

Fate of Glyphosate in a Canadian Forest Watershed. 1. Aquatic Residues and Off-Target Deposit Assessment

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Glyphosate and AMPA residues in oversprayed and buffered streams were monitored following application of ROUNDUP (2.0 kg/ha) to 45 ha of a coastal British Columbia watershed. Maximum glyphosate residues (stream water, 162 µg/L; sediments, 6.80 µg/g dry mass; suspended sediments, <0.03 µg/L) were observed in two intentionally oversprayed tributaries, dissipating to <1 µg/L within 96 h postapplication. Buffered streams were characterized by very low glyphosate residue levels (2.4-3.2 µg/L in streamwater). Results of the off-target deposit assessment indicated <0.1% of applied glyphosate at 8 m from the spray boundary. Increases in residue levels were observed in relation to the first storm event postapplication. Ratios of maximum stream water concentrations of glyphosate observed in buffered and oversprayed tributaries relative to literature toxicity values indicated a substantial margin of safety under either operational or worst case scenarios.

Glyphosate [*N*-(phosphonomethyl)glycine], marketed under the trade names ROUNDUP or VISION (Monsanto Corp., St. Louis, MO), has been registered for use in site preparation and conifer release programs in Canada since 1984 (Malik and Vanden Born, 1986). The behavior of glyphosate in aquatic systems has been investigated in the United States and elsewhere (Comes et al., 1976; Rueppel et al., 1977; Edwards et al., 1980; Ghassemi et al., 1981; Norris et al., 1983; Newton et al., 1984; Wan, 1988). However, only the latter two reports are pertinent to the environmental fate of glyphosate in a coastal watershed ecosystem. In the province of British Columbia, Canada, coastal watersheds are used extensively for timber production. In such areas, the steep-sloped terrain, high annual rainfall (>2000 mm), and proximity of treatment areas to salmon spawning streams combine to approximate a worst case scenario with respect to potential for aquatic impacts following silvicultural chemical applications. As a result, current regulatory guidelines in British Columbia require the establishment of a 10-m pesticide-free zone with appropriate buffers, usually 100 m, to protect aquatic ecosystems. These guidelines restrict silvicultural treatment of the highly productive forest lands that border rivers and streams in coastal regions. In 1984, as a component of the continuing investigations on the effects of forestry practices on native fish populations in the Carnation Creek watershed (Hartman, 1982), a study was initiated to investigate the environmental fate of glyphosate in major aquatic and terrestrial compartments of the ecosystem, following a silvicultural application of ROUNDUP herbicide. Components of the environmental fate research program relating to aquatic residues and off-target deposit assessment are described in this, the first of a two-part series. The specific objectives of this portion of the environmental fate research were (1) to monitor residue levels and dissipation rates of glyphosate and AMPA in water,

stream-bottom sediment, and suspended sediment of both buffered and oversprayed streams and (2) to assess the off-target deposit of glyphosate following an aerial spray application and evaluate the effectiveness of a 10-m vegetation zone in protecting forest streams from contamination resulting from off-target deposit.

MATERIALS AND METHODS

Site Description. The study site was located in the Carnation Creek watershed on the west coast of Vancouver Island, British Columbia (45°50' N, 125°2' W), approximately 200 km northwest of Victoria (Figure 1). The 10-km² watershed is within a coastal hemlock and cedar ecozone (Krajina, 1969) and is characterized by annual precipitation ranging from 2500 to 3800 mm, occurring mainly from October through March (Hetherington, 1982).

Following clear-cutting in 1975, the study area was site-prepared and planted in 1976 (Dryburg, 1982). Seedlings were soon dominated by salmonberry (*Rubus spectabilis* Pursh) and red alder (*Alnus rubra* Bong.) (King and Oswald, 1982). In September 1984, salmonberry and alder ranged in height from 1.5 to 2.5 m and 7 to 10 m, respectively.

The main stream of Carnation Creek meanders through an alluvial floodplain and is fed by a number of permanent and ephemeral tributaries. The main stream and side channels support populations of coho (*Oncorhynchus kisutch* Walbaum) and chum (*Oncorhynchus keta* Walbaum) salmon. The four tributaries involved in this study have confluences with the main stream channel at 750, 1450, 1600 and 2200 m (C-Creek) upstream from the Carnation Creek estuary. The locations of spray blocks relative to the streams and main creek channel are shown in Figure 1. Tributaries 750, 1450, and C are ephemeral and in 1984 started flowing with the first seasonal rainfall (35 mm), which occurred on September 4.

Tributary 750, a small, ephemeral stream, occluded by riparian vegetation for most of its length was intentionally oversprayed in this study. At the time of application, it was slow flowing (0.001 m³/s); however, owing to its steep drainage pattern, flow rates increased markedly during storm events. Tributary 1600 received direct chemical application for about 600 m of its 800-m length. At the time of application the stream was fast flowing (0.02 m³/s) and contained pools ranging from 0.5 to 1 m in depth. Stream banks were covered with salmonberry and alder vegetation, but occlusion of the stream channel was less than that for tributary 750.

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