Some Effects of Mt. St. Helens Volcanic Ash on Juvenile Salmon Smolts

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Introduction

The eruption on 18 May 1980 of Mt. St. Helens in southwestern Washington (Fig. 1) resulted in airborne volcanic material being deposited in many watersheds of the Pacific Northwest (Fig. 2). Particularly hard hit was the Toutle River basin on the northwest side of Mt. St. Helens, which was completely decimated with volcanic ash and mud slides.

Heavy sediment loads in the Toutle River were carried downstream through the lower Cowlitz River and into the Columbia River. This sediment load created a plume in the Columbia River which initially extended

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ABSTRACT—Chinook, Oncorhynchus tshawytscha, *and sockeye,* O. nerka, *salmon smolts were exposed to various concentrations of airborne volcanic ash from the 18 May 1980 eruption of Washington's Mt. St. Helens. These bioassays were conducted at Bonneville Dam on the lower Columbia River between 7 and 27 June 1980. In static bioassays, 25 percent (v/v) ash caused 100 percent mortality in 1 hour, whereas 10 percent (v/v) ash caused 60 percent mortality in 6 hours. No mortality was noted at concentrations of 5 percent (v/v) or less airborne ash over 24 hours. In dynamic bioassays with continuous resuspension of ash,* LC_{10} *= 0.5 g/l,* LC_{50} *= 6.1 g/l, and* LC_{90} *= 34.9 g/l at 36 hours (at 15-17°C; oxygen near saturation).*

The gills of dead juvenile chinook and sockeye salmon smolts were uniformly coated with mucus and volcanic ash; no gross evidence of abrasion or hemorrhage was seen. Impaired oxygen exchange is suggested as the primary cause of death.

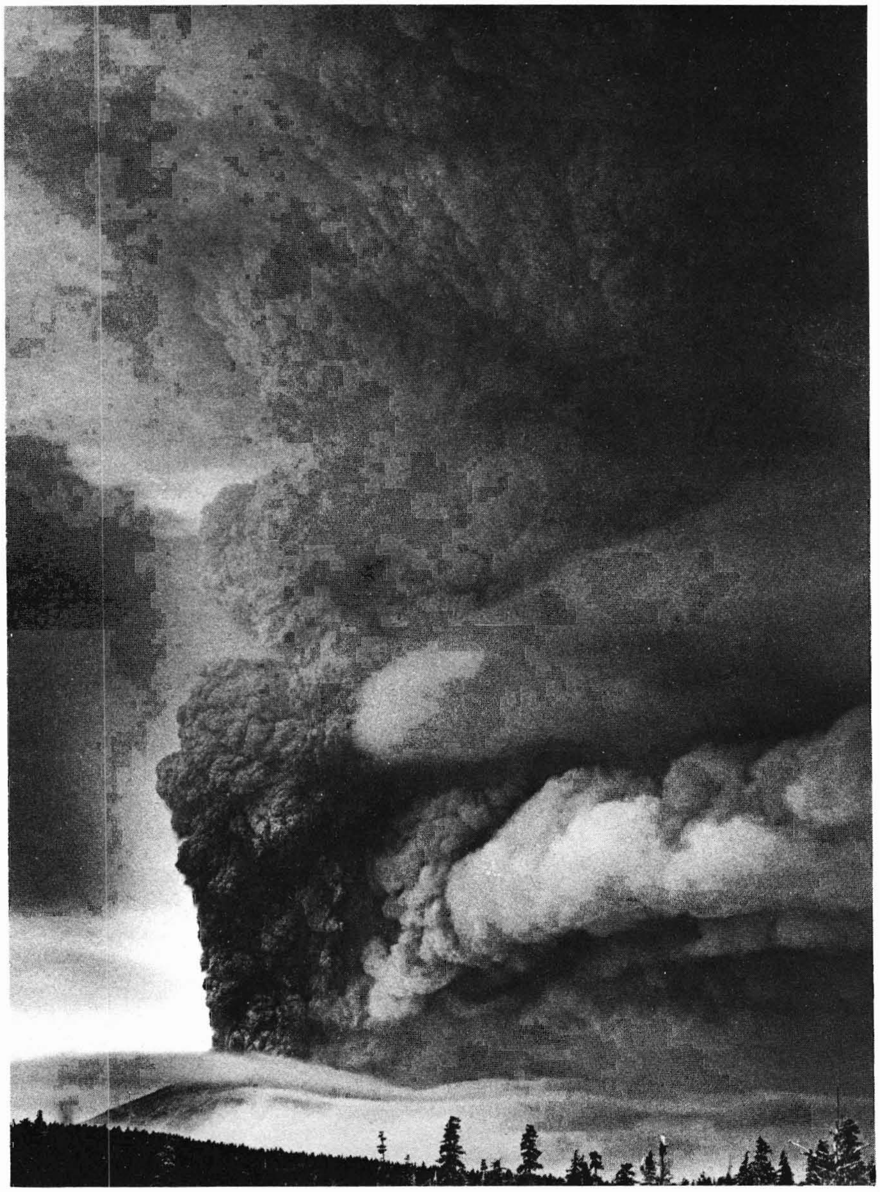

Figure 1.—A southeast view of the 18 May 1980 eruption of Mt. St. Helens near Stevenson, Wash. (Photograph courtesy of E. McLarney, Skamania County Pioneer, Stevenson, WA 98648.)

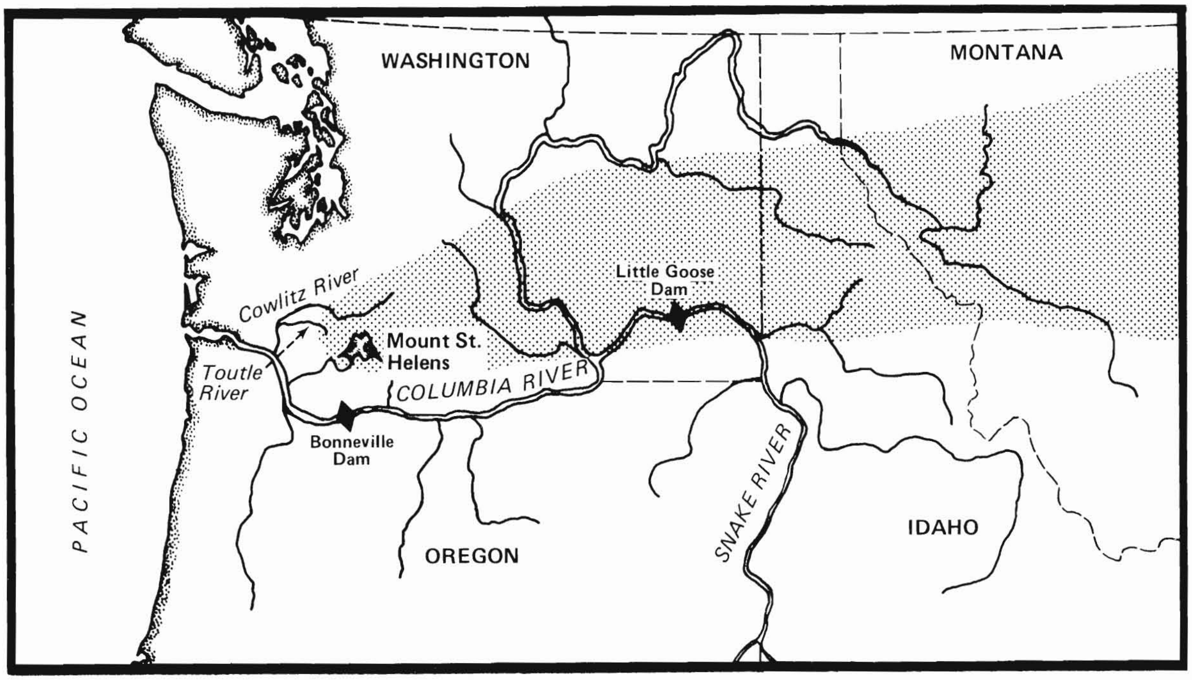

Figure 2.—Fallout pattern of airborne volcanic ash ejected during the 18 May 1980 eruption of Mt. St. Helens. (Redrawn from data supplied by A. Sarna-Wojoicki, U.S. Geological Survey, Western Region, 345 Middlefield Rd., MS-75, Menlo Park, CA 94025.)

68 miles to the estuary. Because the initial major eruptions of Mt. St. Helens occurred during the seaward migration of juvenile Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri,* in the Columbia River drainage, there were major concerns over the effects of the ash on the migrants.

Since 1968, the National Marine Fisheries Service (NMFS) and U.S. Army Corps of Engineers (COE) have been collecting and transporting large numbers of naturally migrating salmon and steelhead trout smolts around the dams of the Snake and Columbia Rivers in an effort to increase survival (Ebel, 1980; Ebel et al., 1973). Currently, the NMFS and COE transport up to 7 million juvenile salmonid smolts annually by truck and barge from the lower Snake and middle Columbia Rivers to Bonneville Dam. The bioassays described in this report were carried out between 7 and 27 June 1980 to investigate the potential impact on these fish of airborne ash from Mt. St. Helens.

Methods and Materials

Three juvenile salmonid stocks were evaluated. Spring chinook salmon, *O. tshawytscha,* smolts (mean fork length = 129 ± 13 mm) were obtained from the Leavenworth National Fish Hatchery (NFH), Leavenworth, Wash.; fall chinook salmon smolts (mean fork length = 75 ± 6 mm) were obtained from the Little White Salmon NFH, Cook, Wash.; and wild stock sockeye salmon, *O. nerka,* smolts (mean fork length = 105 ± 8 mm) collected at McNary Dam on the Columbia River. These fish were transported to the NMFS laboratory at Bonneville Dam (Fig. 2) on the Columbia River and acclimated to Columbia River water for a minimum of 2 weeks before testing.

Fish were starved for at least 2 days before each bioassay and were not fed during each experiment. At the time of testing, fish were randomly sampled and assigned to the bioassay test containers (19 l plastic buckets with about 15 l of ash-water mixture). The bioassay test containers were held in a water bath supplied with Columbia River water to maintain a steady natural temperature.

These bioassays used volcanic ash which fell at the fish collection facilities at Little Goose Dam on the Snake River (Fig. 2, 3). This unleached ash was collected on clean concrete from the airborne deposits which fell as a result of the 18 May eruption. The particulate size of this ash ranged from <5 to 100 μm with the majority of the particles <15 μm in size[1]. This material was composed largely of angular material[2].

Two bioassay methods were used. One method was a static situation representing the initial insult that would occur in an airborne ashfall

[1] D. Rosema, Boeing Commercial Aircraft Co., Materials Technology, P.O. Box 3707, MS 08-48, Seattle, WA 98124. Pers. commun., 1982.

[2] A. Sarna-Wojoicki, U.S. Geological Survey, Western Region, 345 Middlefield Rd., MS-75, Menlo Park, CA 94025. Pers. commun., 1980.

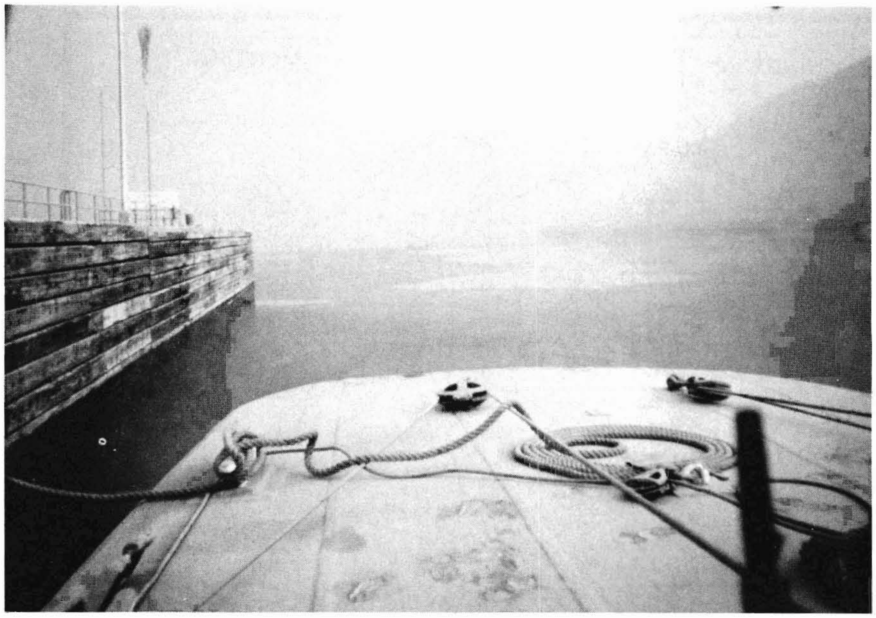

Figure 3.—Volcanic ash falling on the Snake River near Little Goose Dam following the 18 May 1980 eruption of Mt. St. Helens. Note the dark, ash-covered water, the footprints in the ash on the stern of the tugboat, *Patricia*, and the obscuring of the hills in the background. (Photograph courtesy of S. Demuth, NMFS Mukilteo Field Station, P.O. Box 21, Mukilteo, WA 98275.)

over still water. In this bioassay on spring chinook salmon, ash (calculated as volume percent of dry ash/volume of water (v/v)) was introduced at concentrations of 25.0, 10.0, 5.0, 1.0, 0.1, and 0.0 percent. Lethal effects of the water-soluble components of the ash were also investigated.

In this test the fish were exposed to the soluble fraction filtered from a mixture of 25.0 percent ash over Whatman No. 541 paper[3] (retaining 98 percent of particles above 20 μm). Ash at the specified concentrations was initially well mixed, and the fish (n = 15) were immediately introduced into the well-aerated mixtures. With this technique, no further mechanical mixing occurred, and oxygen levels were kept near saturation by means of large air stones. Throughout the test period (24 hours) the temperature averaged 14°C.

The second bioassay method represented rivers carrying suspended volcanic ash loads. These bioassays consisted of three replicates of 10 fish per concentration for spring chinook salmon, three replicates of 20 fish per concentration for fall chinook salmon, and one test of 10 fish per concentration for sockeye salmon. At least five concentrations of ash, together with a control, were used for each bioassay replicate (10.0, 7.5, 5.0, 2.5, 1.0, and 0.0 percent v/v). In the first replicate with spring chinook salmon, additional concentrations of 0.5, 0.1, and 0.01 percent v/v ash were also used. During the test periods (to 36 hours) water temperatures averaged 15°C for spring chinook salmon, 17°C for fall chinook salmon, and 17°C for sockeye salmon.

Submerged pumps and spray bar arrangements were used in conjunction with air stones to continuously resuspend the volcanic ash load within the test containers. These pumps were not 100 percent efficient in the resuspension of the ash. Therefore, water samples were taken after the introduction of the test fish for determination of the actual suspended ash loads. These samples were filtered (on Whatman GF/B filter paper which retains 98 percent of 1.0 μm particles) and dried to constant weight at 100°C for 24 hours. Samples were then weighed to the nearest 0.025 g, and the actual concentration of ash held in suspension was calculated as g/l. It was found that, on the average, 20 percent of the introduced material (representing the coarser particles) would not remain in suspension.

In both bioassay procedures the mortalities were monitored at 0.12, 0.25, 0.50, 0.75, 1, 2, 3, 4, 5, 6, 9, 12, 18, 24, 30, and 36 hours. All dead fish were grossly examined to determine cause of death. Gills of selected specimens were microscopically examined to determine the effect of ash particles on the gill epithelium.

Mortality information was compiled and analyzed using the methodology of Doudoroff et al. (1951) as modified by Sprague (1969). Log-log plots of the mortality data were constructed for concentrations lethal to 10 percent of the population (LC_{10}), 50 percent of the population (LC_{50}), and 90 percent of the population (LC_{90}). A least-squares regression equation and a correlation coefficient, *r*, were then calculated for each log-log plot.

Results and Discussion

Airborne ash has the potential to cause a one-time insult to lakes or other still water. In a static bioassay with juvenile spring chinook salmon, an initial insult (with no further mixing) of 25 percent by volume caused 100 percent mortality in 1 hour, and an initial insult of 10 percent by volume caused 60 percent mortality in 6 hours. Volcanic ash insults of 5 percent and below by volume were not harmful to juvenile spring chinook salmon within 24 hours. Since 5 percent by volume is equivalent to 6 inches of ash falling over a 10-foot

[3]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

water column, most airborne volcanic ashfalls should not cause acute mortality to salmonid stocks in still water. However, hatchery managers should carefully weigh the risk of resuspending airborne volcanic ash when cleaning ponds and raceways.

Airborne volcanic ash material can be held in suspension through the mixing action of river currents. In this study, each test replicate was exposed to a unique suspended ash concentration. Spring chinook salmon were held in concentrations ranging from 0.5 to 87.3 g/l; fall chinook salmon were held in loads ranging from 5.7 to 82.0 g/l; and sockeye salmon were held in loads ranging from 6.1 to 87.8 g/l (Table 1). These concentrations are believed to cover the potential range which may occur in river systems directly draining the affected volcanic area. The 10, 50, and 90 percent linear-regression mortality models (on a log-log basis) are presented in Figures 4, 5, and 6. In all cases, increasing the concentration of suspended volcanic ash resulted in greater overall mortality occurring in progressively shorter time intervals. There was no apparent correlation between fork length or species and the mortality rates noted in the present bioassays.

Our mortality models should be of considerable use to fishery managers involved in assessing the current potential dangers during periods when suspended volcanic ash loads are present in the river systems. The test results indicated that it is the river systems carrying high suspended volcanic ash loads ⩾6.1 g/l (Fig. 5) that are hazardous to juvenile salmonids, whereas suspended ash loads >34.9 g/l (Fig. 6) are catastrophic and those <0.5 g/l (Fig. 4) do not present acute (within 36 hours) problems. Fishery managers should keep in mind these mortality rates may be accelerated if the average particle size is larger (Rogers, 1969), or if reduced oxygen levels are present (Peddicord et al., 1975). These mortality rates may be reduced if there is a recent history of exposure to suspended sediment (Noggle, 1978).

Table 1.—Relation between the percentage of Mt. St. Helens volcanic ash initially added to bioassay containers and the chronic suspended ash load actually presented to the test fish over the course of the experiments.

Percent ash introduced (v/v)	Suspended ash recovered and dried from Whatman GF/B paper (g/l)		
	No. of tests	Mean	S.D.
10.0	7	82.4	6.5
7.5	7	62.0	2.3
5.0	7	39.3	4.1
2.5	7	19.9	1.9
1.0	7	6.4	0.4
0.5	1	3.1	—
0.1	1	0.5	—
0.01	1	Trace	—

In addition, due to design limitations in the present experiments, we were unable to evaluate any additive effect of water velocity as might occur in a river situation.

High levels of suspended sediments may cause mechanical gill damage (Herbert and Merkens, 1961; Noggle, 1978) and/or blockage of the osmoregulatory surface (Ball, 1914; Kemp, 1949). In this study, mortalities appeared to be due to ash particles and mucus causing blockage of the osmoregulatory surface. The gills of dead fish were uniformly coated with ash particles and mucus, and live fish in the high ash concentrations appeared lethargic. There was no gross evidence of abrasion or hemorrhage of the gill filaments. Gills of fresh mortalities were uniformly dark red after gentle irrigation. This suggests impaired oxygen exchange as the primary cause of death.

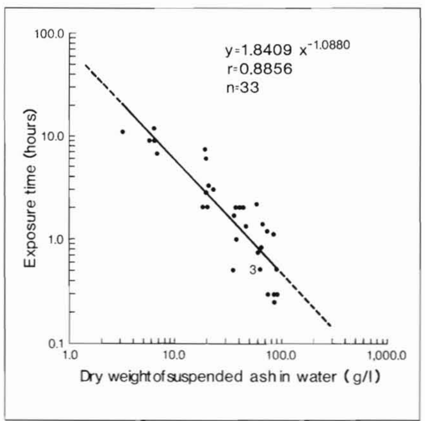

Figure 4.—36-hour LC_{10} for juvenile salmon smolts in mixtures of Columbia River water and airborne volcanic ash collected from Little Goose Dam (at 15-17 °C; oxygen near saturation).

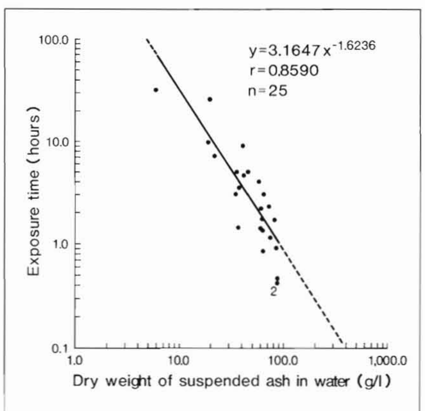

Figure 5.—36-hour LC_{50} for juvenile salmon smolts in mixtures of Columbia River water and airborne volcanic ash collected from Little Goose Dam (at 15-17 °C; oxygen near saturation).

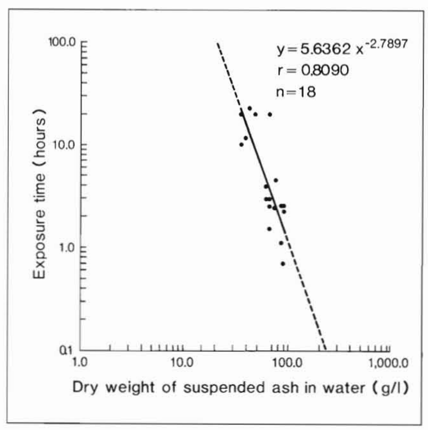

Figure 6.—36-hour LC_{90} for juvenile salmon smolts in mixtures of Columbia River water and airborne volcanic ash collected from Little Goose Dam (at 15-17 °C; oxygen near saturation).

There are also possible detrimental effects resulting from the release of water-soluble material (e.g., heavy metals or hydrogen ions) coating the ash. Exposure to the soluble fraction filtered from a mixture of 25 percent (v/v) ash did not result in mortalities even after 36 hours, whereas exposure to an insult of 25 percent (v/v) ash resulted in 100 percent mortality within 1 hour. This further indicated that it is the particulate matter, rather than soluble material coating the ash, that is acutely harmful to salmonids.

The possibility that the release of water-soluble material coating the ash can lower the pH to levels detrimental to salmonids (pH 5.5, McKee and Wolf, 1963) has been of concern to fishery biologists (Kurenkov, 1957). Our measurements indicate that a 10 percent (v/v) level of volcanic ash lowered the pH of the moderately hard Columbia River water used in these bioassays from 7.8 to 7.6. Even though pH was judged not to be a problem in our experiments, it should be noted that each watershed and ashfall has unique chemical properties and should be treated accordingly.

The concentration of ash in the lakes, rivers, and hatcheries east of the blast zone from Mt. St. Helens probably did not exceed the minimum 36-hour LC_{50} level (6.1 g/l, Fig. 5)[4]. In contrast, the initial eruptions of Mt. St. Helens undoubtedly caused the Toutle-Cowlitz and lower Columbia River systems to exceed a concentration of 6.1 g/l. However, our monitoring of these systems indicated that this was not a prolonged situation, except in the Toutle River. The effects of volcanic ash in these systems should be of continuing concern, since either high-runoff situations (causing scouring of the massive deposits of volcanic material in the Toutle River basin) or subsequent eruptions could again inundate these waters.

[4]B. Crawford, Washington Department of Game, Region 5, 5405 N.E. Hazel Dell, Vancouver, WA 98663. Pers. commun., 1980.

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