view, no blinding, no randomization, the exposures aren't measured systematically very often. The outcome variables aren't always obvious and the exposures keep changing as new products replace old. It's interesting, you know, that industry tends to be very sensitive to concern and when red flags go up, often before the real science is in, the product will change because it's not going well in the marketplace and so there is a new exposure.

Now we are back to square one. Certainly glyphosate is a new product and although there is a body of information on acute effects we know nothing really about what happens to human beings who are exposed, especially those exposed over long periods of time.

On the subject of confrontation, again something that I think we are all probably fairly familiar with, I think we have to acknowledge that there is marketing pressure behind a lot of products. I'm fairly familiar with some of the recent research on 2,4-D following the famous, or infamous depending on your point of view, Kansas's Farm Workers Study. There is a tremendous volume of literature produced by a group called the "Industry Task Force" with the Dow people who in a sense countered what they felt was adverse publicity by this one study. And we all know in science that funding has a big part to play in what gets done, although hopefully within that we are able to sort through and look at good research and bad research and make appropriate decisions about it. I've got something I call "environmental fundamentalism," no offense to people who happen to be religiously fundamentalist, I use that word to mean people who see things entirely as either black-and-white and are impossible to reason with in any sort of gray areas. This is the phenomenon of quoting things out of context, taking one small passage from a study and holding it up and saying "look at this, here's a chromatid exchange problem related to pesticides in such and such a study"; but if you look at the thing in context, really there was no conclusion and the study wasn't even looking at what people claim it was.
On this one, as I say, you can't do human experiments because unlike medicines, which most physicians are familiar with, there are no potential benefits that I know of to being exposed to herbicides. When we deal with medicines we can set up experiments like that ideal one I showed you because there are tradeoffs and we believe there is a benefit and we can actually get some pretty good information about drugs. This is a new area for a physician to be involved in; there are no potential benefits so we can't outright do human experiments.

The other day when I asked the question about people being exposed to the overspraying, from my point of view it would have been great if people weren't wearing protective gear and if they would have been willing to be part of an experiment: to submit urine samples. I wouldn't have expected glyphosate in urine, but we could have collected some sort of biological sample that we could analyze and find out what their exposure really was. That would never pass an ethics committee and we might as well forget it; people would probably be wearing six layers of space suits if we even tried to do such an experiment. Post-marketing surveillance is what we call our attempt to find out about exposure, and the information that we can get is like pesticide permits: we can look at them and see where pesticide permits were granted. We can look at sales records for pesticides and herbicides, occasionally special studies are done to find out about exposure. There have been some studies looking at urinary metabolites of people using backpack sprayers or in farm workers.

Outcome reports--occasionally physicians will report that I've got a patient here who got sprayed with something and seems to be sick--that's usually in the area of acute effects. Cancer registries--B.C. is fortunate in having a Cancer Control Agency that does a lot of cancer mapping, incidence mapping, so you can attempt to correlate rates of various things with the exposures that you know about. Birth defect registries--again in B.C. we are kind of unique in having what they call a birth defect monitoring system in place--the vital statistics division of the Ministry of Health has this monitoring system in place. Ideally a red flag goes up when there is a cluster or an unusual rate of birth defects of a particular type in a particular area. Hospital records pesticide incident monitoring system is something that I think they used to have in the U.S. I'm not sure that they still do; it is really just a computer listing of all reports of exposure to pesticides. If there is a health effect involved it's something you can look at to see if there are patterns if you are concerned about a particular herbicide. To my knowledge we don't have anything of that sort in Canada or in B.C.

Some of the issues. From a point of view of someone in public health wanting to find out about exposures and outcomes in terms of herbicides, access to data can be an issue. Much of the registration data, the actual original studies on rats and rabbits, is not readily available to even physicians or public health people or to provincially funded research groups. There is a group that looked at the effects of chemicals in agriculture and forestry--the use of chemicals on reproductive problems in New Brunswick, a three-page report that came out last year. The author then wrote an article in the Canadian Medical Association Journal this summer complaining about that point. That they really had a tough time getting particular information about toxicology, the original research on toxicology, and no offense, but Monsanto was the group they seemed to have the most difficulty with. And they actually got a fair amount of their information through the U.S. Freedom of Information legislation. As I should point out, as I became an instant expert on ROUNDUP, I found everyone that I talked to, from Agriculture Canada to Monsanto, to be most helpful, but what I got were summaries. People had already looked at the data, drawn conclusions and printed it up. The difficulties with post-marketing surveillance has pointed to the fact that "no demonstrated human health effects" doesn't necessarily mean "no effects" and I really can't stress that one too much. It's very difficult to pull off a proper epidemiological study. Just because we haven't been able to show something doesn't mean it may or may not be happening. The
recent association that's been made between aspirin. children who have had chicken pox and Rye's syndrome is a good example of that; very common exposure. very rare outcome. plenty of opportunity to look at it, but the interactions are so complex that it has taken a very long time to put that one together. Passive versus active information gathering. who's going to look for this information, who's going to keep these registries of exposures and outcomes? Its risks and benefits, again, something in a sense that we are all involved in: in health if you're gambling there's not much I can tell you about risks, long-term risks in particular. but in your industry there is certainly a lot you can do to reduce exposure. I refer to the regulations that require people to wear the proper gear, and being very site specific and careful in your use of these materials. Also in documenting and demonstrating the benefits to the public at the provincial level and municipal level and throughout the democratic process. The people in these communities, if they are well-informed, will hopefully make good decisions. I won't talk about the process, since that will come out in the workshops, but I see that as a very key area. The process is ongoing: the evolution of how the democratic process works and the role of science and intuition; the bottom line is who decides and how are decisions made.

I've got a good old-fashioned fundamental virtue listed last, which is prudence. There is a degree of uncertainty in terms of long-term toxicity and that's inevitable; there is nothing we can do about that. Public concern, as you know, in some areas and over some issues, is quite high, and I'm suggesting the evaluation of alternatives ought to be encouraged. This is a page from the report that I gave to the Kitimat council. I had two weeks to get this out and there were tremendous feelings flying, lots of headlines, lots of red flags being waved. Just to give you an idea of the ways a person might look at this, I actually did a survey of the people in these townhouses to see if they had in fact experienced symptoms. There was nothing much in the way of objective data, most of the people who complained of symptoms had not gone to physicians and no laboratory tests had been done so there were just some people saying we've got 35 people with all these symptoms as a result of this spraying.

So, I went in and did a survey and asked about symptoms and then I looked at this pesticide incident monitoring system they have in the U.S. I found 30-some reports. mostly sprayers working with chemicals who had been exposed to glyphosate and I just counted up the symptoms that they had reported. None of this is hard data and none of this is very scientific, but was to see if the pattern fitted with what the people in the townhouses experienced. You can see that 58% of the townhouse people complained of headaches following the spraying; the U.S. sprayers were only 15%. Skin rash was pretty much the same and skin rash is something that you might expect given the animal toxicology of ROUNDUP. Nausea or vomiting not all that different really, considering the small numbers. Eye irritation, or inflammation. 41% of the U.S. sprayers experienced that, only 16% of the people from the townhouses. and again eye irritation is something that one would expect from the rabbit testing. Sore throat; pretty much the same. Nose bleeds is an interesting one and the people were making a lot of that. The children had nose bleeds, 19% of the townhouse people reported nose bleeds and it was mostly in the young people. None of the sprayers in the incident monitoring system reported that. That was one particular small area where I would have loved to have gotten hold of the original data to see if rats were getting nose bleeds when the LD50 studies were being done. Obviously, this is sensitive information for the public to handle, to read about the agonizing deaths of various animals as the LD50 levels are approached, but hopefully it can be useful information and there is a place for that within the public health range.

Key words to leave with are Prudence and Humility in terms of acknowledging that there is a lot we don't know. I've certainly heard that although you've learned a lot about glyphosate and how it affected Carnation Creek there are also a lot of areas where you need to know more. The Process--is an extremely important thing to look at. Exposure--it's important to limit exposure
because as I say, there are a fair number of things we don’t know. I want to admonish you to keep up the good work. I’ve certainly enjoyed the quality of the presentations. I almost look forward to being involved in forestry issues as the process continues to evolve. I’d like to now quote a well-known politician who has an interest in forestry and therefore by definition has a liver problem and say that if someone will buy me a drink I’ll quit now.
DISCUSSION GROUPS 1 & 2 - SOILS

Group Leaders - Mark Walmsley and Terry Lewis

Conclusions

The conclusions from our groups are:

1. Glyphosate and its major metabolite, AMPA, appear not to be subject to significant leaching, primarily due to strong adsorption within the soil complex. These adsorption processes are not well understood.

2. Soil biological activity is affected very little by glyphosate. It seems that applications of the herbicide may result in a short-term variation (up to 1 month) in microflora numbers. While little impact has been observed, we must accept also that studies have only been short-term. There appears to be a need to examine the effects of glyphosate on soil organisms more intensively and over a longer period.

3. Herbicide effects on biogeochemical processes appear minor in comparison to those caused by logging, site preparation or alternative vegetation management activities. This was a point that was driven home numerous times in our working session; we have to look at the use of herbicides as one tool within a broad spectrum of tools, not only from the point of view of vegetation management but also with respect to other forest management activities.

4. Herbicide use is not expected to cause increased soil erosion. The evidence does not indicate a correlation between the use of herbicides, normally, and an increase or acceleration in surface soil erosion of mass movement. However, we should recognize a need to retain what we term 'brushy seral communities' (e.g., red alder) on severely degraded sites that are rehabilitated. We are concerned with marginally stable sites, for example on the Queen Charlotte Islands, or on the west coast of Vancouver Island, and on the mainland. After these sites have been denuded by slides, red alder communities commonly help to rehabilitate them by stabilizing the slope and increasing site productivity.

Recommendations

Our recommendations for further research can be summarized in the following five points.

1. Although the results of this study have shown that dissipation rates for glyphosate were quite rapid, it appears to us that further work is needed in understanding not only rates but also the processes involved in dissipation of the herbicide, particularly under varying environmental conditions and in different biogeoclimatic units.

2. We feel that the mechanisms of soil adsorption and desorption of glyphosate in relation to soil phosphate are poorly understood and require further research. In this study, a good adsorption relationship with organic matter has been shown, but there is evidence also for quite a range of adsorption sites in soils, including clay, minerals and sesquioxides, which may also play a role in herbicide efficacy and dissipation dynamics. Organic matter is obviously very important but perhaps the different fractions of organic matter are involved in different ways.
3. We discussed evidence from other research that there appears to be a small proportion of glyphosate (about 5%) that is quite slow to degrade. Factors and mechanisms that affect the degradation of this 5%-fraction need to be determined. There may be a linkage between this particular fraction and some of the adsorption mechanisms mentioned in Point 2. Perhaps this small fraction is so strongly adsorbed on the clay or organic matter present that it is protected from microbial degradation.

4. We would like to see an evaluation (using Kimmins’ approach, perhaps) of biogeochemical changes resulting from vegetation removal alone. The study should test some manual cutting treatment versus the use of herbicide to isolate the effects of the herbicide per se from vegetation removal or cover reduction itself. We felt that these two effects are confounded in existing study results and information.

5. A relatively straightforward laboratory study is needed to look at the effects of temperature and soil type differences on the microbial degradation rates of glyphosate. This study is essential if we wish to understand the processes involved in herbicide dissipation.

DISCUSSION GROUP #3 - WATER: HERBICIDE CHARACTERISTICS AND WATER QUALITY

Group Leader - Doug Wilson

Conclusions

The results of the Carnation Creek Study, as well as other work that has been done in B.C. and in Oregon, basically show that herbicide residues are transient in streams. Glyphosate does appear to persist in sediment, but there is some feeling that these residues in sediment are not bio-available. The mobility of glyphosate in the streams studied can be related to major rain storm events. The in-stream herbicide levels that have resulted from operational sprays in the Carnation Creek study were not observed to be acutely toxic to fish. Also, our current knowledge and the evidence we have seen from some of the sublethal effects research, albeit laboratory research, indicate that subacute effects are unlikely.

We indulged in some discussion with regard to public perceptions of the use of herbicides around streams. The public concerns, as you may be aware, remain high. There is a concern about the proximity of herbicide treatments to public water supplies. One of the most intractable problems is the public concern for possible long-term effects of low level applications of herbicide on the environment. We agreed that public perceptions of risks are dramatically different from those of the users of herbicides. The public perception of risk appears to arise because they do not feel in control of the use of herbicides in forestry and on public lands: they do not really know what is going on in forest management; and they feel threatened by this situation. We contrasted this to, for example, cigarette smoking or drinking alcohol where people feel that they are in control but they do not perceive these activities as greater risks.
Recommendations

1. We agreed that it would be very useful to consolidate the environmental and forestry information and make it understandable to the general public. An example of this could be the translation of the results generated by the Carnation Creek study into layman's language.

2. There has to be more of a 'show-and-tell' effort to inform the public about the use of herbicides in forestry. The B.C. Forest Service has been doing some of this by showing their operations and the results to farmers in local areas who are interested in what forest management activities were underway in the watershed of concern.

3. Further research:
   (a) Because the surfactant used in ROUNDUP is more acutely toxic than the glyphosate itself, it was felt that further research is needed to generate useful data about the toxicity and environmental fate of the surfactant.
   (b) We are concerned about ephemeral streams as potential sources of herbicides to mainstream streams. Research is needed on the movement of herbicides from ephemeral to mainstream streams.
   (c) Another research need is information on the toxicity and environmental fate of AMPA.
   (d) More research studies are needed on the 'worst case' scenarios, and toxicity and environmental fate for other chemicals (e.g., Garlon).

4. To reiterate, we feel it would be very useful to have a consolidation of summary statements, conclusions and recommendations from the Carnation Creek herbicide project.

PESTICIDE-FREE ZONES/BUFFER ZONES

Conclusions

After a discussion of the pesticide free zone (PFZ) and buffer zone (BZ) concepts, we concluded that the PFZ generally protects both water/stream quality and the riparian vegetation/habitat. The consensus of our discussion group was that the PFZ was most important for the protection of the riparian zone.

There was some discussion of the use of the MICROFOIL BOOM along streams; we felt that the recommendation for using a 10 meter PFZ and a 25 meter BZ was acceptable. We felt that this recommendation would be useful in B.C., particularly given the accuracy and precision of the microfoil technology. We would like to see some analysis of the economics of ground treatment versus the use of the MICROFOIL BOOM in sensitive areas; it might actually be more cost-effective to use the MICROFOIL rather than ground treatment in areas where aerial sprays using conventional equipment cannot be used.

As I mentioned earlier, we concluded that the PFZ is primarily for the protection of the riparian zones. There was some discussion about possible impacts of the new coast fish/forestry guidelines. There was much discussion about the PFZ and BZ evolving into streamside vegetation management zones, based on stream classification. We feel that the PFZ and BZ are good concepts; they certainly have widespread public acceptance, and should be maintained for the next few years while more impact information is collected. Most people in forestry are aware that individual, site-specific treatments, particularly manual treatments can occur within the PFZ and BZ, so the use of these concepts should be continued.
Recommendations

1. We feel that there should be more monitoring in the PFZ and BZ to determine the effectiveness of these zones in buffering possible adverse impacts from operational forestry treatments.

2. There needs to be development of a policy on the use of the PFZ around ephemeral streams, and research is needed on the movements of herbicide from ephemeral to main streams.

3. Research is required to determine the effectiveness of the PFZ and BZ in protecting domestic water quality and supplies, and on the mobility of herbicide residues in watersheds used for domestic water supplies.

DISCUSSION GROUP #4 - WATER

Group Leader - Dave Wilford

Hydrology

The major influence on both site and watershed hydrology is the initial forest harvesting. Herbicide use extends the period of effect, but since the application is intended to accelerate the growth of coniferous regeneration, the net effect is seen as positive.

If herbicides are used for rehabilitation of sites with deciduous forests, the net effect will be similar to the original clearcutting.

While it is recognized that small roots are important for the maintenance of slope stability, operational staff have not encountered mass wasting subsequent to herbicide application. The erosional problems encountered were associated with the original logging disturbance. The researchers in our discussion team did not have personal experience with mass wasting subsequent to herbiciding, nor did they know of any literature references.

The use of herbicides to release conifer regeneration was seen as a positive treatment relative to rain-on-snow. Such treatments will speed up the return to pre-harvest conditions.

Site hydrology was seen as an important factor for herbicide mobility, but the level of importance is dependent on the herbicide itself. ROUNDUP quickly binds to soil particles and off-site movement was not seen as a problem. The fact that ROUNDUP binds so easily to soil is evident when one considers how ineffective the herbicide is when the mix-water is dirty.

Herbicide Characteristics And Water Quality

Rate of siltation and sedimentation were not considered to increase following herbicide applications. Effects on fish habitat were seen as:

- stream temperatures increase - this can be positive or negative depending upon the natural temperature levels. Whether positive or negative, the effect was not seen as a long-term influence.
- riparian litter input - decreases with herbicide application. This is a negative factor but it is a short-term effect. The effect would be significant if a situation developed in which the stream had a closed coniferous canopy.

Herbicides are poisons and they can have a toxic effect on fish. Recognizing this, the team was relatively surprised with the research results indicating that ROUNDUP had a very limited and non-persistent effect on fish and other aquatic life (we were not totally surprised because all of the previously reported research indicated that ROUNDUP was not a serious hazard to the environment). Even doing the tests with the commercial chemical, the surfactant and degradation products likewise had very limited effects. Increases in nutrient flow were not reported to be problematic. These results improved the confidence of operational staff in the use of the herbicide - it is not an environmental disaster.

The current studies into sublethal effects on fish were endorsed. This work may not lead to a relaxation of PFZ regulations along main fish streams, but it may provide useful data for the development of guidelines for the overspraying of tributary streams.

**Domestic Water Quality**

As noted above, herbicides should not alter sediment rates, flow volumes, or the regulations of runoff. The release of nutrients could be a concern in some situations where nutrient levels in streams are already high.

The group recommends that acceptable and safe levels of herbicides be defined for potable water use. While domestic water users do not want any herbicide in their water, if acceptable levels were established, field staff could have a better level of confidence. To date, the water quality monitoring projects in domestic watersheds have not reported any ROUNDUP. This indicates that the applicators are making efforts to use the herbicide carefully.

When herbicides are used in domestic watersheds, it is important to know what the water is used for (i.e., drinking, irrigation, etc.). This knowledge was seen as critical for the applicator to take precautions and proceed with confidence. Of note, a forester in the group indicated that, when he encountered an area with numerous small watercourses draining into salmon-rearing corrals, he would use only hack-and-squirt, not aerial methods of application. The use of herbicides in domestic watersheds relies on a knowledgeable public. R & D were seen as major factors if herbicide projects are to be supported (or even allowed).

**Buffer And Pesticide-Free Zones**

It is surprising that while the results of the Carnation Creek Herbicide Project showed limited impacts, even in over-spray situations, all of this discussion team supported the continued use of the PFZ. PFZ's are taken as a given for fish-bearing streams. We did see a need, though, for research or extension to define situations where tributary streams could be over-sprayed. We see a need for a stream classification system that could be used to identify these situations. Our enthusiasm was held in check by a recognition that herbicides are "deleterious" and that, by law, it may not be possible to over-rule the PFZ. We noted that herbicides (particularly ROUNDUP) tend to dissipate and breakdown rather than accumulate in the food chain (such as DDT does). This fact should assist in helping to reduce the need for PFZ's on small tributary streams. If PFZ's are relaxed, we saw a need for R & D to improve the knowledge and judgment of applicators. They would have to have a crystal-clear understanding of where and where not to over-spray.
Both PFZ and BZ have an effect on silvicultural objectives and cost. The effect is least in the case of ground application, but can be significant with aerial application. Our group noted that in some cases the objectives can change significantly, as in cases where it is decided to reclassify deciduous species as commercial. The use of preharvest silviculture assessments (PHSA's) was seen as a very positive move. They lay out the whole forestry process and allow for a thorough referral review and input to plans. Options can be discussed and such factors as roads and block layout can be determined based on what is seen as acceptable. This discussion of options should include the environmental effects of alternative site preparation techniques (some can have greater adverse impacts than herbicides). PHSA's should help solve some of the referral problems associated with treatments of older logging sites.

Both physical and biologic site factors have an influence on buffer strip recommendations. Unfortunately, these factors are not taught in the current courses: they are learned operationally (through referrals and participation in operational spraying projects).

Other Points

Silvicultural treatments such as prescribed burning, mechanical site preparation, and herbicides all have potential risks and environmental impacts. Herbicides can produce the least impact in some situations. This should be recognized at the PHSA stage. An interesting risk associated with herbicides was not discussed in the main workshop, and that has to do with the shift in plant species and a subsequent increase in the fire hazard. One group member related a situation from this summer in which a herbicide-treated area was burned. The area had changed from a shrub community to a grass/forb community. Due to the very dry summer, the new community dried and cured early in August (earlier than the shrub community would have). Interestingly, the fire was started by a careless worker who was manually cutting brush in an adjacent area.

There was quite a discussion in the main workshop about real world research. Our group concluded that the Carnation Creek Herbicide Project was not a real world situation due to the equipment used, the time of spraying, and the amount of water mixed with the herbicide. We wondered if the results would have been significantly different if the project had been operational. We recognized that efficacy would have been higher and stream temperatures would have been increased higher than those recorded. What other impacts would have been found? There is a need for real real world research.

In the main workshop we concluded that the operational application rate of ROUNDPUP resulted in a concentration below the LC₅₀ level. We also saw photos of the strip of dead vegetation left by an aerial application of ROUNDPUP. Our group wondered how environmentally serious was the herbicide drift beyond the vegetation-kill swath? If the direct application of ROUNDPUP to streams had a very minor effect, could we conclude that the herbicide does not need a BZ to protect the PFZ?
DISCUSSION GROUP #5 - AQUATIC ORGANISMS

Group Leader - Steve Samis

Our discussion began with an overview of the relevant terms, such as the 10 meter pesticide free zone (PFZ) and buffer zone (BZ) concepts. It was then assured that everyone agreed on the principles for discussion. It was established that the 10 m PFZ is a requirement in B.C.; it protects potable water supplies, fisheries waters, riparian areas, and critical wildlife habitat. As John Henigman stated yesterday, the 10 m PFZ is also expected and deemed necessary by the public. A BZ is a recommendation. It is site-specific, flexible and surrounds the 10 m PFZ to protect its integrity. There was discussion on standardization of approach to using PFZ’s and routinely allowing individual tree treatment within the 10 m PFZ.

Some operational foresters stated that the 10 m PFZ concept is interpreted and applied differently in the various areas of the province; there was inadequate standardization of approach regarding areas upstream of fish habitat. This shortcoming was identified as a major action item for DFO. A question was raised whether the 10 m PFZ is applicable to all waterbodies throughout the province. From a DFO viewpoint, it is not. The PFZ is only applicable to fish habitat, and immediate tributaries thereto. If information does not exist on fisheries values, however, the 10 m PFZ is assumed to be applicable to a waterbody, or ephemeral stream.

We discussed flexibility in the 10 m PFZ requirement upstream of areas of anadromous utilization or waters supporting recreational fisheries. It was determined that in upstream areas a 10 m PFZ would be a site specific judgement, based on the likelihood of downstream impacts in fish habitat and proximity. Another question raised related to the possibility of not requiring 10 m PFZs around ephemeral streams. Again, a site specific judgement is required, based on knowledge of the stream system, as well as the new information developed through the Carnation Creek project. Concerns based on Carnation Creek findings relate to (1) changes in litter production that might affect stream invertebrates, (2) cumulative water temperature effects, (3) changes in nutrient cycling in the soils, (4) changes in the riparian zone’s ability to produce food for fish and aquatic invertebrates, and (5) any direct toxic effects on invertebrates and fish of overspraying a PFZ.

Foresters want to know how far upstream from fish habitat can ephemeral and tributary channels be over-sprayed or sprayed with no PFZ with no harmful effects downstream. In many upstream areas it would be useful to foresters not to provide 10 m PFZs. How much information is required to judge the need for a 10 m PFZ in upstream areas? This remains a site specific judgement, but should be further studied. We concluded that the present guidelines with respect to PFZ and BZ had functioned well. They have protected fish and fish habitat, enabled the referral system to proceed, permitted foresters to use herbicides near streams, and allowed the public to be protected. In the future, we may wish to re-examine the extent to which 10 m PFZs are applied upstream of fish habitat, if appropriate data are developed.

Another area of inquiry that emerged from our discussions was the question of the BZ. A lot was said at this workshop about different application technologies (e.g. MICROFOIL BOOM). These are good opportunities to re-assess recommended BZ widths needed to protect the PFZ with these new technologies. Regardless of BZ width, there must be assurance that riparian vegetation and water quality are both fully protected. The PFZ, however, should be exactly that pesticide free.
There was discussion on whether the Carnation Creek Herbicide Project should be considered a worst case scenario. We were able to identify a number of reasons why it may not have been so. In the hydrology paper by Eugene Hetherington, for example, there was evidence of a significant amount of water on the site and plenty of rainfall. The impression given was that the herbicide that reached the stream was highly diluted. Had the soil been covered with frost or received heavy rainfall after an extended dry period, they might have found that there was less dilution. We also determined that since the stream flushed rapidly because of the high flows, the fish and other aquatic organisms in bioassays were exposed to even lower concentrations of herbicide in the streamwater.

There was discussion yesterday regarding determination of herbicide levels in water. We question whether it would be more representative to collect the analytical samples from the water column or the surface, where aquatic life may be concentrated, but also where the herbicide lands during an over-spray. There was a disparity between the theoretical calculated value in a stream overspray situation versus what was actually sampled experimentally.

**DISCUSSION GROUP #6 - AQUATIC ORGANISMS**

Group Leader - Vince Poulin

The approach our group took was four-fold. First to review the objective of the workshop - which was information transfer; second, examine the conclusions and recommendations from each of the papers related to aquatic organisms; third, review current regulations to determine if a synthesis of the results would enable us to suggest changes in the regulations; and last, to identify areas of further research.

Given the manner in which the workshop papers were organized, no speaker presented an overview or summary of the research undertaken. Because of this, our first step was to summarize the results, then relate what we learned to our understanding of current practices. We tried to do this by asking several simple questions. The most important was whether the results were positive, negative, or had no impact.

**Temperature**

Blair Holtby indicated that temperature had increased in the study streams, but only during the summer months. The phenomenon lasted for two years, but did not persist in winter and spring. As a result, the temperature increases observed did not have an adverse effect on fish survival nor timing of the smolt outmigration. However, it was noted that it was not possible to isolate potential cumulative effects of the small increases in summer temperatures on rates of detrital decomposition in the stream. An important issue discussed at length was the potential effects of even small increases in water temperatures on fish in streams located in the interior of the province where herbicides are being applied. In these areas, defoliation may have significant and substantive impact on stream temperatures.
Water Quality

In dealing with water the results we focussed on pertained principally to fish. It was reported that conductivity increased 33%. These increases would likely have a net positive impact on stream productivity, as would the 20-30% increase in nitrates following herbicide application. With regard to the increase in nitrates, it was suggested that the typically positive effects of nutrient enrichment could be offset by decreases in fish egg survival. This possibility was highlighted by Scrivener in the workshop. We felt it important, however, to keep in mind that the increases reported following herbicide application were still only 20-30% of those observed after clearcutting. Stream phosphate concentrations doubled after clearcutting, and doubled again after herbicide application. Because phosphate levels were extremely low to begin with, we concluded the increases would have a positive effect on stream productivity.

Periphyton

We then considered the information presented on periphyton. Periphyton is an algae that grows on the stream bottom and is used as a measure of overall stream productivity. Results showed some short-term declines in periphyton levels, but these were later enhanced by increases in nutrient levels. Thus, we concluded the changes would have little effect on the stream ecosystem.

Detritus

We focused next on the question on detritus, material derived from leaf litter that supports benthic invertebrate communities, otherwise known as litter-fall. While the herbicide treatment was not as effective in defoliating the targeted canopy cover as expected, there was significant, if not complete reduction in leaf litter, in the over-sprayed tributary. Measurements of micro-organisms and invertebrate communities in this area, however, indicated no significant changes in numbers or populations. The most important aspect of leaf litter discussed was its role in fuelling the food chains of coastal streams. The amount of food directly available to fish is determined by the detrital input to streams. Hence, preserving some level of detrital input to streams is a key issue among fisheries managers. It is quite obvious that several of our major questions relate to how much litter is required in small tributaries to maintain benthic food supplies and whether present practices involving herbicide use can ensure adequate supplies or would upstream sources be sufficient? Upstream sources may well be enough to satisfy the downstream needs of small streams or sections of streams.

In summary, there seemed to be little conclusive evidence presented that herbicide treatments had a negative impact on benthos populations in the study streams. On the other hand, it was emphasized that plants that grow in seasonally flooded swamps can be important benthos-producing areas and that despite lack of signigicant changes in benthos populations observed in the study, they are areas of concern to fisheries managers. This issue has led to problems between regulatory agencies and users. The group concluded that more research is needed to better quantify the importance of seasonally wetted areas to stream benthos production and to fish productivity in particular.
Fish Populations

An important outcome of the study was the lack of any discernable impacts to fish. Relatively insignificant numbers of fish died, thus no differences were observed in survival following spraying. Three fish in Channel 1600 and six in Channel 2600 were lost. No mortality or changes in weight were recorded in the resident fish populations, and no changes in timing of smolt out-migration observed. Studies of the acute toxicity further indicated concentrations of the herbicide were within a 10-fold margin of safety.

Overall, application of glyphosate in this study appeared to have only minor impact on aquatic organisms. However, issues such as loss of production in important seasonally flooded areas may need further exploration.

The above discussion occupied most of the group's time, but was considered necessary to narrow the results down enough to relate them to current practices. Hence, we didn't get all that far on current practices. Several of the group indicated there were problems with implementing the PFZ and BZ, particularly in regard to what appears as unnecessarily large BZ's and difficulties in locating PFZ's on hard-to-identify and hard-to-avoid back channels or ephemeral sites. There is a need for either a better planning exercise or better implementation of the existing one. Better operational monitoring and follow-up was also recommended.

The group also felt there was little flexibility in interpreting Section 3.31 of the Fisheries Act. For example, are PFZ's the targeted outcome of the regulations or are they being used to simply manage riparian zones for other reasons? The results of the Carnation Creek Herbicide Project suggested that the impacts of glyphosate application at Carnation Creek related primarily to reduction in vegetation and detrital production in streams. As a result, there was difficulty in defining BZ's and PFZ's and their functions. A key question left unresolved was: are PFZ's the management goal or are they to protect the riparian zones?

Two key areas of future research were considered worthwhile: (1) role of detrital input and benthic production from tributaries and ephemeral streams in maintaining fish production in larger streams; and (2) initiation of similar studies in the interior where small changes in temperature may have a significant impact on summer fish survival.

DISCUSSION GROUP #7 - WILDLIFE

Group Leader - Harold Armieder

Management Implications and Directions

Much has been said about the PFZ's (pesticide-free zones) over the last few days. It is a good concept that, for the most part, has worked quite well. In spite of the low toxicity of this particular herbicide, we did not feel that there was any reason to lessen the width of the PFZ as it protects valuable riparian habitat for fish and wildlife. However, we recognize the need for some flexibility in the PFZ concept on a site-specific basis and we want to emphasize that site-specific basis for flexibility. For example, some of the smaller side channels, which are perhaps not important for fish and wildlife habitat, and very difficult to identify operationally could be treated differently.
There is a real need to put things into perspective when considering the use of this and, indeed, any herbicide. We can't just think of these herbicide treatments in isolation and try to manage in relation to them. We have to recognize that there are all sorts of other habitat impacts to deal with, for example, harvesting, prescribed burning, and mechanical brushing and weeding. These different activities alter habitat in different ways; we have to recognize each activity and manage with the whole spectrum in mind.

Diversity of habitat is extremely important to many wildlife species. Good opportunities exist to reduce the impact of herbicide treatments on wildlife and habitat by giving more consideration to the temporal and spatial arrangements of those treatments to maintain habitat diversity. This should be considered in terms of all types of habitat alterations and not just those resulting from herbicide applications.

Areas of habitat that are extremely valuable to a particular species or group of species must be identified before any treatment occurs. For example, if there are wildlife trees that are of particular importance in an area to be treated, the method of herbicide application might be changed from aerial to ground-based application.

Much technical information was presented over the last two days but, for the most part managers were not given the bottom line. There is a serious need to transfer technical information into a form useful to field managers. This process has just begun and must be vigorously pursued if the full impact of the research is to be realized.

Communication must also extend to the general public. People must be informed about the safety of this herbicide, including the safety to the wildlife species that it may have an impact on, as well to human consumption of those particular wildlife species. If this is not done, the operational use of this treatment could be easily curtailed.

Research Needs

Determination of the effects of herbicide on wildlife cover and forage is a pressing research need. There are a number of topics that need to be examined specifically. For example, the variability of the response, both within a plant species and among species, and the impact of the timing of application on various forage and cover species must be understood. The duration of the response must also be investigated. If there is only a one-year impact on cover and forage resources, the effect on wildlife will be vastly different than if the impact lasts several years. There is also a strong need to tie this research into the integrating framework of the biogeoclimatic ecosystem classification system. The responses to treatment at Carnation Creek may be quite different than those in some of the interior biogeoclimatic subzones.

There is a great need to investigate the impacts of herbicide in comparison to the impacts of alternative management options (for example, prescribed fire, and manual brushing and weeding). Because we live in a world where all of these treatments are commonly applied, we have to be able to judge the impacts of all the treatments on wildlife, thus placing the silvicultural use of herbicides in the proper perspective.

Wildlife can also have an impact on crop trees. When a habitat is significantly altered by reducing the herb and shrub component, there is a potential for certain species of wildlife to damage the remaining crop trees. This possibly must be examined.
It is necessary to continue with long-term studies on the lethal and sub-lethal impacts of this particular herbicide, not only to satisfy the managers, but also the public. A satisfied public is essential, especially when game or high profile species are involved.

The last point is not a research topic, as much as an approach to research. We must work hard at co-ordinating interagency research so that we get at the answers in the most efficient and timely manner. Often, by spending just a little more time and money, key questions related to resources other than trees, can be answered, if we plan for it at the beginning of the research program.

DISCUSSION GROUP #8 - WILDLIFE

Group Leader - Sylvia von Schuckmann

Conclusions

We started our discussions with a general look at the kind of research that was done at Carnation Creek, and whether or not it was clearly applicable to wildlife. We concluded that there was a fair bit of research done there which does have some implications for wildlife. And, in general, I would say that the interest in wildlife research elsewhere has been fairly recent. There has been a shift in interest from toxicology to habitat impacts, and I think that if you consider the types of information that have been presented at this workshop and the dialogue that has ensued in the discussion groups, you will agree with me that most of the concern seems to be shifting toward habitat impact.

One of the wildlife papers presented in the past 2 days was Alton Harsted’s paper. He feels that this type of work is just a beginning. It is a snapshot, as it were, of what happened in a particular system with a particular species at a certain period of time, albeit a rather short period of time. This is really an indication that there can be more work done in this area, not just with small mammals but with larger mammals as well.

A paper presented by Doug Pitt listed the variable impacts of ROUNDUP on different plant species. When many non-crop tree species (and there was some concern about the definition of crop tree versus non-crop tree), i.e. non-coniferous trees, are considered extremely valuable to wildlife, it is very important for us to understand the impact of herbicides on this vegetation.

In addition, the two papers that were co-authored by Hamish Kimmins were really of interest because they pointed out that this type of research does not generally produce good, usable results in a very short period of time. Habitat research is long-term research, and that means that we are just at the very beginning of it.

We talked a bit about whether or not one could draw some conclusion about potential changes to the way things are done in the field now. Given the wildlife-related information that we have been presented here. We agreed that there was basically too little information on which to recommend changes in operational practices and operating regulations. A focus of future research should be to perhaps develop some guidelines that would usefully integrate forestry and wildlife concerns. This might mean, for example, some sort of compromise in harvesting systems or in using herbicides.
From our discussions about the 10 meter PFZ, our conclusion was that basically it was of high value for maintaining riparian habitats. It was stressed that riparian areas are extremely valuable not just for small mammals and birds but for ungulates as well. We strongly support that the PFZ should be seen as a guideline but there definitely should be flexibility to make site-specific adjustments where necessary.

Further Research

We feel that, with research such as the Carnation Creek Herbicide Project, it is very important to take a holistic approach. And as we all know, when you are designing your unidisciplinary research it is very difficult, but I think the payoff in the end is better than just doing little pieces here and there.

Again, our group underlined that there is more to silviculture than just herbicides. There was a real sense that perhaps more could be accomplished at the planning end of things, the pre-harvest planning stage, to perhaps obviate the need for using herbicides or, for that matter, any other vegetation management strategy down the road. Not only would this allow a better selection of treatment options and better long-term forest management planning but it would also allow comprehensive examination of the land management objectives, and integrated development of a plan which could minimize the impacts but maximize the productivity for all resources in the land base.

Research should be carried out in areas of high forestry value and high wildlife value, i.e., areas of potential conflicts, the resolution of which might lead to the development of operational guidelines. We must not only identify critical wildlife areas but we must also do research in these areas to understand wildlife habitat needs: critical ranges, riparian habitats, winter ranges and snag trees (or wildlife trees as wildlife biologists like to call them!). In B.C., deciduous trees can harbor up to 20 different species of wildlife per tree. This diversity is high compared to that in the rest of Canada and underscores our need to understand particular habitat needs.

While it is important to do wildlife research, it is important to not concentrate only on big game animals (on things that you can put holes into as someone said earlier!), but we must also identify and understand the habitat needs of small, non-game animals. We cannot ignore these fauna because of the importance of their interrelationships in the ecosystem, their role in the food chain, and their possible impacts on regenerating forests.

In a general sense, it is important to do long-term research on the functional relationships of wildlife to their habitat, to comprehend how the ecosystem components work together, to know how, why and for how long forest management affects wildlife habitat and wildlife, and to understand how to minimize those impacts.

We also stressed the need for research on basic plant succession, a topic of considerable overlap between foresters and wildlife managers. In relative terms, there is actually very little integrated forest ecology work done in this province; we find that quite distressing.

We feel that extension is very important. There are a number of things which can be done, not only for the operational people but for the general public as well. These include more workshops of the format experienced here today. The participants here are very enthusiastic about this method of information exchange and feel that it is very beneficial and healthy to get together with people with whom they normally do not interact, and to exchange ideas and do perception checks. We suggest that it is extremely important to get the available information out in
circulation. One of the vehicles for the extension of wildlife habitat information, which has been very slow coming, is the wildlife habitat handbook.

And, lastly, our group suggests perhaps it is time in B.C. to have a riparian workshop to underline this very important habitat and valuable resource.

In conclusion, this whole workshop has been a very positive experience. The main reason appears to be that people are no longer concentrating on concerns about toxicology. We have moved beyond that stage to look at habitat impacts. This is a strong step forward, and I have a feeling that the general public might not be that far behind us.

DISCUSSION GROUP #9 - FORESTRY

Group Leader - Dick Kosick

Implications

Our discussions began with an assessment of the sequence of activities from logging to a free-growing plantation. As many of you know, we do develop, prior to the actual logging, a pre-harvest silvicultural prescription (PHSP) which indicates 2 and sometimes 3 years in advance what will be done to the area subsequent to logging. I know that some of the Forest Service people here would like to see us do one of these prescriptions for the whole five years of the development plan, but that is not possible. We are not that far advanced in our engineering or our forestry work, but we do succeed in achieving at least 2 full years of prescription.

After we completed this assessment, we tried to evaluate the opportunities for implementation of the research findings and to identify further research needs. Our group found that there were a few opportunities for operational changes based on research results. Kimmins mentioned the importance of nutrients, nutrient regimes and nutrient cycling, and pointed out that burning some areas could result in a loss of as much as 1200 kg per ha of nitrogen. We all have seen areas where this type of damage from fire has occurred. Our group suggested that, where opportunities for choice exist, and consideration is given other resources, it may be preferable to use herbicides instead of prescribed fire. At the PHSP stage there is opportunity to incorporate considerations of nutrient regimes. In other words, based on nutritional considerations, a forester can decide at the PHSP stage whether he will burn the cutblock or mechanically prepare it or, perhaps, opt for herbicide use.

I think it is important to do a better job of communicating to the public, the nature of the forest management options available to us, and the probable consequences of selecting particular options. Perhaps, if we did communicate a bit better in a language the public understands, and if we did emphasize integrated resource management, we might not encounter quite as much opposition to forest management practices, in general, and the use of herbicides, in particular.

As an example of poor communication, an open opposition to the use of fertilizers in forestry operations has been displayed because of the assumption that the people who live in that watershed will suffer from nitrate poisoning. There is an actual campaign on the east coast of Vancouver Island against fertilization right now.
Another thing which we have gleaned from the opportunities for implementation of research findings would be the timing of application, which is certainly different for rehabilitation areas than it would be for plantation release. Another aspect that I think we should all consider is that total elimination of competing vegetation is not essential. In other words, a 60-70% alder kill or a 50% kill of salmonberry might be adequate to release the plantation. Quite often in the past, our objective has been to eliminate all the alder, for example, but we tend to look at things a bit differently now.

Further Research

The other objective was to see what further research is necessary. Foresters still have to select those areas targeted for herbicide treatment. Our conclusion was that we do not have enough efficacy and screening trial information to be able to make that decision accurately for every area. There is still some question as to actual dosage required. Is a dosage of 2 kg/ha actually the right dosage? Can we get by with 1.5 or 1.25 kg/ha? There should be more research done on the question of timing of applications as well. The effects of height of the target species on treatment efficacy, survival and growth response of crop species, and, as some previous speaker mentioned, the impact of the surfactant are questions that were not dealt with adequately at this particular workshop. We should know the toxicity of the surfactant so we can determine whether in fact we can alter the herbicide : surfactant ratio for efficacy or economic reasons. Of course, in his planning, the forester must consider the overall economics of the treatment and, perhaps, a need for repetitive treatments. He may opt for one treatment which is quite inexpensive but may find down the road that he has to repeat that treatment again and again.

We are not doing a good enough job of communicating and taking advantage of all available information. For example, I did a little research on alders recently and found that there were at least 400 articles published on nitrogen fixation in forestry. It would be interesting to have someone collate and summarize this information for the operations perspective. I would like also to see a flow chart illustrating the pathways of herbicide through the environment; e.g., if one applies 2 kg of active ingredient per ha, what is the fate of the herbicide, how much is intercepted, how much ends up in the soil (and if it does get into the soil, what happens to it?), how much leaches out, how much is transformed and what are the degradation products?

We must continue and improve technology transfer to the operational people (i.e., timber managers, foresters and engineers), and to the public. In conclusion, our group recommends:

(1) a group interpretation of scientific results, and application and testing of these results in the field;

(2) further technology transfer take place in all aspects of herbicide use and resource management; and

(3) further research in the areas identified.

We would like to say that we found the work of this workshop to be very constructive and very positive.
DISCUSSION GROUP #10 - FORESTRY

Group Leader - Wayne Coombs

There was a wide cross-section of participants in our group. Within that cross-section we had individuals who had used herbicides (ROUNDUP and others) quite a bit and there were some who did not have any experience in herbicide use. But, we also had a good representation from a range of agencies, which allowed for a good discussion. We felt that this was the advantage of these group discussions, that we were able to establish, on a one-to-one basis, good credibility and rapport. I think that this is really what resource management is all about, working together as a team.

We initially established that the major objective of the Carnation Creek Herbicide Project was not to examine herbicide efficacy for forestry but was to assess the environmental impacts of operational applications of ROUNDUP. Further to that, we discussed the Carnation Creek study in detail and one of the things we felt was that, although there were results similar to those from other operations, there were limitations to the experimental design. Again, as we know, the emphasis was towards assessing environmental impact, but we felt that there could have been more of a comparison of various treatment tools. Using the MICROFOIL BOOM and not comparing it to the conventional tools that we are using right now limit the applicability of the results to other operational contexts. We feel that there is some question on the efficacy of the MICROFOIL BOOM technology and its applicability to cutblocks of varying sizes, shapes and terrain. We concluded that the Carnation Creek herbicide study had minimal operational value for field forestry because of the lack of the comparison of different treatments (both herbicide and manual), treatment intensities and timing.

We think that there is a tremendous need to have research results more available and more readily communicated. There is a diversity of research being carried out, and there is a need to coordinate the dissemination of information from these research projects.

We felt strongly that, in the study reported by Nick Payne, there would have been some value if there had been some on-target evaluation at the same time as the assessment of the off-target drift from the three booms. This may have reflected the lack of coordination of research efforts, but in any case, the result was a loss of valuable information in B.C. relative to deposition on-site as well as off-site.

Relative to Kimmins’ study, we felt that nutrients are very important not only for crop trees but weed species growth as well, and this is one area which has to be addressed in future research. We voiced a concern that the interpretation to be derived from Kimmins’ study is that no burning should be carried out. We thought that this was not the real message. A lot of sites that are burned have plenty of nutrient capital and appear to suffer little, if any, long-term impact. Other sites are, of course, much more sensitive. We are suggesting that we should evaluate the sites during the development of the PHSP and burn only those sites which are nutrient-rich and will not suffer irreparable damage. Because burning in many areas is a very valuable tool for reducing brush competition and increasing the number of plantable spots, we must have the capabilities of predicting possible fire impacts and of altering treatment strategies accordingly.

In evaluating Raj Prasad’s paper, we felt that there was a need to better assess treatments and time of treatments on conifers by correlating these to seedling morphological features (e.g., bud development, thickness of wax, woody tissue development in shoots, and physiological condition of the target species). In other words, in order to better protect the
conifers from herbicide damage, we need to know at what points in the growing season the morphological state of the seedlings will be most resistant to chemical damage, and, to more effectively control or eliminate the weed species, we need to know when they are most vulnerable to herbicides. This information will lead to more timely and efficacious treatments.

From all the papers that were presented and other papers we have heard in other workshops, we perceive a need to standardize methods of assessment of the effects of herbicide applications. Without standardized protocols, the comparability of research results and the transferability of results and interpretations will be seriously impaired.

With regard to buffer strips and PFZ, we concluded that the information provided by this study was inadequate to formulate any judgments as to efficacy and best uses of buffers. We recognize that buffer strips and PFZ restrict our capabilities to carry out forestry operations in areas where small tributaries and ephemeral streams occur. How critical are these areas in receiving and transporting herbicide downstream to fish-bearing waters? We should be providing fisheries staff and other agencies with the decision-making information to evaluate the treatment of minor side channels (i.e., rates and volume of flow, resource use(s), slope overhead vegetative cover) to allow overspraying. We need guidelines as to which streams can have PFZ restrictions lifted.

We concluded that there was a definite need for the testing and registration of new herbicides for forestry in B.C. It is interesting to note that this need was also identified by not only the foresters, but by other resource and regulatory agencies. We think that research is needed to address herbicide efficacy in forestry and environmental impacts (including those related to sublethal effects on fish and wildlife). There is a need for full involvement of all agencies in this research. The Carnation Creek Herbicide Project was a good example of a group of various agencies and resource users that worked together and developed a positive working relationship.

While there is quite a bit of forest ecology research underway, there is little research directed towards the autecology of competing species of vegetation. I can name only 2 or 3 studies, all of which are being carried out under FRDA. But the autecology of weed species is one area that the group felt should be addressed to better understand the weed species and their ecological capabilities and how various treatments affect those species.

Another major point raised related to the transferability of research results and interpretations, i.e., how are the Carnation Creek results to be extrapolated to other areas of B.C.? Can we actually transfer this information to other geographical areas and avoid having to carry out similar studies in the interior? Or do we have to invest in additional studies?
DISCUSSION GROUP #11 - SPRAY TECHNOLOGY

Group Leader - Dan Cronin

Major Observations

Our first major observation related to the value of the MICROFOIL BOOM within the context of current operational practices. It was felt that the MICROFOIL BOOM had rather limited application on a broad scale operational basis. Some of the limitations were that it was slow in delivery; it required high volumes for application, thus making it expensive to operate; it has questionable availability (we were led to understand that they are not being made any longer and there may be some difficulty in procurement); it is characterized by large droplet sizes, which decreases efficacy; and its usage over broad areas has been plagued by some stripping and skipping. We felt, though, that there is value and potential for the MICROFOIL BOOM and the thru-valve-boom (TVB) systems for use in sensitive sites, perhaps along the PFZ or water beds to be protected. This potential is increased because indeed a single application delivery vehicle, a helicopter, can be fitted with convertible systems. The use of boom systems in research, I suppose, could be defended in that they are a more controlled system of delivery with higher accountability. We had some agreement that in operations such as the Carnation Creek study it was acceptable and therefore may be used again.

The second major observation was that these studies have direct implications on our maintenance of what we have called the PFZ, and are also related to the BZ, which is more frequently referred to in the papers delivered. One implication of Nick Payne's work in particular is that a no-deposit zone is unattainable. Even with drops of 3 mm he was finding deposits 200 m from the edge of the spray swath; depending on the methods of detection, deposits could be found even further away from the target. The 10 m PFZ concept, therefore, has more or less been exposed as being arbitrary and unscientific. There was really no dispute that we could not maintain a PFZ as pesticide free. There will therefore be continuing pressure against the concept of a PFZ and the terminology used.

The risk in maintaining the PFZ concept in current management practices is that we could lose credibility in the eyes of foresters and the public when this information is disseminated. The value of maintaining the status quo with respect to the PFZ concept in current management practices is that it has operationally maintained a safety margin or at least the appearance of a safety margin that has been comfortable to deal with, at least from the standpoint of the public and perhaps some resource managers. The other implications of removing the PFZ requirement appear to be somewhat onerous, but we did not get into those.

Recommendations

The primary recommendation the group made was that we need guidelines based on science that can identify, for the practicing forester, the buffer zones (including PFZ) which he can likely achieve under the varying range of conditions and equipment presented to him. The studies we were presented gave us several, rather specific circumstances, with only a few pieces of equipment used. But there is a much broader range of field conditions and it would be useful to develop a matrix for the selection of buffer zone specifications, which could be then implemented. This could be essentially either an operational research compilation or a research program in itself.
The second recommendation is that some additional form of training for applicators be introduced so that there could be greater confidence in their ability to maintain the BZ and PFZ that are required. We recognized that the Ministry of Forests and Lands and some companies have higher standards of experience that must be met before one becomes an operational manager, but this was not considered universal and there is lots of evidence of mistakes being made.

The third recommendation for continuing agency dialogue relates to the PFZ and BZ guidelines themselves. We feel it is necessary to maintain discussions on the BZ and PFZ concepts in relation to the equipment, methods and approaches that are being developed in order to keep the concepts current and useful for field operations. The suggestion was made that the guidelines could be incorporated into fisheries/forestry guidelines as they are developed and introduced.

The last recommendation is that the restrictions for the protection of water bodies per se were too absolute and needed some defining. In some cases, wet footprints and temporarily filled equipment tracks were defined as water bodies although, rationally, there appeared to be no need to avoid them. Therefore, a need exists for a further defining of water bodies needing protection to deal with some of this uncertainty.

DISCUSSION GROUP #12 - SPRAY TECHNOLOGY

Group Leader - John Henigman

We identified very quickly that we failed to see how this workshop had a lot to do with the technology of spraying. Specifically, droplet sizes, the booms, nozzle sizes and so on really were not discussed. The implications certainly were discussed but not the technology per se. However, we decided very quickly, almost spontaneously, to talk about the process whereby one comes to spray an area and how one does that.

Issues

We put together a list of concerns and ranked them. The first concern relates to water bodies. We must be able to identify where they are and their importance in the scheme of things. We were told that fisheries habitat can in fact be dry, not a water body at all. On the other hand, run-off channels, which in fact are so remote from fishery-sensitive water bodies, do not require any protection at all. So, we identified a spectrum of what might or might not be habitat, and yet conceivably all such areas might require buffering. On the other hand, very valuable habitat might not require, under the legislation, any buffering at all. We feel that operational personnel, both fisheries and forestry staff, should be assisted via FRDA to specifically detail habitat and determine the needs of buffers on that habitat. So meetings such as this, or ways of facilitating operational people meeting on the sides of streams and coming to some understanding would be very useful.

The second concern was BZ and PFZ. There was not any great amount of discussion about whether or not the concepts are appropriate, but certainly where they are going to be applied was at issue. It is important to differentiate between different herbicides: ROUNDUP we have talked about, but we have not talked about GARLON at all. There are certainly other ones we could talk about, and all of them have different parameters and possible effects and impacts.
It is also important that we consider differentiating between habitats; i.e., what needs protection and how should it be protected. We recommend that regulatory processes be changed to allow maximum flexibility in determining need and extent of buffers, and to assist field staff in facilitating regulatory changes and writing guidelines. So, in the most extreme case, tackle the basic legislation that creates an overburden on regulatory and operational people; free them up so that they can make tangible, practical decisions on-site about a specific program. So, perhaps the Pesticide Control Act, possibly the Forestry Act, and possibly the Fisheries Act, all of those regulations which demand that there be no flexibility, should be loosened somewhat to incorporate guidelines which allow flexibility and some direction.

Spray Hardware

Contractors conducting aerial spraying should have available, on-site, different kinds of booms and nozzles to handle a job effectively. For example, if a MICROFOIL BOOM or a thru-valve boom (TVB) would facilitate achieving the BZ and PFZ requirements, they should be available to do the margins of particularly sensitive areas. The rest of the site could well be sprayed with a conventional, hydraulic, nozzle boom. This flexibility would be quite cost-effective. Perhaps FRDA could facilitate aerial freight contractors acquiring these specialized types of booms and allow the forest industry across the province to have these available. We feel that there is definitely good reason to want to enhance: (1) site-marking methods, i.e., how one defines the boundaries so that the applicator knows where to spray; (2) swath-marking methods, so that in effect the applicator doesn’t have problems with skipping, overlapping, or restarting when finished refilling; and (3) spray monitoring methods, all of which are pretty shoe-string at the present time.

The ability and the opportunity of the forester to direct the pilot while he is spraying are paramount so that all concerns are met and the quality of the operation is enhanced. It would be nice for the spray supervisor to know that, when the helicopter disappears over the hill doing his work and the spray supervisor is left in the blind, the pilot is going to do as directed.

DISCUSSION GROUP #13 - SOCIAL CONCERNS

Group Leader - David Bowering

Risks

First of all, we looked at risks, but the people in the group actually did not think that there were any risks associated with herbicides, glyphosate in particular, in view of the science that we had seen and the regulatory process in place. The consensus was that there were not significant risks, but there were risks related to the public’s perception. Some of those perceived risks result in economic risk: the allowable cut is related to the ability to efficiently manage the forests now; herbicides are part of the management strategies required; and, thus, jobs in the forest sector now depend on the use of the herbicide tool. There is significant risk to the economy. The public perceptions are not appropriate -- people do not perceive the situation as it actually is.

There are political risks, in the sense that issues blow up and public pressure mounts. There may be irrational acts that have a negative impact on the ability to manage forests. There
are some marginal concerns in terms of direct risk. People who actually are working with and applying herbicides are most at risk. It is important to minimize risk and to not be complacent in relation to herbicides. Another marginal concern relates to accidents when herbicides are being handled and transported (i.e., concerns about spills contaminating the environment). But again, the ability to effectively manage the forests is really at risk because of perceptions, not because of serious concerns about the toxicity or serious environmental impacts of glyphosate. Normal precautions have to be taken both from the public perception point of view and in terms of real safety.

Perceptions

The main problem area seems to be public perceptions. People talk a lot about trust, that there has been a breakdown of trust. Does the public trust foresters and, in fact, do the foresters trust the public? The consensus was that we probably do trust one another. Most people are reasonable except, perhaps, for a small percentage that can never be reached.

It was pointed out that the pesticide appeal process can establish a conflict situation. We saw a need for more public input to the process before both managers and concerned public are backed into corners in conflict situations. Our group felt that there are a lot of old ideas still prevalent, making communication with some people quite difficult.

There has been a tremendous growth in silviculture and intensive management, new ideas that the public still does not fully understand. There is a lot presently being learned but we are in a transition period during which we can expect some rough going. We do not have a lot of long-term experience in silviculture and intensive management. There has not been an opportunity to really build trust over a long period of time. Hence, we are in a trust-building phase.

In terms of formal and public education, it was felt to be important that scientists portray a balanced picture. There is some serious concern that right now they do not, that instead of a balanced forest management perspective there is some anti-herbicide bias which will, if not corrected, lead to future problems. This again emphasizes the idea of relative risks and distorted perspectives on the part of the public about how dangerous things really are. From my point of view, smoking is the major example of a very serious risk that people generally underestimate. The idea that Johnson's Baby Shampoo might be as irritating to the eyes as glyphosate was raised; there was also some discussion as to what is the better shampoo!

As you all know, in traditional Chinese medicine, green is the color of wood and it is also the color of healing. We are all Chinese practitioners in a way, and I sense in this area that there is a healing process going on. There has been some damage in terms of the public and forestry, some pain and some conflict, but I think there is a definite healing process taking place.

Solutions

Some solutions were suggested for spreading the educational message and improving the perceptions. Workers on the ground need to be convinced in terms of efficacy and safety. People actually working in the field apparently do not all feel comfortable with what they are doing. That may be a place to start with the educational message. The positive message to the public is now starting to be delivered. "Forests Forever" received a number of strokes as a positive move, although there was some concern that the message be balanced, that we not try to convince people that everything is perfect and there have never been any mistakes made.
At the local level, things such as tours of forests are effective. It was pointed out that conflicts often disappear when people get out on the ground and see things in a realistic perspective. Videos of forest management strategies and practices are helpful when informing local interest groups. Some of our group suggested becoming involved in environmental interest groups because, at heart, we are all environmentalists and we really do share a common interest. There really is no reason why people should not belong to these groups and hopefully balance that process and perspective.

An interesting idea was proposed to inform people about herbicide treatments in areas where environmentalists and concerned people would accept them. Posting would stress positive management goals, and not convey a message of "black death".

Appropriate formal education is required but there was not a very strong sense of optimism that it could be achieved. Would it be possible to have applied science and resource management considerations in the curriculum for students in the province? Would it be useful to have public input to land classification (i.e., resource use planning) as opposed to land management?

We feel that understanding and practicing the principles of conflict resolution are important. We had somewhat of a demonstration, I would say, in our group, given its diversity of expertise and interests. If one could come to understand his opponent's position(s), many conflicts can be dealt with fairly and expeditiously, particularly in a heavily emotion-laden atmosphere. It is important for people involved with the public in this area to seek such training.

**DISCUSSION GROUP #14 - SOCIAL CONCERNS**

Group Leader - Paul Pashnik

**Issues**

We had a wide perspective in our group and a good discussion. We discussed many things that Dr. Bowering talked about, and it was interesting that we had only one paper that dealt directly with our issue, and that was his. However, I think all the papers had implications on the whole issue of social concerns because of the lack of public awareness and the credibility of test and safety data with respect to health and the environment.

Public perception was deemed to be one of the biggest problems when dealing with herbicides: fear for the health, safety and environment of citizens. Pesticide safety and test data are restricted and are apparently difficult for the public to obtain. Public trust is a problem: are the government regulators living up to their responsibilities? Bad press has, justifiably, been caused by such major environmental issues such as DDT and 2,4,5-T and by credibility problems we have had with falsification of efficacy and test data (I.B.T. Lab.) and related court cases. But, when misconceptions are printed by the media. (e.g. "---2,4-D is Agent Orange", "ROUNDUP causes cancer") there appear to be no response from experts in the industry to correct the obvious errors or to set the record straight. We also dealt with the ethics of forest management and felt that really there was no validity to any concerns raised. The main concern was that the public perceives pesticide use as a profit motive, and perhaps political commitments to both forest and chemical companies.

We looked at risks--risk to the environment, risk to health, and also the lack of risk-comparison data. Such information is needed when we are explaining the levels of risk associated
with different treatments or practices. There is very little risk-comparison information in B.C. The forest industry has avoided discussing this topic due to lack of such information. There are also serious risks to successful forest management in not using herbicides. We will continue to create excess backlog NSR (not sufficient re-stocked) lands and lose forest sites by not using herbicides on many land areas where such treatments are the only effective vegetation management tool available. This will have a direct reflection on industry costs and long-term sustained yield and, of course, the economy, in general.

We also identified forest land use planning as a problem. We felt there is a role for the public in B.C. in the broader planning context: e.g., in timber supply area planning and TFL management working plans. This public role should not be overlooked or glossed over; this is where we can openly discuss the various land use and management options, and consider and accommodate valid public opinion.

We also discussed the misconception that, perhaps, the forest industry is in its 'sunset' stage. Many people believe this and it has not helped that this misconception has, in the past, been supported in part by some uninformed provincial politicians.

Conclusions/Recommendations

We came up with a couple of conclusions/recommendations:

1) Public perception is the biggest problem that we have to address. Accordingly, we require a pro-active public information program. This program should define vegetation management alternatives and ensure that the public is presented with the costs and benefits; the risks and how risks are minimized -- this would involve a brief explanation of the chemical registration process, the application for pesticide use, pesticide permit issuance, the appeal process, and the requirements and standards we have in staff training and project control.

2) Our next recommendation related to emphasizing the judicious use of herbicides based on site-specific prescriptions. Herbicides should be used where they are the most biologically and cost-effective tool; and where alternatives such as prescribed fire, manual brushing or mechanical site preparation are not viable vegetation management options.

3) Pesticide public information centers should be developed to provide reference materials, skilled communicators, demonstrations, videos, etc. These centers could be developed in association with demonstration forests, for example.

4) We recognized the need for resource planning and a continued commitment by government agencies and the forest industry to integrated resource management. A better exchange of information among resource users would produce better resource management plans. Workshops are a good forum in which to exchange information, work on problems, and identify solutions.

5) The public must be involved in the resource planning phase. TSA and TFL management and working plans should be made available for public review and comment. Pesticide use and alternatives should be clearly identified. If such information is contained in development plans, those plans should be then similarly made available for public review and comment. To accomplish this we felt that we should use existing TSA and TFL planning procedures (management and working plans and development plans), organizations and individuals.
6) We individually should be proactive and become more involved through responding to inquiries, being guest speakers at annual meetings and conventions where the whole forest management picture can be explained, including the scope and importance of the pesticide option for vegetation management. We must remember to use simple, layman's language when we are talking to groups, citizens, city councils or municipal water boards.
CONFERENCE SUMMATION:

THE CARNATION CREEK HERBICIDE TEST WORKSHOP

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V0G 1M0

Ladies and gentlemen; this has been a long three days. Have you ever felt that you were drowning in a sea of words? I think it was Phil Gagliardi who once said that the mind could not absorb any more than the backside could endure. As a former press gallery reporter I used to spend every day listening to long speeches and in the last three days we have heard some that were good and long. And some that were more long than good.

It is now close to mid-afternoon on our third day and I notice that our numbers have thinned out a little. Obviously, not all people have an equal ability to endure prolonged pain. I was wondering about those people who left early. It looked like an interesting research opportunity so we monitored those early leavers to see whether there were more forestry or fisheries people among them. But alas; “The results of our research were inconclusive and further study is required.”

Whenever I am asked to be the sum-up speaker at a conference, I usually try to refer to all the papers individually. This is not possible in this case (with about 25 speakers) so I have had to take a different approach. I listened to as many of the presentations as possible; I floated through the various workshops and I read all the abstracts. As usual, I took far too many notes and had to distill them considerably in order to stay within my allotted time. I have three topic areas, which in my judgment have emerged as highlight impressions after being among you for the last three days. They are:

1. The quality of the presentations and the effectiveness with which they were delivered.

2. The conclusions gained after listening to the presentations.

3. This observer’s prognosis for putting your findings into practice.

I find it necessary to say something quite critical of many of the presentations and the way they were delivered. Many of the presenters delivered a fairly thoughtful abstract but then chose to ad lib through some fairly tedious elaboration, frequently (if not well) supported by a number of badly produced slides. People at the back of the hall found some of the text unreadable. There were some fascinating papers and some were quite superb. But on the whole, I found the standard to be disappointingly low. And someone should tell the hotel that this public address system is quite inadequate. If you have trouble seeing the slides and can’t hear the speaker—frustration is understandable. A lot of the speakers wandered off the microphone thus shutting out people at the back of the hall.
In trying to draw some conclusions from the presentations, I had a sense of both optimism and dismay. We might as well get the upbeat stuff out of the way first. The managers who thought of using Carnation Creek as a herbicide test site are to be commended. Having a field project of such long standing, with its accompanying huge data base, made possible the kind of test that emerged with a credibility which could not have been equaled elsewhere. Research findings from Carnation Creek have high credibility and with good reason.

Having heard so many attacks upon forest herbicides it was interesting to be given so much "good" news. I have to point out that I reside in a part of the province where herbicide protest has included public demonstrations, civil disobedience and vandalism. This has been directed at testing, let alone application. Yet, the biogeoclimatic conditions are quite similar to those at Carnation Creek. I refer to the interior wet belt, the cedar-hemlock zone, known also (by the blizzard of signs around the region) as a "pesticide free zone." Regardless of the signs, the west Kootenay, like every other place on earth, is far from pesticide free.

Partly as a result of agitation from the west Kootenay, the debate over herbicide use is now highly polarized. To me, it is an example of the kind of pendulum politics for which the region is widely known. It will thus be fascinating to see what influence, if any, the Carnation Creek findings will have on the provincial herbicide debate. Even at this conference, while there has been a quite high level of statesmanship during the sessions, once into the conversational exchanges, it turns out that the veneer is fairly thin and in a few cases special interest bias sometimes transcended both reason and good manners.

In general, public fears about aerial spray of herbicides in the forest revolve around the following:

There are fears: that spray from aircraft is so imprecise that sprays will drift over vast areas, that rainfall and run-off will leach residues into streams, etc., with deadly results, that the spray will accumulate in the soils, etc., etc.

The use of glyphosate in the Carnation Creek tests revealed that most of these fears (at least with this particular chemical) were groundless. When this chemical (trade name ROUNDUP) is applied in the concentration used in this experiment, and with the technique of this helicopter spray method, the impact on the environment was not only short-lived but confined to the target area and the aftermath was quite minimal if even detectable at all.

One aspect of intensive management is predator control: to increase a harvestable surplus by controlling competing species of plants or animals. Brush or "weed" control in forestry is one example. It is sometimes criticized by fish and wildlife interests, a puzzling response since they themselves frequently engage in the same process. Killing the natural predators of salmonids or terrestrial animals like elk and deer has a long history in B.C. and one which is strongly opposed by the general public. Should predator control be re-introduced for sea lions and seals, public opposition will certainly intensify. The furor over killing a few wolves is proof of that.

In fact, the use of chemicals to kill unwanted competitor species was not started by foresters but by fish and wildlife managers. They were the real pioneers. In the 40s and 50s the wolf was virtually eliminated from southern B.C. Wolf and lake poisoning both required the use of deadly chemicals such as cyanide, strychnine and toxophene which had a toxicity that would make ROUNDUP look like Mom’s chicken soup. These poisons (that’s what they are) have been widely used in B.C. British Columbia lakes are still being poisoned, now using chemicals that are described as "safe."
Obviously, there is now a higher standard of awareness that real ecological risks are inherent in maximizing single plant or animal species. While zoning land to "highest and best use" is often the best choice there are obvious reasons to oppose province-wide monoculture forestry with its unattractive image of some kind of coniferous cornfield. But if maximizing a few species is deemed ecologically inappropriate in forestry it would seem no more attractive in wildlife or fisheries.

Now to the third point; whether or not the Carnation Creek herbicide test results are likely to mean that public fears of ROUNDUP are alleviated. I think that will depend on whether you people get really serious about reaching the public with this information and whether you speak with one voice on the subject. If unanimity is lacking, these findings will be less likely be accepted. The forestry establishment has been saying (for years) that ROUNDUP, properly applied, was safe for use in intensive forestry. These tests would seem to confirm that. Now it is up to the various special interests in the discussion to make some collective public statements about the matter. The information from these studies must be condensed into a single information package, prepared for lay readers and distributed widely.

Some scientists conducting research at Carnation Creek used a procedure that is widely followed in gauging the results of ecologically sensitive activity. They used a so-called "worst case" scenario, projecting results to encompass the worst possible consequences. In considering the public acceptability of these findings I thought I would also pose a "worst case" scenario. This could apply should the question of forest herbicides become more political, as I think it will. Here we go. If there is not an appropriate move to inform the public of these findings, I think there could eventually be a ban on forest herbicides in B.C. In fact, from my own perspective (and barring the kind of major information effort that I have described) I think a B.C. ban on forest herbicides is not only possible but likely.

I would also observe that many of the people currently coordinating herbicide research information are naive politically and fail to recognize the zealousness of the anti-herbicide and anti-logging factions and how sympathetic media is to their cause.

Earlier this year (1987) delegates to the BCWF annual convention voted in favor of a ban on the aerial application of pesticides. At the convention in 1988, there will likely be a motion to have that resolution become part of Federation policy, meaning that the Federation will be required to campaign accordingly.

A ban on forest herbicides would have virtually no benefit to the environment for two reasons. No. 1: the forest use of herbicides is only a fraction of the volume used in agriculture. No. 2: (as we have learned at this conference) at least one forest herbicide (ROUNDUP) is so benign that even when sprayed directly over a stream channel (containing resident coho fry) no unusual mortality was observed. But that does not mean ROUNDUP will never be banned. Banning herbicide use would have a great and negative impact on intensive forestry. It would be like banning all predator control in fish and wildlife programs, a move that would cripple current management objectives and result in drastic cutbacks in hunting and fishing seasons.

If herbicides were banned from use in the forest, the benefits of intensive forestry would be much reduced. The Falldown Effect would happen sooner, sag deeper, and our climb out of it would take longer. In fact, we might never fully recover and could find ourselves forced to accept a much lower allowable cut for a much longer period of time. WHY SHOULD A WILDLIFE

1 In this sense the word "pesticide" refers to herbicides and fungicides as well.
2 A drop in the allowable cut caused by removal of the first growth forest before the second crop is ready. The falldown effect can be greatly offset by intensive forest management.
ADVOCATE BE SO CONCERNED ABOUT THAT? Because a failure of the intensive forestry program will absolutely result in increasing conflicts over fish and wildlife.

It needs to be stressed that herbicide use is intended to be very site-specific and that manual and other non-chemical treatments will still predominate. And more people need to become aware that the amount of herbicide used in the forest is almost insignificant compared to domestic and other industrial use. Agriculture is the big user and it is doubtful if forest use will ever equal the amount used on private lawns and gardens.

With all renewable resources, there are times when the natural processes are the best choices and all agencies should continue to stress that. Moreover, the pressures to manage all renewable resources more intensively comes not from the resource managers but the resource owners. Public demands for all the values of the forest; including range, recreation, fish and wildlife, are rising and the moves toward intensive management are in direct response to that. This was a technical, not a sociological conference but these factors lead to the political action that really drives the game and thus have to be considered as well.

Overall, this conference has been in keeping with the high standard of technical excellence that we have come to expect from the Carnation Creek project. I choose to end this somewhat unconventional summation in an equally unconventional way (at least I am being consistent) and I do so by sharing with you a piece of thought-provoking B.C. poetry.

The work is by Peter Trower, a former coast-logger. And while it was written with an artist's pen, it includes some very sound ecological perceptions as well. It is not delivered for editorial purposes but as a reminder of the very high level of emotion and sensitivity that some people (loggers included) have for the functioning, giving and renewing forest. The poem is called "THE ALDERS."

The alders are the re-occupiers.
They come easily and quick into skinned land:
Rising like an ambush on raked ridges:
Jabbing like whiskers up through the
Washed-out faces of no longer used roads.
The alders are the forest-fixers.
Bandaging brown wounds with apple-green sashes:
Filling in for the fallen firs:
Jostling up by the stumps of
Grandfather cedars: leaning slim
To the wind by logjammed, logger-left streams
The alders are the encroachers.
Seizing ground the greater trees owned once
But no more.
This is the time of the alders.
They come, like a bright upstart army
Crowding the deadwood spaces: reaching
At last, for the hand of the whole.
Uncharted, sun.

Once again, thank you for affording me the opportunity to be both chairman and summation speaker at this important conference. Thank you for coming. Merry Christmas to you all. These proceedings are now adjourned.
A SUMMARY OF CARNATION CREEK HERBICIDE STUDY RESULTS

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ABSTRACT

The Carnation Creek Watershed, located on the west coast of Vancouver Island, was aerially treated with ROUNDUP (glyphosate) from September 6 to 15, 1984 with the intent of examining environmental fate and impact of ROUNDUP treatment on a temperate coastal rain forest. Carnation Creek presents a unique research situation: we possess a 20-yr data base on its salmonid population. This data base has permitted whole life history impact assessment of the effects of numerous forest management practices, including the possible impacts of herbicide use on this resource.

Following ROUNDUP treatment at Carnation Creek, various chemical and biological studies were conducted for up to three years post-treatment. These studies revealed no unexpected or long-term adverse effects on coho salmon or other aquatic organisms using tributaries that had been directly oversprayed with the herbicide. Residue movements within the watershed and residue inputs into the aquatic ecosystem were carefully monitored in relation to autumn and winter storms. Glyphosate residues rapidly dissipated and degraded in the natural environment. After one year, remaining residues were strongly adsorbed to organic matter, soil particles, and/or stream bottom sediments, and were deemed to be biologically unavailable.

INTRODUCTORY REMARKS

In the spring of 1984, ROUNDUP (glyphosate) was federally registered for forestry use by Agriculture Canada. Although in-depth environmental impact and fate research had been conducted with glyphosate elsewhere in the Pacific northwest (Newton et al. 1984). Provincial and federal regulatory officials in British Columbia expressed concern about issuing operational permits to spray ROUNDUP in the coastal zone. The environmental conditions of the cool, temperate rain forest of coastal B.C. (Table 1) are different than those in the more arid, warmer forests in southwestern Oregon, where previous research had been done. There were also lingering federal and provincial concerns about possible short-term fish toxicity of the surfactant used to formulate ROUNDUP.

Table 1. Carnation Creek Watershed characteristics

- high annual rainfall, 2,100 - 4,800 mm
- steep slope
- frequent storm events
- seasonal flooding
- cool temperatures
- soil: highly organic surface horizons; well-drained coarse textured lower horizons
To efficiently manage new forests throughout the British Columbia coastal zone, it is essential that herbicide treatment occur as close as possible to streams without jeopardizing critical riparian vegetation or endangering aquatic organisms. Floodplain areas often contain the best forest land and problems with competing brush species. Government agencies have attempted to protect riparian resources by establishing a 10-m pesticide free zone (PFZ) with appropriate buffers considered by environmental regulators to be essential to ensure that chemical trespass of this zone does not occur. Registration of ROUNDDUP raised several regulatory concerns with regard to this issue: (1) could the PFZ be maintained along visible streams during aerial spraying, (2) what size buffer would prevent chemical trespass of the PFZ, and (3) what environmental and biological consequences might result from accidental overspray of streams not visible from the air because of extensive vegetative overgrowth?

To more fully address these concerns, a ROUNDDUP environmental fate/impact study was designed for the Carnation Creek experimental watershed (Reynolds et al. 1989a) that would:

(1) provide a 10-m PFZ without an additional buffer along the main creek (visible), but

(2) allow for an overspray of certain floodplain tributaries (not visible) used as overwintering habitat by coho salmon.

The Carnation Creek glyphosate study was not designed as a silvicultural study, but silvicultural performance of the herbicide does have a bearing on the magnitude of environmental impact. The justification for herbicide use is that the treatment must work. Crop trees released by glyphosate from brush competition should survive and grow better than those not released.

To achieve the maximal environmental impact of ROUNDDUP treatment at Carnation Creek, the maximum label rate (2.1 kg a.i./ha) was used, and the herbicide application was timed to achieve maximal residue inputs (autumn storms) when coho salmon would be most likely to come into contact with these residues (i.e., entry into oversprayed tributaries). Minimum impact on the crop trees was also anticipated at this time.

A MICROFOIL BOOM\(^1\) was used because this aerial delivery technology could provide a 10-m PFZ without an additional buffer zone. The MICROFOIL BOOM emits very large spray droplets, which fall like rain drops to the ground and create a knife-edge effect between target and non-target vegetation. The three research protocols that were key to understanding the experiment were:

(1) maintenance of a 10-m vegetation buffer on either side of Carnation Creek;

(2) overspray of two tributaries designated as 750 and 1600; and

(3) a third tributary, designated as 2600, was an untreated control for 1600 and 750 (2600 was upstream of the treated portion of Carnation Creek watershed).

The tributary numbers correspond to the distance (m) from the estuary to its confluence with Carnation Creek, and indicate the length of floodplain sprayed above B-weir (500 m, the main flow gauging weir and stream sampling site). The treated floodplain was 80 to 270 m wide, and the total area treated above B-weir was 32.7 ha or 3.4% of the watershed. The two oversprayed tributaries differed substantially in their stream dynamics, and hence in their potential to act as environmental sinks for retaining herbicide residues. Tributary 750 is a short (50 m) valley-floor tributary characterized by rapid flow and flushing along a relatively straight reach of stream. By contrast, 1600 is a longer (250 m), slow-flowing, and slow-flushing tributary that meanders along the valley floor.

\(^1\) Registered Trademark of Union Carbide, Inc., Ambler, Pa.
The Carnation Creek watershed was aerially treated with ROUNDUP between September 6 and 15, 1984 by Rotor Vegetation Control and Alpine Helicopters of Calgary (Reynolds et al. 1989a). Following treatment, environmental fate monitoring continued for one year and coincided with major winter storm events (Feng et al. 1989; Feng and Thompson 1989). Environmental impact and biological response research continued for up to three years post-treatment (Holby 1989; Holby and Baillie 1989a,b,c; Preston and Trofymow 1989; Reynolds et al. 1989b; Scrivener 1989; and Scrivener and Carruthers 1989). Weather conditions after treatment provided opportunities for measuring maximal redistribution of the herbicide in the environment (Hetherington 1989).

At Carnation Creek, ~75% of annual precipitation (Table 1) occurs during autumn and winter storm events (Hetherington 1982). The first sizable fall storm took place within 24 h of the completion of spraying. During autumn storms, many coho salmon moved out of the main channel to overwinter in tributaries such as 750, 1600 and 2600 until the beginning of spring when they again returned to the main channel (Tschaplinski and Hartman 1982). Fish moved into the tributaries to avoid the excessive turbulence of the mainstream during the winter. However, this movement placed the coho in direct exposure to glyphosate residues entering the tributaries as a result of autumn or winter storm events.

The Carnation Creek study provided several unprecedented opportunities to examine various aspects of fate, impact or biological response not addressed in prior research. Key among these opportunities were:

1. the long-term salmonid data base for Carnation Creek (since 1970) is the most complete in North America,

2. the concurrent coupling of the fisheries data base with environmental fate and impact research,

3. a first-time ever examination of long-term watershed residue inputs from winter storm events and observations of long-term fish toxicity or avoidance resulting from these inputs, and

4. a first-time ever examination of habitat changes induced by herbicide treatment, and the effects of these on fish populations and other aquatic organisms.

Toxicity, fate of residues, and biological responses of the resident fish population have been examined in other watersheds, but only in the short term. The impact on aquatic organisms of herbicide-induced habitat changes have not been addressed by these previous studies.

RESULTS AND CONCLUSIONS

A few silvicultural results and conclusions are stated first as a foundation for conclusions from individual studies. Specific conclusions are preceded by the specific study objectives that were outlined in the introductory article (Reynolds et al. 1989a).

Silvicultural conclusions are as follows:

1. Formulation, tank mix, and deposit collector analyses indicated an accurate chemical application (Feng et al. 1989).

2. Herbicide efficacy was species dependent, but generally high for species that glyphosate is known to be effective against (Reynolds et al. 1989b).
3. Control of all noncommercial species declined 2 and 3 years after treatment (Reynolds et al. 1989b). This finding is consistent with other major glyphosate studies conducted on a global basis (Lund-Hoie and Gronvold 1987). There is no evidence that herbicide efficacy was reduced as a result of using the MICROFOIL BOOM.

4. Crop tolerance was species dependent with only minor injury to western redcedar and western hemlock and no injury to Sitka spruce (Reynolds et al. 1989b).
   - full recovery 1 year after treatment;
   - no cases of crop mortality;
   - no cases of stem deformity

5. Sitka spruce released by glyphosate treatment had a 40% advantage in diameter and a 63% advantage in diameter-increment over untreated trees 3 yrs after treatment (Reynolds et al. 1989b). Western hemlock growth also improved significantly, but data from western redcedar was too limited to show any growth enhancement from release.

6. Considering the late timing and the advanced state of the competition, ROUNDUP performed well silviculturally (Reynolds et al. 1989b).

Conclusions of Individual Studies

Objective 1: Monitoring off-target glyphosate deposit.

Conclusions:

a. No residues were observed in buffered streams (Feng et al. 1989).

b. Under the specific conditions of this study, the 10-m vegetation buffer adequately protected streams from chemical contamination (Feng et al. 1989). Results reported by Payne et al. (1989) lend support to these findings.

Objective 2: Monitoring short-term glyphosate residues in oversprayed tributaries and those entering Carnation Creek from these tributaries.

Conclusions:

a. Highest residues in streamwater of a directly sprayed tributary (162 µg/L) were 50-fold below the lowest accepted 96 h LC₅₀ dose (7800 µg/L) for rainbow trout (Feng et al. 1989 and Servizi et al. 1987).

b. Residues declined to non-detectable levels within 96 h post-application (Feng et al. 1989).

Objective 3: Monitoring short-term, immediate effects of aerial ROUNDUP application on salmon fry behavior, movements, and mortality in relation to measured glyphosate residue levels in flowing tributaries and isolated pools in the experimental area.

Conclusions:

a. No fish mortality occurred that was attributable to the herbicide application (Holtby and Bailie 1989a).
   - mortality of caged fish appears to have been caused by storm injury;
   - there was no unusual mortality of resident coho at the time of spraying.
b. Caged coho showed signs of stress within 2 h of the application (Holty and Baillie 1989a). Stress was minor and temporary.

c. Resident coho were caught less frequently in baited minnow traps and they appeared to avoid the fence on the oversprayed tributary (1600) for 3 wks after herbicide treatment (Holty and Baillie 1989a).

Coho avoidance of minnow traps was accompanied by an increased movement of Paralepiophlebia (an aquatic mayfly) within 24 h after overspray (Kreutzweiser and Kingsbury 1989). This also indicated that stress observed for caged coho may have been caused by ROUNDUP. Field observations of coho stress are not in agreement with laboratory toxicity studies with ROUNDUP (Chapman 1989) reported elsewhere in this proceedings. In addition, residues were not measured where caged fish were held, but only where the tributary joins Carnation Creek. Residues may have been diluted as compared with elsewhere within the tributary, because canopy overgrowth of 1600 varied greatly from the lower to the upper reach of the tributary (Holty and Baillie 1989a). Values observed at the mouth of 1600 may underestimate herbicide exposure. Vegetation shielding appeared to cause variation of glyphosate concentrated in natural and artificial ponds (range = 20 to 376 μg/L) immediately after overspray with ROUNDUP in northern Manitoba (Beck 1987). Holty and Baillie (1989a) have also suggested that laboratory results are probably not applicable to the natural habitat where fish are actively seeking winter refuge soon after herbicide treatment. Fish entering a new environment would be more predisposed to the additional stress of being exposed to ROUNDUP.

Objective 4: Monitoring short-term aquatic invertebrate drift resulting from ROUNDUP exposure.

Conclusions:

a. Aquatic drift rates (downstream movement) of Paralepiophlebia mayflies and Gammarus amphipods doubled within 24 h after direct overspray (Kreutzweiser and Kingsbury 1989).
- avoidance was short-lived;
- Paralepiophlebia and Gammarus are especially sensitive species, and they might be useful indicator species for aquatic invertebrate drift induced by pollutants (Williams and Moore 1982; Muirhead-Thomson 1985);
- drift rates did not increase for any other invertebrate species.

Objective 5: Monitoring the movement of glyphosate residues into side channels following major autumn and winter storm events.

Seven major storms with peak flows from 7.7 to 28 m³/s occurred from 23 to 150 days post-application.

Conclusions

a. Trace levels in streamwater of oversprayed tributaries (1600 and 750) were associated with these storm events (Feng et al. 1989). No detectable residues were found in buffered tributaries (C creek and 1450) during this monitoring period, indicating that the PFZ effectively prevented stream contamination from both off-target deposit and subsequent inputs (Feng et al. 1989).

b. The highest residues were observed in tributary bottom sediments, which are the major sink for this compound (Feng et al. 1989).
c. Glyphosate was found in bottom sediments throughout the 150-d period in one treated tributary (1600); but it was observed only sporadically in the other tributary (750) during this period (Feng et al. 1989). Differences in glyphosate accumulation for the two tributaries are the result of differences in stream dynamics and flushing for the two tributaries.

d. Sediment residues were not biologically active because they remained bonded to the sediments (Feng et al. 1989).

**Objective 6: Measuring the persistence and dissipation of glyphosate in riparian foliage and soils.**

Red alder and salmonberry are the major riparian vegetation growing along tributary streambanks at Carnation Creek and elsewhere within the British Columbia coastal forest. Both species are the major brush competitors at Carnation Creek, and are two of four major brush competitors throughout the coastal area. Ironically, both species are key components of the physical habitat (stability, cover) and of the aquatic food web sustaining coho salmon. Hence, regulators have expressed concern that glyphosate residues deposited on target vegetation, especially alder or salmonberry, not serve as a possible source of toxic contamination for aquatic organisms that use their leaf-litter in the aquatic food web.

**Conclusions:**

**Foliage**

a. High deposition of glyphosate occurred on target brush species (Feng and Thompson 1989).

b. Foliage residue levels declined significantly within 15 d after ROUNDUP treatment and continued to decline progressively over time (Feng and Thompson 1989).
- less than 1% remained 29 days post-application;
- less than 0.1% remained 75 days post-application;

c. Results showed that residue levels in leaf-litter of major brush species presented an insignificant, transient source of chemical input onto forest floor or into streams.

**Soils**

a. Soil residues of both glyphosate and its metabolite, AMPA, declined over time in both seasonally flooded and well-drained soils (Feng and Thompson 1989).
- estimated glyphosate half-life (DT50) is 45 to 60 days;
- only 6 to 18% of initial levels remained after 360 days:

Floodplain soils varied in their degree of soil saturation throughout the year. Drainage of these soils at Carnation Creek has been described by Hetherington (1989). Chemical decomposition rates varied depending on soil saturation levels (Feng and Thompson 1989). For well-drained soils, more aerobic conditions existed for longer periods throughout the year, and more rapid microbial decomposition of chemical residues was expected. For seasonally flooded soils, anaerobic conditions existed over longer periods, and slower microbial decomposition of chemical residues was expected. Declining glyphosate residues coupled with transient increases in metabolite residues were indicative of microbial degradation. The latter conclusion is in agreement with results reported by Preston and Trofymow (1989). They also found no toxic effects of soil glyphosate and metabolite residues on soil microbes or macrofauna. No changes in soil microbe populations or in soil denitrification were observed as a consequence of herbicide treatment.
b. The Carnation Creek study provided no evidence of extraordinary soil persistence of either glyphosate or its metabolite (Feng and Thompson 1989).

Results at Carnation Creek are in agreement with those reported by Newton et al. (1984) for a semi-arid Oregon forest watershed study.

c. Limited leaching potential was observed for both soil types (Feng and Thompson 1989).
- most of the residues (90%) were usually associated with the top 5-cm organic layer;
- no quantifiable residues were detected in samples taken from the 30-35 cm layer.

Hydrologic studies for the Carnation Creek watershed suggest that any mobile residues would leach vertically until the water table was reached, then tend to move laterally once the water table or surface water was encountered (Hetherington 1989). For seasonally flooded soils, the water table generally occurred near or at the surface for several months each year. Throughout the observation period, residues were lowest at the seasonally-flooded site; it is probable that reduced levels could be attributed to movement of chemical away from the sampling site by surface water, with residues either in solution or on transported fine sediment (Feng and Thompson 1989).

d. The limited mobility exhibited by glyphosate in Carnation Creek soils is due to strong adsorption to cation saturated clays and/or organic matter in the upper soil horizons (Feng and Thompson 1989).

Glyphosate binding to soils is positively correlated with clay content, cation exchange capacity and unoccupied phosphate adsorption capacity (Hance 1976; Hensley et al. 1978; and Sprankle et al. 1975). Carnation Creek soils are characterized by a relatively high cation-exchange capacity and organic matter content, especially in the upper 15 cm layers.

e. The data provides no evidence of potential for long-term groundwater or surface water contamination as a result of inputs from terrestrial substrates (Feng and Thompson 1989).

Objective 7: Assessing habitat changes induced by glyphosate treatment (water temperature, changes in riparian vegetation, erosion, sediment inputs, stream chemistry, algal populations, aquatic and terrestrial invertebrate fish-food, litter inputs, etc.) in the main stream and treated tributaries.

Conclusions:

a. Litter-fall for tributary 1600 was reduced to 6% of expected deposition in 1985, the year after overspray (Holby and Baillie 1989b), without apparent measurable biological impact.

Reduction was short-lived, with rapid progressive recovery 2-3 yrs post-application. Herbicide efficacy progressively declined in year two and three after treatment (Reynolds et al. 1989b). Alder and salmonberry rapidly resprouted, reversing environmental changes induced by defoliation, including reduced stream litter inputs in 1985. Other environmental changes induced by herbicide defoliation of alder and salmonberry included: (a) increased sunlight reaching the stream surface, (b) warmer stream temperatures, (c) increased erosion, and (d) increased nutrient inputs. These changes occurred for 1 or 2 yrs and they were accompanied by biological responses which were either beneficial, neutral or detrimental.

b. Streamwater temperature increased in 1600 in 1985 resulting from defoliation of riparian alder (Holby 1989).
- temperatures decreased to pre-treatment levels within 3 yrs;
- no adverse effects of temperature increase on resident salmonids in 1600;
- increased temperatures probably contributed to increased algal production in the year after treatment (Holby and Baillie 1989c and Scrivener 1989).

c. Streamwater conductivity increased 21% during freshets in the year following herbicide treatment (Scrivener 1989).
- increases were due to enhanced leaching of ions;
- increases were short-lived (1-2 yrs);
- increases had no apparent biological impact.

d. Streamwater nitrate (NO$_3^-$) levels for 1600 increased 3-fold during freshets in the year following herbicide treatment (Scrivener 1989).
- increases resulted from release of NO$_3^-$ from roots of dead vegetation;
- increases were short-lived;
- streamwater concentrations did not reach levels that were known to be toxic to salmonid eggs; there were no adverse biological impacts observed.

These results are in agreement with those reported by Kimmins et al. (1989) for another coastal British Columbia watershed.

e. Streamwater phosphate (PO$_4^{3-}$) concentration increased after herbicide treatment (Scrivener 1989).
- increases resulted primarily from deciduous litter inputs;
- similar increases were not observed after logging and slash-burning; after herbicide treatment, PO$_4^{3-}$ was released from herbicide-treated brush (litter from treated brush was not destroyed by slash-burning and had a much higher PO$_4^{3-}$ content than coniferous logging slash);
- increases were short-lived (1-2 yrs);
- increased algal production (10 to 100-fold) occurred in the year after herbicide treatment due to increased levels of PO$_4^{3-}$ and light (Holby and Baillie 1989b);
- increased algal production was short-lived;
- phosphorus was the primary factor limiting algal production in Carnation Creek (Stockner and Shortreed 1978).

Enhanced algal production may have off-set, to some degree, any food losses that may have resulted from the temporary interruption in stream litter inputs.

f. Herbicide overspray of 1600 had no measurable direct effects on invertebrate abundance or community composition during the post-spray monitoring period, but densities declined in conjunction with streamflow, a primary limiting factor (Scrivener and Carruthers 1989).
- densities of aquatic fish-food organisms were inversely related to mean streamflow during the 60-d period prior to the date of sampling;
- invertebrate abundance was similar at treated and untreated sites during most streamflows, but after periods of frequent freshets invertebrate abundance was 40-50% lower at sites that were treated with ROUNDUP (Scrivener and Carruthers 1989);
- high water velocities accompanied by the movement of fine sediments along the streambed were probably responsible for any loss of fish-food organisms (Culp and Davies 1983).

The presence of ponded water in the tributaries during the ROUNDUP application (Hetherington 1989) probably protected the aquatic plants from any damage. This aquatic rooted vegetation would be damaged if the sites had been dry because it is susceptible to ROUNDUP (Grossbard and Atkinson 1985). Aquatic invertebrates would have been impacted further because
their densities at bare mud sites were 10-25% of those at sites with aquatic rooted vegetation in 750, 1500 and 1600 tributaries (Scrivener and Caruthers 1989).

**Objective 8:** Monitoring fish use of side channels in the long-term following glyphosate application relative to habitat changes or relative to residues in water and stream sediment.

**Conclusions:**

a. There were no differences in pre-treatment and post-treatment use of oversprayed streams by overwintering coho (Holby and Baillie 1989a).

b. Post-treatment mortality, growth rates, and spring emigration during 1985 and 1986 did not differ for overwintering coho as compared with pre-treatment years (Holby and Baillie 1989a).

**SUMMARY CONCLUSIONS**

Several regulatory concerns about the use of ROUNDUP were discussed in the Introductory Remarks. Briefly, these were:

1. Concerns that coastal British Columbia forest environmental conditions are dissimilar to previously studied forest ecosystems in the Pacific northwest. (This difference might produce substantially differing results with regard to the environmental fate/impact of ROUNDUP following aerial application, and as a consequence, elicit undesirable biological responses from non-target organisms.);

2. Concerns about toxicity of the surfactant used in the ROUNDUP formulation to salmonids. (The surfactant might be more toxic to aquatic organisms than the active ingredient of ROUNDUP - glyphosate.);

3. Concerns that provincial and federal government policy requiring a 10-m pesticide free zone (PFZ) with appropriate buffers to protect riparian resources was burdensome, or might not be adequate to protect against undesirable ROUNDUP trespass. (Is the current PFZ of 10-m adequate and what, if any, additional buffers are needed to protect the integrity of the PFZ?);

4. Concerns about the environmental and biological consequences that might result from overspray of streams not visible from the air. (Even if the PFZ is adequate to protect visible streams, undesirable environmental impacts and biological responses might result from overspray of nonvisible streams).

**Similarity of Carnation Creek to Other Ecosystems**

Short-term ROUNDUP environmental fate results at Carnation Creek are in agreement with those reported for a semi-arid Oregon forest watershed study (Newton et al. 1984), and for a Manitoba study (Beck 1987). Monitoring of residues lasted for 55 days and 30 days post-application in the Oregon and Manitoba studies, respectively as compared with one year for this study. Results of both studies provided no basis for concern. Coho salmon fingerlings did not accumulate detectable amounts of glyphosate or metabolite residues in the Oregon study. However, direct toxicity and behavioral responses of coho salmon to ROUNDUP stress were not monitored in the Oregon study. Fish were not present in the Manitoba ponds. To date, the Carnation Creek
herbicide study is the most complete and exhaustive ecosystem study with ROUNDUP and coho. There are no other studies with which all aspects of the Carnation Creek research can be compared.

Surfactant Toxicity

No fish mortality occurred at Carnation Creek that was attributed to the herbicide and no juvenile coho avoidance was observed in streams with a vegetation buffer following ROUNDUP application (Holoby and Baillie 1989a). However, resident coho salmon appeared to avoid entering tributary 1600 and baited traps in tributary 1600 for 3 wks after herbicide treatment. Holoby and Baillie (1989a, c) suggested that the surfactant in the ROUNDUP formulation, not the active ingredient (glyphosate), may have been responsible for inducing temporary stress in caged and resident coho fry and for decreasing algal production in the oversprayed tributary during the first 2 wks after application. The surfactant is known to be at least 4 times more toxic than glyphosate, although its concentration in the tributary could never have been more than 1/25 of concentrations that caused 50% mortalities within 96 h (ROUNDUP formulation = 30.5% glyphosate, 15% surfactant: Servizi et al. 1987; Feng et al. 1989 and Folmar et al. 1979). Surfactant residues were not measured directly during the present study, therefore future research on surfactant toxicity may be worthwhile. The temporary stress that was observed among aquatic organisms justifies present procedures for ROUNDUP use without additional restrictions.

Value and Adequacy of PFZ

The value of a PFZ, or adequate buffers to protect it, is to prevent toxic chemicals from entering streams and to prevent damage to riparian vegetation. Protection of riparian vegetation is of greater concern than aquatic toxicity when ROUNDUP is used. Streamside trees and brush, and logs in the stream reduce erosion of the banks and channel, and provide the riffles, pools and cover that are essential to resident fish (Hartman et al. 1987). Stream channels straighten, shallow and widen over time in order to transport water during freshets unless large trees and brush remain on the stream banks.

At Carnation Creek, a MICROFOIL BOOM was used because this aerial delivery technology should have maintained a 10-m PFZ without an additional buffer zone. This assumption was proven correct since riparian vegetation was unaffected and no residues were observed in streams with a PFZ (Feng et al. 1989). The large droplets, slow speed (40 km/h) and low elevation (6-18 m) permitted maximum control (Reynolds et al. 1989a) of a low toxicity herbicide. The MICROFOIL BOOM has rarely been used operationally in British Columbia.

The use of more toxic, less bio-degradable or less chemically bonding herbicides that are applied with less control (smaller droplets, fixed-wing aircraft) require greater protection of the riparian zone. In British Columbia, conventional boom and nozzle equipment (e.g., D8-46) is more commonly used operationally. An additional buffer was recommended for the 10-m PFZ when ROUNDUP was applied with a Thru-Valve Boom (TVB2) or with D8-46 hydraulic nozzles (Payne et al. 1989). Acute toxicity studies have shown herbicides such as GARLON 4 to be 14 times more toxic to salmonids (96 h - LC50) than ROUNDUP (Servizi et al. 1987). All workshop discussion groups, tasked with evaluating the PFZ concept, concluded that the PFZ is both desirable and adequate as currently enforced to protect coastal riparian resources in British Columbia (e.g., discussion groups 11 and 12, this proceedings).

Overspray

Results of the present research confirm that no short-term (96 h) toxicity was observed for fish or other aquatic organisms that could be attributed to glyphosate or metabolite residues in oversprayed tributaries. Short-term stress was observed for fish, algae and two invertebrates for up to 3 wks following overspray of tributary 1600. The present research found no evidence of long-term environmental consequences resulting from overspray, since rapid refoliation of treated vegetation occurred within 3 yrs of ROUNDUP application (Reynolds et al. 1989b). Little erosion potential was evident in the oversprayed tributaries that would necessitate a 10-m PFZ. The beds of all these treated tributaries consisted of mud with rooted aquatic plants instead of coarser materials (e.g. gravel) that were evident in streams transporting significant amounts of sediment. However, it was evident that if the aquatic rooted vegetation had been killed by the herbicide, aquatic invertebrates would have been affected (Scrivener and Carruthers 1989). Most of these aquatic plants were covered by ponded water that prevented direct contact by the spray at the time of herbicide application.

All workshop discussion groups that attempted to evaluate the PFZ concept were unable to determine just how much riparian habitat destruction can be tolerated before unacceptable or irreversible ecosystem damage might result. Until this can be better determined, all groups felt that existing provincial PFZ guidelines should not be relaxed. The size of PFZ and buffers necessary will depend on the herbicide and the application method used. The regulatory system must be flexible enough to accommodate this reality.

To conclude, the present research demonstrates that glyphosate can be used operationally within the British Columbia coastal forest zone without posing an unacceptable impact on salmonids provided current label and regulatory guidelines are strictly observed.

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