damage" to an extensive list of species, almost exclusively dicots.

Damage related to the vegetative life form. Where the uncompacted ash was > 0.5 cm, most herbaceous angiosperms were procumbent to a noticeable degree because of simple mechanical overloading. Shrub and dicot tree branches, although retaining ash, were not broken. The branches of most woody species were largely ash-free, however, by mid-June (ash was removed by rain). For acaulescent species, such as *Balsamorhiza careyana, Clintonia uniflora, Hieracium albertinum*, and *Trillium petiolatum*, mechanical overloading persisted. This was particularly evident for *Balsamorhiza sagittata*, a large acaulescent composite. The plant's numerous large deltoid leaves were pinned to the soil surface, and by mid-June necrosis of the ash-covered leaves was apparent. The percentage of missing leaf parts was directly proportional to the ash thickness at each site (Table 1) (*7*).

Ash clinging to long trichomes enhanced overloading for *Hieracium albertinum*, although other pubescent species, such as *Lupinus sericeus* and *Achillea millefolium* var. *lanulosa*, were not similarly affected. In the *Abies grandis–Pachistima myrsinites* habitat type (*5*), the broad leaf blades of *Trautvettaria caroliniensis* were extensively damaged locally as ash overloading collapsed the plant's long fleshy petioles. Low-lying, broad-leaved dicots including *Heuchera cylindrica, Frasera fastigiata, Arnica cordifolia*, and *Disporum oreganum* and the monocot *Trillium ovatum* also displayed damage locally. A new flush of leaves emerged on some *Hieracium al-*

Reports

Initial Effects of Ashfall from Mount St. Helens on Vegetation in Eastern Washington and Adjacent Idaho

Abstract. *Extensive plant damage from the 18 May 1980 eruption of Mount St. Helens was largely restricted to acaulescent and prostrate dicot species in the ashfall area east of the Cascade Range (more than 150 kilometers from the vent).* Veratrum californicum, *a large monocot, displayed widespread stem death through mechanical overloading of the plant's clasping leaves. The ash surface in this area presents new opportunities for both seeds and seed predators.*

The 18 May 1980 eruption of Mount St. Helens, a stratovolcano in the Cascade Range of Washington, deposited tephra in a fan-shaped plume across much of eastern Washington and northern Idaho. The opportunity for assessing the initial effects (during the first 4 months) after ash deposition on diverse temperate vegetation east of the Cascade Range was without precedent because (i) the ash plume bisected previously described vegetation zones (*1, 2*), thus constructing both control and treatment areas; (ii) the affected areas were accessible within 3 weeks after the eruption (*3*); and (iii) the ash fell during or just prior to the growing and flowering season for most vascular species (*4*). Observations reported here are limited to those individuals that were emergent on 18 May and to the fate of seed cast since ash deposition. Emphasis was placed on the collection of qualitative (rather than exclusively quantitative) information in order to record the ephemeral nature of this unique event over the greatest possible diversity of vegetation. The study area is along a west-to-east transect from arid steppe (for example, *Artemisia tridentata–Agropyron spicatum* zone) to middle-elevation forest (*Abies grandis–Pachistima myrsinites* zone) (*5*).

Damage to vascular plants was primarily related to the morphology of each species and varied locally in intensity as a result of ash depth and particle size distribution (*6*), amount of surface litter, slope, stand canopy, and local phenology. Damage can be categorized under three headings: (i) damage to the vegetative parts of acaulescent or prostrate species and those with clasping leaves, (ii) interruption of flowering and fruiting caused by ash coating, and (iii) "spot

Fig. 1 (left). Moribund *Veratrum californicum* toppled by ash overloading in the broad, strongly sheathing leaf blades (arrow) on 9 July 1980 at Potlatch, Idaho. Fig. 2 (right). Throughfall of ash to form a prominent annulus of deposition at the base of *Abies grandis* (July 1980 near Harvard, Idaho). Understory plants (for example, *Trautvettaria caroliniensis* and *Smilacina stellata*) within the annulus were mechanically overloaded by ash.

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bertinum individuals in the *Festuca idahoensis–Symphoricarpos albus* zone, which were generally smaller (average, 6 cm) than the other (> 10 cm) leaves on these plants on 18 May. Some *Balsamorhiza sagittata* also produced several small (leaf blade < 10 cm) leaves after the ashfall.

Veratrum californicum, a large monocot with clasping leaves, was conspicuously affected by mechanical overloading from meadow steppe to middle-elevation forest. Ash collected in the bases of the ovate to broadly elliptic leaves and compacted by rain caused the plants to topple over (Fig. 1). The stems died in many cases (Table 2), although some plants eventually flowered after assuming a decumbent habit.

Interruption of flowering and fruiting. Anthesis in spring within the study area (*4*) proceeds along a general altitudinal transect from west to east. As a result, flowering was either completed or was well under way by 18 May in all the steppe communities, whereas it was just beginning in higher-elevation forest understories. The floral parts of many species shed the ash within 3 weeks of the eruption. In *Geranium viscosissimum* ash-free flowers were seen by 20 May in the *Festuca-Symphoricarpos* zone. However, the heads of *Balsamorhiza sagittata* and *Balsamorhiza careyana*, at anthesis on 18 May, were mechanically overloaded. Many heads on most individuals remained buried under ash and decayed by mid-July still attached to the plant. Flowering of *Veratrum californicum* was affected both through stem death and a later high frequency of panicle death even on still-erect stems. Some plants produced an additional panicle in summer with an ash-coated dead inflorescence still attached. In the forest communities (primarily *Pinus ponderosa–Symphoricarpos albus, Pseudotsuga menziesii–Physocarpus malvaceus*, and *Abies grandis–Pachistima myrsinites* habitat type) *Trillium petiolatum, Trillium ovatum*, and *Smilacina racemosa* fruits or flowers, or both, were buried under ash on mechanically overloaded plants. In *Trillium petiolatum* ash collected in the broad corolla which encloses the developing fruit. Although viable capsules were found, still encased in ash, most plants had aborted the fruit by mid-July.

Spot damage. Many species with no morphologic similarity locally displayed ash-induced damage on leaves. Typically, ash-coated leaves developed a speckled appearance by midsummer. Practically all perennial dicot species in the study area had representatives in this

Table 1. Percentages of total leaf area damaged or lost for individual leaves of *Balsamorhiza sagittata* in 48 m^2 in heavy (stands 1 and 2) versus light (stand 3) ashfall areas by August 1980. All stands occur in the *Festuca-Symphoricarpos* habitat type (*5*).

Stand No.	Total leaf area (m^2)	Percentage		*N*
		Damaged	Missing	
1	1.866	24.2	24.9	200
2	1.362	22.2	11.8	152
3	4.852	23.1	4.4	523

broadest category of damage. For example, some of the large spring leaves of *Artemisia tridentata* covered by rewetted ash had become chlorotic by 20 June and abscissed. This premature leaf drop involved < 5 percent of the leaf area on these shrubs. Such spot damage did not affect seed output.

Damage to graminoids was very minor. Ash was consistently shed by these species but tended in caespitose grasses to form lumpy clumps at the bases upon wetting. Although much ash remains in these clumps, this had no apparent effect on flowering. *Agropyron spicatum* and *Festuca idahoensis* produced seed, even though both grasses show extremes in year-to-year seed production (*8*). *Bromus tectorum, Poa sandbergii*, and *Festuca octoflora* set seed after 18 May even where the compacted ash was > 3 cm. In the *Pinus-Symphoricarpos* habitat type many tillers of the rhizomatous *Calamagrostis rubescens* were mechanically overloaded, but this probably caused no change in the status of this infrequently flowering grass.

Table 2. Percentages of flowering, erect, and downed stems for *Veratrum californicum* in 250 m^2 in ash-covered (stands 1, 2, and 3) versus ash-free (stands 4, 5 and 6) areas. Individuals per category are indicated in parentheses. Stand classification is according to (*5*): stand 1, *Pinus-Physocarpus;* stand 2, *Festuca-Symphoricarpos;* and stands 3, 4, 5, and 6, *Pinus-Symphoricarpos*.

Stand No.	Flowering stems (%)	Nonflowering stems (%)		Total
		Erect	Downed	
1	0	100		
	(0)	(0)	(17)	(17)
2	8	92		
	(5)	(26)	(29)	(60)
3	7	93		
	(4)	(3)	(47)	(54)
4	53	47		
	(44)	(36)	(3)	(83)
5	57	43		
	(28)	(14)	(7)	(49)
6	71	29		
	(41)	(9)	(8)	(58)

Seeds cast after 18 May in the arid steppe soon collected into smooth concavities (approximately 15 ml, 1 cm deep) formed in the ash as it settled and compacted with wetting over surfaces with little litter. These depressions may alter the nature of foraging by seed predators because the seeds are located in clumps (*9*). Elsewhere sites of seed residence were determined by the position of the toppled parent plants. Dense swards of *Bromus tectorum* were locally overloaded such that the configuration of fallen tillers, as viewed from above, appeared much like the radiating spokes of a bicycle with the seed cast at the outer rim of the configuration.

As the ash was repeatedly wetted in the steppe during late spring, it tended to crack around caespitose grasses, in a generally reticulate pattern on lithosolic sites and into irregular polygons in drainages. The ash formed a much less discernible pattern of irregular cracks over thick graminoid litter, especially in the *Festuca idahoensis–Symphoricarpos albus* habitat type. Holes developed around tillers in the ash layer, formed as the wind whipped the emergent stems back and forth. All these openings in the ash, regardless of origin, have become safe sites for seeds cast after 18 May. In contrast, the following annuals (both native and alien) had completed seed set by 18 May in the steppe: *Draba verna, Holosteum umbellatum, Stellaria nitens, Erodium cicutarium*, and *Sisymbrium altissimum*. Consequently this year's seed production of these species is now largely under the ash.

Few species flower in late summer in the arid steppe. However, *Orobanche corymbosa* subsp. *mutabilis*, a root parasite of *Artemisia tridentata*, emerged through > 2.5 cm of compacted ash and flowered near Ritzville, Washington, in late July.

Branches of *Abies grandis* spread horizontally to form flat sprays, with distinctly flattened needles. Ash continues to be retained in grand fir canopies as a result of the tree's architecture. In contrast, ash throughfall and surface accumulation have been conspicuous below the largely twig-free cylinder within 2 m of the bole of large trees (diameter at breast height > 5 dm) (Fig. 2). Understory plants within this "ash annulus" at the tree's base were still completely covered by ash even by mid-September, but elsewhere in the stand plants were ash-free. As a result, a new agent of spatial pattern has been superimposed on this community in which species such as *Trautvettaria caroliniensis* may be debilitated within these annuli. No such disproportionate distribution of ash was seen in habitats dominated by either *Pinus ponderosa* or *Pseudotsuga menziesii*. The dense canopy of grand fir has also served to retard evaporation from the ash on the forest floor. As a result, the ash layer is noticeably more compacted than in either the more open *Pseudotsuga* or *Pinus* stands where the ash quickly dries after rain.

Any beneficial effect of the ashfall for the native species (for example, through release from ash-damaged competitors, reduced predation arising from the insecticide effects of the ash) is as yet unexplored in the steppe. But the white ash, where fine-textured, may have lowered soil surface temperatures and blocked physical evaporation, thus increasing the effective precipitation (*10*). The nutrient increment of the ash is trivial (*6*). Furthermore, any effect of ash in the atmosphere or precipitation probably cannot be detected because of the normal year-to-year variability in summer precipitation. The monthly totals of precipitation (in millimeters) for June, July, and August 1980 at Yakima, Lind, and Spokane, Washington, three sites along the axis of the heaviest ash fallout, were as follows: 29, trace, 7.4; 17, 1.3, 10.7; and 25, 5.3, 20, respectively (*11*). These values are well within 1 standard deviation of the 27-year (1951 to 1977) mean precipitation for these months for each site (*12*).

Ash damage to plant parts on and since 18 May is not so severe to any species as to cause extermination. Perennials such as *Balsamorhiza sagittata* and *Veratrum californicum* will certainly recover from one season of curtailed seed production. The indirect effects of the ash may prove more significant as a compacted ash layer in the arid steppe alters the distribution, frequency, and nature of seed residence sites and seed predation. The duration of this effect will depend on the rate at which the ash layer is ruptured by abiotic mechanical forces (freeze-thaw cycles, wetting-drying cycles, and erosion) and by the penetration of established perennial plants. Annuals now dependent upon germination in these ash openings may soon display diminished distribution if not prominence in these communities. Any further effects of the ash in forest and meadow steppe communities without this compacted ash layer probably will be within the amplitude exerted by more frequent climatic forces.

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Mount St. Helens Eruption of 18 May 1980: Air Waves and Explosive Yield

Abstract. *Strong atmospheric acoustic-gravity waves were recorded by sensitive microbarographs and seismographs at large distances from the Mount St. Helens eruption of 18 May 1980. Wave signatures were similar to those of waves from large nuclear explosions. Independent theoretical and empirical analyses indicate that the explosive yield of the eruption was approximately 35 megatons.*

The main eruption of Mount St. Helens on 18 May 1980 at 0830 Greenwich mean time (GMT) generated strong pressure perturbations that propagated globally and were detected by a variety of pressure-sensitive instruments. Recorded signals had characteristics typical of acoustic-gravity waves generated by large, sudden releases of energy into the atmosphere. Natural sources of such disturbances in the past have included the eruption of Krakatoa (1883) and the great Siberian meteor (1908). Artificial sources of equivalent disturbances have been large nuclear tests in the atmosphere.

The traveling waves from these large-magnitude events have two propagation modes, one controlled mainly by gravitational inertial effects and the other by the compressibility properties of the atmosphere; hence these disturbances are called acoustic-gravity waves. Characteristically, the gravity mode has a higher velocity and longer wave period (of the order of several minutes) than the acoustic mode, which has an upper limit of about 2 minutes in period at large distances. Because of the density stratification of the atmosphere, both modes show dispersion. The velocity is a function of the wave period. Such signals thus have a characteristic signature that provides ready identification.

In this study we utilized records from five special, highly sensitive microbarographs and a number of long-period vertical component seismographs that were not adequately sealed or buoyancy-compensated. Only such instruments have the proper response and sensitivity to provide data for reliable analysis of air waves.

In the microbarograph records of Fig. 1, a to e, the prominent signals are the gravity-mode (or Lamb mode) waves; the lead wave period is up to 6 minutes, and the period increases with distance as a consequence of dispersion. The dispersive character is most evident in the Hamburg and Buchholz records, which have less noise interference in this period range than most of the other records. The acoustic mode, shown by the short-period, low-amplitude waves following the main gravity wave signal, is not very prominent in any of the records. This is because the acoustic mode propagates in the channel between the stratosphere and the surface; the duct is strong when the stratospheric winds are in the direc-