Arthropod responses to the 1980 eruption of Mount St Helens—implications for Noahic Flood recovery

Keith H. Swenson

Noah's Flood was the greatest ecological disturbance in earth history, and yet Earth's biota subsequently recovered, demonstrating remarkable resilience. In similar manner, the 1980 eruption of Mount St Helens in Washington State, USA, severely disrupted a large ecosystem, the responses of which have been, and continue to be, observed and documented. General mechanisms of disturbance and principles of recovery have been delineated, which likely apply to other large disturbances, including Noah's Flood. Therefore, lessons learned at Mount St Helens should assist biblical creationists in constructing a model for post-Noahic Flood biological recovery. This article looks at one facet of the Mount St Helens eruption—the impact on arthropods and their subsequent responses to disturbance, including the following topics: high mortality, biological legacies, dispersal, role in primary succession, enrichment of developing soils, alteration of successional trajectories, and great resilience. Implications for a post-Noahic Flood recovery model are discussed.

Noah's Flood was the most catastrophic ecological disturbance in the history of the earth. Occurring several thousand years ago, it severely disrupted biological systems on the entire planet (Genesis 7: 21–23; 2 Peter 3:6). Yet, following the Flood, the biota recovered, producing the forests, grasslands, deserts, tundra, and other biomes of the post-Flood world (Genesis 8:11; Genesis 14:13). Both skeptic and believer might ask whether such amazing transformations are possible, and, if so, by what ecological processes they would occur.

An important source of information in attempting to answer such questions is the study of modern disturbances, including those caused by wildfire, windstorm, local flooding, disease, avalanche, and glaciation. But of far greater intensity than these is volcanic eruption, and no eruption has been documented, either geologically or biologically, nearly as well as was the 1980 eruption of Mount St Helens in Washington State.[1] One would think, therefore, that a careful review of lessons learned at Mount St Helens would reveal general principles of disturbance recovery,[2] which would shed light on processes operating following Noah's Flood.

This article examines biological recovery at Mount St Helens from the standpoint of terrestrial arthropods,[3] which have been the subjects of several studies. Attention will be given to predisturbance arthropods and their habitats, the disturbance itself, and ecological responses of arthropods to the disturbance. Lastly, implications for understanding biological recovery following Noah's Flood will be discussed.

Predisturbance setting

Prior to its 1980 eruption, Mount St Helens was a 2,950 m ASL (above sea level) stratovolcano located on the west side of the Cascade Mountain Range in the state of Washington, USA.[4] It was known to be active, having last erupted in 1857. The mountain's summit and upper slopes were seasonally clad with deep snowpack and also supported about a dozen glaciers. Alpine meadows occupied high and medium elevation sites. Below timberline, and extending onto the surrounding landscape, grew expansive old-growth, plantation, and recently clear-cut coniferous forests. Several mountain lakes, the largest being Spirit Lake, lay to the north and streams draining the area emptied into the Columbia River. The climate was Pacific maritime, with a mean annual precipitation of 2,373 mm at an elevation about 1,000 m ASL.

Pre-1980 Mount St Helens provided manifold habitats for a diverse assemblage of arthropod species. Unfortunately, this arthropod diversity was not well documented.[5] The most comprehensive inventory for a westside forest in the Cascade Range is from the H.J. Andrews Experimental Forest, an ecological research site located 200 km to the south.[6] Containing over 4,000 arthropod entries, it approximates a baseline species list for pre-eruption Mount St Helens.

The disturbance

The 1980 eruption of Mount St Helens was a complex event involving diverse geological processes which interacted with the pre-disturbance landscape to form a mosaic pattern of multiple disturbance zones.[7,8] A gradient of disturbance was established, extending from areas near the mountain, where intense processes eliminated all pre-eruption organisms, to distant sites, where limited disturbance allowed survival of most organisms. Five major disturbance processes and the zones of disturbance they formed are as follows (figure 1):

1. *Debris avalanche*: The eruption began with a 5.1 Richter magnitude earthquake, which triggered a massive debris avalanche composed of the mountain's summit and north flank.[9] Part of this landslide travelled through Spirit Lake, generating a giant oscillating wave extending 260 m up onto adjacent mountains. The wave brought thousands of logs and other forest materials back into Spirit Lake, forming a giant floating log mat occupying about 40% of the lake's surface.[10] Most of the remaining avalanche material entered the North Fork Toutle River Valley where it buried 60 km^2 of land with deposits having a mean depth of 45 m.
2. *Directed (lateral) blast*: The debris avalanche exposed magma inside the volcano, along with superheated water, resulting in a north-directed, lateral, ground-hugging blast, which devastated 600 km^2 of forest within less than 10 minutes.[11] In most of this area, trees were flattened (blowdown zone), except at the periphery, where they were heat-killed but left standing (scorch zone). The landscape impacted by the directed blast is now known as the 'blast zone'.
3. *Vertical eruption*: Following the lateral blast, Mount St Helens produced a vertical eruption plume for 9 hours, resulting in a continuous rain of tephra (ash and pumice fragments) on the blast zone and extending hundreds of kilometres to the east (figure 2).[12] The erupted material was composed of a silica-rich, nutrient-poor volcanic rock called 'dacite'.
4. *Pyroclastic flows*: In the afternoon of May 18, incinerating pyroclastic flows of pumice spilled from the crater onto debris avalanche deposits north of Mount St Helens, forming the 15 km^2 Pumice Plain.[13]
5. *Mudflows (lahars)*: Heat from the eruption rapidly melted the mountain's winter snowpack and glaciers. The runoff mixed with volcanic debris, forming mudflows, which travelled down streams draining Mount St Helens, leaving deposits.[14]

The complex landscape produced by these processes forms the stage on which the drama of biological recovery is playing.

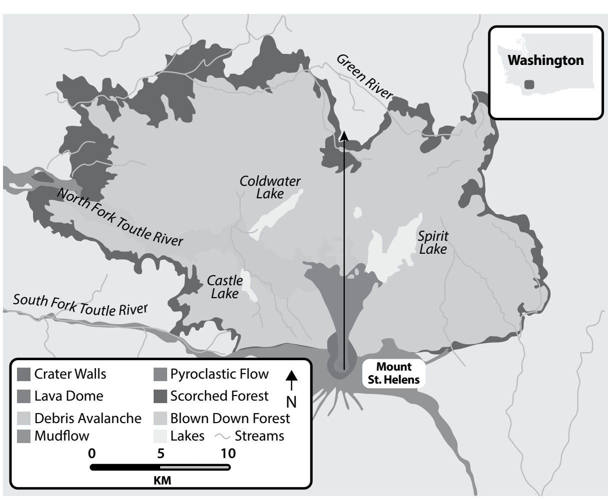

Figure 1. This map of the blast zone shows disturbance zones, including: debris avalanche deposit, forest blowdown zone, scorch zone, Pumice Plain, and mudflow deposits. The arrow represents a gradient of disturbance, which depicts a progressive decline in disturbance intensity between the Pumice Plain and the intact forest.

Figure 2. On 18 May 1980, Mount St Helens erupted a plume of ash extending upward over 20 km and lasting 9 hours. Ash reached the Atlantic coast in 3 days and circled the earth in 2 weeks.

Arthropod responses to disturbance

Arthropods experienced high mortality

Untold billions of arthropods succumbed to the 1980 eruption of Mount St Helens due to high-impact forces, extreme heat, abrasion, and deep burial.[15]

Additional mortality resulted from the insecticide effect of dry volcanic ash on arthropod populations,[16] not only within the blast zone, but extending hundreds of kilometres eastward within the tephra deposit left by the advancing ash plume. Ash killed by physical, not chemical, means. Tiny, sharply angular particles abraded the moisture-retaining, waxy cuticles of exoskeletons, causing arthropods to desiccate and die. Laboratory crickets and cockroaches exposed to Mount St Helens ash also salivated excessively trying to clean ash from themselves, thus adding to their water loss. To complete the insult, ash clogged respiratory spiracles and intestinal tracts.

Following the eruption, private timber companies, along with governmental agencies, argued for large-scale salvage logging of the blast zone, one reason being to prevent beetle (*Dendroctonous pseudotsugae*, *Pseudohylesinus granulatus*, and *P. grandis*) infestations in the dead trees, which might have then spread to live trees. The fact that such outbreaks never occurred is attributed to the insecticide effect of volcanic ash.[17]

Another example of ash-induced mortality was found in September, 1980, within the blowdown zone northeast of Mount St Helens. A massive die-off of yellow-spotted millipedes (*Harpaphe* sp.), an important decomposer species, occurred after these organisms ingested ash-coated forest floor litter, obstructing their guts.[18]

Arthropods became biological legacies

Even though mortality was high, many arthropods survived the eruption. Several factors favoured this, including the organisms' small size, cryptic habits, and complex life cycles, often including egg, larval, pupal, and adult stages.[19] Survival was generally in protected sites termed 'refugia', such as rock crevices, talus slopes, ice-covered ponds, soil, and dead wood. For example, Edwards, in the summer of 1980, observed western carpenter ants (*Camponotus modoc*) foraging for windblown insects on a barren, sunbaked pumice surface.[20] Nearby, the ants' colony was found residing in a large log, which had been buried deeply in winter snowpack at the time of the eruption. It had served as a 'life boat', preserving the ant colony, allowing it to emerge onto the post-eruption landscape.

A new term, 'biological legacies', was coined at Mount St Helens for all biological materials, both living and dead, that persisted into the post-disturbance period.[21] It was discovered that the quantity and type of biological legacies in an area was the most important determinant of the pace and pattern of subsequent ecological development. Sites high in biological legacies quickly formed 'hotspots' of life, from which organisms spread outward into less populated territories.[22]

Figures 3. This spider (Araneae), photographed on the debris avalanche at Mount St Helens, either dispersed into the blast zone by ballooning or is descended from spiders that did.

Arthropods dispersed into the blast zone

Arthropods from the surrounding landscape wasted no time dispersing into the blast zone, joining the survivors. Edwards wrote:

> "Even before the tumultuous events following the lateral blast were complete, arrival of microorganisms, arthropods, and perhaps plants had begun. We know from reports of the first humans on the scene (the crews of rescue helicopters) that flies, yellowjackets and other conspicuous insects had preceded them."[23]

The air column each summer is alive with a host of dispersing insects, spiders, and other organisms. Coad, by attaching sticky traps to aircraft, found abundant insects up to 4,572 m over Louisiana,[24] while Hardy and Milne, using towed nets fastened to kite lines, estimated that there were about a million insects in a 2.6 km^2 of air column between 46 and 610 m.[25] Witness also the high-flying foraging of swallows, swifts, and bats. Of course, small organisms, lofted by prevailing winds, eventually are deposited at distant sites, including the blast zone at Mount St Helens.

Prominent among this ‘arthropod fallout’ on Mount St Helens were dispersing juvenile spiders (figure 3). Many arachnid species ride the wind in a process known as ‘ballooning’.[26] Juveniles perch on vegetation and release lengthy silken threads into the air currents. These act as kites or balloons and transport young spiders tens of kilometres. University of Washington spider researcher Rodney L. Crawford identified over seventy-five species of spiders which ballooned onto the Pumice Plain.[27]

In addition to sampling arthropods with standard pitfall traps, scientists at Mount St Helens developed a unique device for collecting arthropod fallout. It consisted of a 0.1 m^2 frame filled with a layer of golf balls, designed to simulate the desert pavement surface of the Pumice Plain.[28] Arthropods falling among the golf balls were periodically retrieved, identified, dried, and weighed. Calculations revealed that approximately 36 kg of arthropods (dry weight) landed per acre each four-month growing season.[29] Species, in addition to spiders, included flies (Diptera), beetles (Coleoptera), true bugs (Hemiptera), wasps (Hymenoptera), butterflies and moths (Lepidoptera), lacewings (Neuroptera), and others.[18]

Arthropods initiated primary succession

Prior to the 1980 eruption of Mount St Helens, the site of the Pumice Plain was old-growth forest, a haven of life. However, the eruption blasted, incinerated, and deeply buried it with deposits tens of metres thick, thus extinguished all organisms.[13] The resulting Pumice Plain provided 15 km^2 of sterile substrate, a perfect location within which to observe and document primary succession.[30]

The reigning hypothesis in 1980 held that plants and lichens would be the initial macroscopic organisms to colonise the Pumice Plain. However, the first species to establish were not plants, but various insects and spiders of the arthropod fallout.[31] Most proved unfit for the harsh conditions and died. Some, such as spiders, lived but failed to reproduce. The first colonists to establish breeding populations were scavenger and predatory beetles, largely of the Family Carabidae (ground beetles).[32] Most successful of these was *Bembidion planatum*, a carabid beetle known as a ‘pioneer’, specializing in highly disturbed habitats.

But what provided food for these pioneer species? It turned out that they fed exclusively on their fellow arthropod fallout companions, both living and dead.[33] Such a habitat, in which resident organisms depend solely on inputs of nutrients transported by wind, is termed an ‘Aeolian zone’.[34] This situation may not be rare. Edwards and Sugg suggest the pattern is a “widespread and perhaps a general one for terrestrial primary successional habitats” and that “comparable pioneer predatory and scavenging arthropods operate around the entire Pacific Ring of Fire and other volcanic areas, wherever volcanic activity produces new surfaces”.[35]

After 3–4 years, as plants established on the Pumice Plain, the arthropod fauna began to change. Paramenter documented the decline of *B. planatum* and its replacement by a relay-like series of beetle species, each adapted to its prevailing environment.[36]

Arthropods enriched developing soil

The newly deposited pyroclastic-flow and tephra surfaces of the Pumice Plain lacked nutrients essential for life. Measured values of nitrogen and organic carbon were zero[37] and available phosphorus was likewise low.[38] However, repeat determinations for the same elements in 1985 showed significantly increased values.[39] A major source of these added nutrients was atmospheric fallout of arthropods.

Based on analysis of debris obtained from the ‘golf ball’ fallout collectors and other determinations, it was estimated that arthropods contributed a minimum of 80 mg of fixed nitrogen and 5.5 mg of phosphorus per square metre annually.[40] Notably, plant material is deficient in phosphorus, so the input of this element was mostly from arthropods.

Another example of arthropod-mediated nutrient enrichment of developing soil involved mosquitoes and the degraded water of Spirit Lake.[40] The giant wave that emanated from Spirit Lake on the morning of 18 May 1980 washed part of an old-growth forest back into the lake. Combined with volcanically warmed water, this vegetation rapidly produced a nutrient-rich organic brew which became the substrate for a massive bacterial bloom that depleted all the lake’s oxygen. Under these anoxic conditions, only anaerobic organisms existed in the lake, with one exception, that being mosquito larvae.

Although requiring oxygen, mosquito larvae thrived in the lake due to their snorkel-like siphons through which they obtain air. Large numbers of the resulting adult mosquitoes were subsequently captured on the Pumice Plain, several kilometres distant from Spirit Lake. This situation persisted for up to two years and is a remarkable example of an arthropod species ferrying essential nutrients from a rich source area to nutrient-deficient developing soil.

Atmospheric fallout of arthropods (along with dust, microorganisms, and plant materials) provided nearly all of the nutrient input on the Pumice Plain for the first few years of recovery. Thereafter, plants established and also contributed to nutrient enhancement of the substrate.

Arthropods altered the trajectory of succession

As plants progressively colonise the blast zone, so do associated herbivorous insects, which sometimes restrict plant growth and spread. In so doing, herbivores alter the trajectory of community succession (figure 4). Prairie lupine (*Lupinus lepidis* var. *lobbi*) provides an example.[41]

Although ground beetles were the first organisms to colonise the primary successional surfaces of the Pumice Plain, plants were not far behind. In the summers of 1981 and 1982 researchers found isolated individuals of prairie lupine, the first plant coloniser of the Pumice Plain.[42] This low mat-forming subalpine herb arrived as wind-dispersed seeds, blown from source areas several kilometres away. The plant's prolificacy astounded researchers. One carefully monitored founder plant grew to a large patch of 24,000 individuals by 1985![43]

Besides being a successful primary producer, prairie lupine performs several other important functions. Foremost among these is nitrogen fixation.[41] Associated with lupine are nitrogen-fixing bacteria (*Rhizobium*) which live symbiotically within small root nodules. These microbes transform atmospheric nitrogen, which plants can't use, into nitrogen compounds, usually ammonia (NH_3), which plants readily utilize. Lupine thus adds usable nitrogen, along with organic carbon, to nutrient-deficient pumice deposits.

In addition, mats of prairie lupine trap wind-blown plant propagules and organic detritus.[41] Several species of plants, derived from wind-dispersed seeds, have colonised lupine patches, taking advantage of the nutrient-enriched soil. One example is paintbrush (*Castilleja miniata*), which is hemiparasitic on lupine. Others, such as fireweed (*Chamaenerion angustifolium*), pearly everlasting (*Anaphalis margaritaceae*), seedling conifers, and various grasses add vertical structure to developing communities, attracting pollinating and herbivorous insects, birds, rodents, and elk (*Cervus elephas*).

Because of its diverse and critical functions, prairie lupine has earned the designation of 'keystone species'.[44,45] It follows, therefore, that any organism which regulates the growth and spread of prairie lupine is also of great ecological significance.

Prairie lupine grew and spread unfettered in the early years after the eruption, but by the latter 1980s many lupine patches were in decline and their rates of spread greatly reduced. A likely cause became apparent in 1985 when the first herbivorous insects, root-boring moth larvae of the Family Tortricidae, were observed.[46] By consuming root vascular tissues these insects produced a die-off, particularly on the advancing edges of lupine mats, thus slowing the plant's spread. Despite initial explosive growth, Bishop's survey in 2002 found that lupine was still absent or in low density on 70% of the Pumice Plain. Bishop concluded: "Given the known effects of prairie lupine on soil and community development on the Pumice Plain, herbivory on prairie lupine has likely altered the pace and pattern of succession."[47] Continued observation has shown that other Pumice Plain plant species[48] are similarly affected by herbivorous insects, often producing major 'boom-bust' population cycles.[49]

Arthropods demonstrated remarkable resilience

Scientists observing the monotonous grey of the blast zone following the 18 May eruption voiced dire predictions concerning the return of life. Forest ecologist Jerry Franklin referred to an 'apparently sterile landscape'[50] and silviculturist Eugene Sloniker commented, "If anything, we were anticipating the worst, that maybe the entire ecology of the area had changed".[51] Researchers, A.B. Adams and S. Leffler lamented, "There seemed to be justification to believe that it would be impossible for insects to recover at all."[52]

But the resilience[53] of the Mount St Helens' ecosystem was greatly underestimated. Franklin subsequently observed: "But ecological recovery has been generally rapid. Three years later, 90% of the plant species that originally inhabited the area could be found",[49] and Adams and Leffler noted that "insects have been quick to recolonise the blast zone".[52]

Was the initial pessimism warranted? And should the remarkable resilience have been a surprise? No! The

Figure 4. Herbivorous insects, such as this grasshopper (Orthoptera), resting on a pumice deposit at Mount St Helens, help control plant growth and spread. By so doing, they alter the trajectory of community succession.

pre-eruption organisms at Mount St Helens, and surrounding areas, were already highly adapted to major disturbances. They had "been there ... done that"— as the saying goes. Edwards expressed it this way: "The plant and animal species that are returning to the mountain's slopes have seen it all before; for them, as species, it was no unique event, and our studies of colonization must take this into account."[54]

It is important to recognise that arthropods play numerous critically important roles in ecosystem function. They are involved in herbivory, granivory, pollination, predator-prey interactions, parasitism, pathogenesis of diseases, decomposition and nutrient cycling, soil dynamics and other processes. High arthropod resilience, therefore, is essential for optimal ecosystem responses to major disturbances.

Implications for post-Noahic Flood recovery

Volcano ecology is an emerging discipline concerned with ecological responses to volcanic disturbances.[2,55] Much early research in this field was limited because it was begun years or decades (or longer) following an eruption and often focused on only one subject, such as plants.[1] Studies of three eruptions stand out as the most significant: Krakatau, a catastrophic eruption on an Indonesian island in 1883;[56] Surtsey, a new island produced by a submarine eruption off the coast of Iceland in 1963;[57] and Mount St Helens in 1980. Of these, Mount St Helens has been the most productive, generating almost 40% of the world's literature on ecological responses to volcanic eruption.[58] Most Mount St Helens studies were initiated shortly after the 1980 event and were continued for at least several years. Research at Mount St Helens has also been multifaceted, covering most relevant topics, including arthropods.

An important issue in volcano ecology is whether or not biological responses observed at one volcano also apply to other volcanoes, or even to other types of disturbances. That is, do some processes achieve generality or universal status? It is reasonable to think this would be the case because diverse disturbances often produce common mechanisms, which are experienced by organisms, including excessive heat, high impact forces, abrasion, and deep burial.[21,59] For example, both volcanic eruption and flooding deeply bury organisms in sediments. Likewise, heat from either a forest fire or a volcanic flow can stimulate spores of certain fungi to germinate.[60]

Crisafulli believes there is significant commonality between different types of disturbances. Comparing Mount St Helens with Krakatau and Surtsey, he states: "We can tease out idiosyncrasies of individual eruptions versus overarching generalities. The biological agents may vary but the ecosystem processes may be quite similar".[58] And a publication of the U.S. Forest Service reads: "The in-depth ecological research on Mount St Helens and at other volcanoes is enabling researchers to identify universal themes in ecosystem response to disturbance" and "This means the lessons learned here can be relevant in other disturbance settings."[61]

Certainly, there are many similarities between Noah's Flood and the eruption of Mount St Helens. Both were cataclysmic geological events involving volcanism, flooding, and the destruction of a predisturbance ecosystem, in which most organisms perished, but some also survived. And following both events, ecological processes assembled functioning ecosystems. However, there are also major differences, the foremost being that Noah's Flood was global and the eruption of Mount St Helens regional. Dispersal distances were generally small at Mount St Helens because most colonising organisms originated in the surrounding intact forest.[62] In contrast, following Noah's Flood, dispersal for some species on the Ark was global. Finally, the end product at Mount St Helens will be an ecosystem similar to that which existed prior to the eruption. Following Noah's Flood, it is unlikely that ecosystems in any given area closely resembled corresponding pre-Flood ecosystems.

Another issue is whether or not arthropods were among the animals specifically directed by God to Noah's Ark for preservation. Or did they survive as biological legacies outside the Ark (except for incidental 'hitchhikers' on the Ark)? The majority view among biblical creationists is that arthropods primarily survived outside the Ark. The Bible states: "Everything on dry land that had the breath of life in its nostrils died" (Genesis 7:22). This included all terrestrial vertebrates, but not invertebrates, as they do not 'breathe' through nostrils. Insects, for example, obtain atmospheric oxygen through pores on their bodies called 'spiracles'. In addition, Scripture indicates that "every living thing on the face of the earth" died; only those on the Ark survived (Genesis 7:23). If the 'Ark kinds' all perished outside the Ark, and that included arthropods, then no insects survived in the floodwaters. That hardly seems possible, given the numerous opportunities for arthropod legacies detailed below. A good case can also be made that the Bible does not consider arthropods and other invertebrates to be 'living creatures' (Hebrew: *nephesh chayyah*).[63]

The discovery of universal themes in volcano ecology, as well as similarities between Mount St Helens and Noah's Flood, encourage us to apply lessons learned at Mount St Helens to post-Noahic Flood recovery. However, differences between the two events mandate caution. Any model of post-Flood recovery is speculative and should be held with humility. Several principles learned at Mount St Helens that likely do have application to the post-Noahic Flood period will now be discussed.

Principles from Mount St Helens

The concept of biological legacies,[21] developed at Mount St Helens, probably applies to most, if not all, disturbances. Arthropod legacies in Noah's Flood likely included aquatic insects in the floodwaters, terrestrial arthropods within huge floating vegetation mats (including inside coarse woody debris),[64] flying insects, passively dispersing arthropods lofted into the atmosphere, and arthropods as incidental passengers on the Ark. In addition, large floating pumice rafts produced by undersea volcanic eruptions have been documented to harbour marine organisms (coral, algae, crabs, anemones) and transport them thousands of kilometres.[65] Probably, numerous such rafts formed during the Flood and, in addition to marine organisms, supported an aeolian community of terrestrial insects and spiders acquired from atmospheric arthropod fallout. Following the Flood, arthropod biological legacies were immediately available to colonise suitable sites over the entire earth.

Colonizing arthropod populations, derived from legacies, would have expanded rapidly, perhaps, even explosively.[66] Food was abundant after the Flood, in the form of animal carcasses, plant debris, newly emerging fungi and plants, and arthropod fallout. Initially, checks and balances on these arthropod populations would not have had sufficient time to establish. For example, insectivorous vertebrates (lizards, bats, rodents, swallows, and many others) on the Ark would have required weeks, months, or years to disperse globally. Also, early in recovery, there would have been few competitor organisms. One control over burgeoning arthropod populations during this time most likely was 'insecticide ash' from erupting post-Flood volcanoes, producing effects similar to those observed at Mount St Helens.[16]

As the floodwaters subsided, massive floating vegetation mats, composed of plant and animal legacies, grounded, producing large, expanding 'hotspots' of biological activity. These oases likely functioned as source areas for organisms, including arthropods, which dispersed into nearby 'coldspots' (areas with few or no biological legacies). Dispersing arthropods would have used methods observed at Mount St Helens, including pedestrian travel and aerial dispersal, such as ballooning of spiders. For example, scavenging and predatory beetles (or other species) from the arthropod fallout likely initiated primary succession by forming aeolian communities on sterile lava flows and pyroclastic deposits produced by erupting post-Flood volcanoes. Arthropod fallout would also have provided an important initial and ongoing influx of nutrients, facilitating soil development and plant establishment.

Colonisation of recovering sites by herbivorous insects probably limited growth and spread of specific host plant species. This would have altered successional trajectories and produced large population swings as observed with prairie lupine and other plant species on the Pumice Plain at Mount St Helens.[40,48]

Terrestrial vertebrates, dispersing from the Ark following Noah's Flood (Genesis 8:19), repopulated the earth more slowly than organisms distributed worldwide by receding floodwaters. This would allow time for significant development of microbial, fungal, plant, and invertebrate communities prior to the arrival of dispersing birds, mammals and, eventually, humans.[67] Arthropods, therefore, likely provided an immediate global food supply for dispersing insectivorous vertebrates.[66]

The overarching recovery theme at Mount St Helens is that of great resilience. Ecosystems appear to have been designed with the ability to effectively respond to major disturbance. This observation lends credibility to global recovery, within a biblical timeframe, following the ecological cataclysm of Noah's Flood. Arthropods certainly played an important role in that response.

References

1. Dale, V.H., Swanson, F.J., and Crisafulli, C.M., Disturbance, survival, and succession: Understanding ecological responses to the 1980 eruption of Mount St Helens; in: Dale, V.H., Swanson, F.J. and Crisafulli, C.M. (Eds.), *Ecological Responses to the 1980 Eruption of Mount St Helens*, Springer, New York, p. 3, 2005.
2. Mazza, R., Volcano Ecology: Flourishing on the flanks of Mount St Helens, *Science Findings,* Issue 190, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, pp. 1–5, 2016.
3. Arthropods are invertebrate animals of the phylum Arthropoda, having a segmented body, jointed limbs, and a chitinous exoskeleton that undergoes moltings, including insects, arachnids, myriapods, and crustaceans.
4. Swanson, F.J., Crisafulli, C.M., and Yamaguchi, D.K., Geological and ecological settings and settings of Mount St Helens before May 18, 1980; in: Dale, Swanson, and Crisafulli, ref. 1, pp. 13–26.
5. Swanson, Crisafulli and Yamaguchi, ref. 4, p. 23.
6. Parsons, G.L., Cassis, G., Moldenke, A.R., Lattin, J.D., Anderson, N.H., Miller, J.C., Hammond, P., and Schowalter, T.D., Invertebrates of the H.J. Andrews Experimental Forest, Western Cascade Range, Oregon, *V: An Annotated List of the Insects and Other Arthropods*, PNW-GTR-290, USDA Forest Service, Pacific Northwest Research Station, Portland, OR, 1991.
7. Swanson, F.J. and Major, J.J., Physical events, environments, and geological-ecological interactions at Mount St Helens: March 1980–2004; in: Dale, Swanson, and Crisafulli, ref. 1, pp. 27–34.
8. Morris, J. and Austin, S.A., *Footprints in the Ash*, Master Books, Green Forest, AR, 2003.
9. Swanson and Major, ref. 7, p. 30.
10. Dahm, C.N., Larson, D.W., Peterson, R.R., and Wissmar, R.C., Response and recovery of lakes; in: Dale, Swanson, and Crisafulli, ref. 1, p. 258.
11. Swanson and Major, ref. 7, pp. 30–32.
12. Swanson and Major, ref. 7, p. 32.
13. Swanson and Major, ref. 7, pp. 32–33.
14. Swanson and Major, ref. 7, pp. 33–34.
15. Edwards, J.S. and Sugg, P.M., Arthropods as pioneers in the regeneration of life on the pyroclastic-flow deposits of Mount St Helens; in: Dale, Swanson, and Crisafulli, ref. 1, pp. 129–131.
16. Edwards, J.S. and Schwartz, L.M., Mount St Helens ash: A natural insecticide, *Canadian J. Zoology* **59**:714–715, 1981.
17. Dale, V.H., Swanson, F.J., and Crisafulli, C.M., Ecological perspectives on management of the Mount St Helens landscape; in: Dale, Swanson, and Crisafulli, ref. 1, p. 282.

18. Edwards and Sugg, ref. 15, p. 131.
19. Crisafulli, C.M., Swanson, F.J., and Dale, V.H., *Overview of Ecological Responses to the Eruption of Mount St Helens:1980–2005*; in: Dale, Swanson, and Crisafulli, ref. 1, p. 289.
20. Edwards, J.S., Arthropods as pioneers: recolonization of the blast zone on Mt. St Helens, *Northwest Environmental J.* **2**:65, 1986.
21. Dale, Swanson, and Crisafulli, ref. 1, p. 7.
22. Crisafulli, Swanson, and Dale, ref. 19, pp. 295–296.
23. Edwards, J.S., Crawford, R.L., Sugg, P.M., and Peterson, M.A., Recolonization of the Blast Zone of Mount St Helens; in: Keller, S.A.C. (Ed.), *Mount St Helens—Five Years Later*, Eastern Washington University Press, Cheney, WA, p. 329, 1986.
24. Coad, B.R., Insects captured by airplane are found at surprising heights, *Yearbook of Agriculture* (U.S. Department of Agriculture, 1931), pp. 320–323.
25. Hardy, A.C. and Milne, P.S., Studies in the distribution of insects by aerial currents: Experiments in aerial tow netting from kites, *J. Animal Ecology* **7:** 199–229, 1938.
26. Crawford, R.L., Mount St Helens and spider biogeography, *Proceedings of the Washington State Entomological Society* **46:**700–702, 1985.
27. Edwards, Crawford, Sugg and Peterson, ref. 23, p. 332.
28. Edwards and Sugg, ref. 15, p. 129.
29. Frenzen, P.M. and Crisafulli, C.M., Biological responses to the 1980 eruptions of Mount St Helens (information sheet provided by the Mount St Helens National Volcanic Monument, 1990), p. 6.
30. Primary succession is the gradual development of living communities on sites, such as volcanic deposits, having no biological legacies.
31. Edwards and Sugg, ref. 15, pp. 127–138.
32. Edwards and Sugg, ref. 15, p. 133.
33. Edwards and Sugg, ref. 15, p. 128.
34. Swan, L.W., Aeolian zone, *Science* **140**:77–78, 1963.
35. Edwards and Sugg, ref. 15, p. 138.
36. Paramenter, R.R., Crisafulli, C.M., Korbe, N.C., Parsons, G.L., Kreutzian, M.J., and MacMahon, J.A., Posteruption arthropod succession on the Mount St Helens volcano: The ground-dwelling beetle fauna (coleoptera); in: Dale, Swanson, and Crisafulli, ref. 1, pp. 139–150.
37. Engle, M.S., *Nitrogen and Microbial Colonization of Volcanic Debris on Mount St Helens*, Masters Thesis, Washington State University, Pullman, WA, 1983.
38. Newly deposited volcanic rock contains phosphorus, but a period of weathering is required for it to become available to plants.
39. Nuhn, W.W., Soil Genesis on the 1980 pyroclastic flow of Mount St Helens, Master's thesis, University of Washington, Seattle, WA, 1987.
40. Edwards and Sugg, ref. 15, p. 136.
41. Bishop, J.G., Fagan, W.F., Schade, J.D., and Crisafulli, C.M., Causes and consequences of herbivory on prairie lupine (*Lupinus Lepidus*) in early primary succession; in: Dale, Swanson, and Crisafulli, ref. 1, pp. 151–161.
42. Bishop, Fagan, Schade, and Crisafulli, ref. 41, p. 153.
43. Carson, R., *Mount St Helens:The Eruption and Recovery of a Volcano*, Sasquatch Books, Seattle, WA, 1990, p. 94.
44. Bishop *et al.*, ref. 41, p. 152.
45. A keystone species is an organism that plays a unique and critical role in the functioning of an ecosystem.
46. Bishop *et al.*, ref. 41, p. 155.
47. Bishop *et al.*, ref. 41, p. 161.
48. Species include Sitka willow (*Salix sitchensis*), pearly everlasting (*Anaphalis margaritaceae*) and fireweed (*Chamaenerion angustifolium*).
49. Personal communication, John Bishop, 22 July 2017.
50. Franklin, J.F., MacMahon, J.A., Swanson, F.J., and Sedell, J.R., Ecosystem responses to the eruption of Mount St Helens, *National Geographic Research* **1**: 198, 1985.
51. Sloniker, E.V., *The Fire Below Us,* Global Net Productions, Camano Island, WA, 1995 (videocassette).
52. Adams, A.B. and Leffler, S., Insect recolonization of the northwest sector of the Mount St Helens blast zone; in: Keller, S.A.C., ref. 23, p. 307.
53. 'Resilience' is the ability of an ecosystem to recover from disturbance.
54. Edwards, ref. 20, p. 64.
55. Crisafulli, C.M., Swanson, F.J., Halvorson, J.J., and Clarkson, B.D., Volcano ecology: disturbance characteristics and assembly of biological communities; in: Sigurdsson, H., Houghton, B., McNutt, S., Rymer, H., and Stix, J., (Eds.), *Encyclopedia of Volcanoes,* 2nd edn, Elsevier Publishing, chap. 73, p. 1266, 2015.
56. Thornton, I.W.B., *The Destruction and Reassembly of an Island Ecosystem*, Harvard University Press, Cambridge, MA, 1996.
57. Lindroth, C.H., Anderson, H., Bodvardsson, H., and Richter, S.H., Surtsey Iceland. The Development of a New Fauna, 1963–1970, Terrestrial Invertebrates, *Entomologica Scandinavica, Suppl. 5,* Zoologiska Museet, Lund, Sweden, 1973.
58. Mazza, ref. 2, p. 3.
59. Crisafulli *et al.*, ref. 55, p. 1268.
60. Carpenter, S.E., Trappe, J.M., and Ammirati Jr., J., Observations of fungal succession in the Mount St, Helens devastation zone, *Canadian J. Botany* **65:** 717, 1987.
61. Mazza, ref. 2, pp. 1–2.
62. Migratory animals, such as Pacific salmon (*Onchorhynchus* sp.) and neotropical birds, travelled hundreds of kilometres to Mount St Helens.
63. Sarfati, J.D., *The Genesis Account: A theological, historical, and scientific commentary on Genesis 1–11*, Creation Book Publishers, pp. 247, 248, 2015.
64. Oard, M.J., *The Genesis Flood and Floating Log Mats: Solving Geological Riddles* (e-book), Creation Book Publishers, Powder Springs, GA, 2014.
65. (No author named) Pumice Rafting, *Creation* **35**(4):59, 2013. (Based on: Pumice rafting brings new life to reef, *QUT Links alumni magazine* **16**(1):18, Autumn 2013.)
66. Woodmorappe, J., *Noah's Ark: A Feasibility Study*, Institute for Creation Research, El Cajon, CA, 1996, p. 171.
67. Human dispersal was delayed over 100 years by the Tower of Babel events (Genesis 11:1–9).

Keith H. Swenson *earned Bachelor of Science degrees in Zoology and Premedical Studies from the University of Idaho and an M.D. from Washington University in St. Louis School of Medicine. He holds board certification in Internal Medicine and Dermatology. Keith served as President of Design Science Association in Portland, Oregon, for 20 years and currently teaches courses in biology and geology at Multnomah University, also in Portland. He vividly recalls the eruption of Mount St Helens in 1980 and has extensively researched the biological responses to the eruption.*