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Science FINDINGS

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"Science affects the way we think together."

Lewis Thomas

Volcano Ecology: Flourishing on the Flanks of Mount St. Helens

Charlie Crisafulli

Nitrogen-fixing lupine was the first plant to colonize the sterile Pumice Plain created during the 1980 Mount St. Helens eruption. Its presence attracted insects, birds, and mammals and facilitated the establishment of other plant species. 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.

"Simplicity is nature's first step, and the last of art."

—Philip James Bailey, English poet, 1816–1902

A massive landslide; hurricane-force, stone-filled winds of scorching gasses; mudflows triggered by melting snow and ice; hail of tephra; pyroclastic flows—these were the elements of the Mount St. Helens volcanic eruption on May 18, 1980. It was a catastrophic disturbance that dramatically altered more than 220 square miles of forest in southwest Washington. In the 36 years since the initial eruption, a winding path of ecosystem assembly has unfurled. Along with the returning lupine, spiders, frogs, willow, birds, pocket gophers, deer, and elk—to name a few—hundreds of researchers have come to the volcano to observe and document the area's ecological response to severe disturbance.

Volcano ecology, as a discipline, is a subset of disturbance ecology. It examines the interactions of volcanic eruptions and ecosystems, and the lessons learned reveal much about

IN SUMMARY

Mount St. Helens' explosive eruption on May 18, 1980, was a pivotal moment in the field of disturbance ecology. The subsequent sustained, integrated research effort has shaped the development of volcano ecology, an emerging field of focused research. Excessive heat, burial, and impact force are some of the disturbance mechanisms following an eruption. They are also mechanisms of other, nonvolcanic disturbances. Studying ecosystem response to these disturbances across the gradient of disturbance intensity created by the 1980 eruption has revealed lessons relevant to the process of succession in Pacific Northwest forests and to other disturbed areas.

Charlie Crisafulli, an ecologist with the Pacific Northwest Research Station, has worked on Mount St. Helens for the past 36 years. He and colleagues recently developed a database that provides information on eruption sites around the world. They compiled the literature on all studies related to volcano ecology published between 1883 and 2015. This is enabling them to identify universal lessons on ecosystem response to disturbance versus lessons specific to the Mount St. Helen's eruption and setting.

An effort is underway to archive the hundreds of thousands of data collected from Mount St. Helens and to preserve biological samples at museums around the country, ensuring they will be accessible to future generations of researchers.

how ecosystems respond following a severe disturbance. The ecological research begun at Mount St. Helens following the eruption has revealed rich lessons on the early stages of succession in Pacific Northwest forests. The sustained effort has also shaped the development of volcano ecology as an emerging field of focused research.

Charlie Crisafulli, an ecologist with the Pacific Northwest (PNW) Research Station, began working on Mount St. Helens two months after the 1980 eruption. “Our approach has always been to focus our research along the volcanic disturbance gradient and to key in on specific mechanisms of disturbance, for example, heat, burial, abrasion, or impact force. This is what plants, animals, and other organisms experience during an eruption. These mechanisms also are found in other disturbances—fire has heat, floods and tsunamis have burial and abrasion, a windstorm has impact force. A volcanic eruption includes components of nearly all other natural disturbance,” he explains. This means the lessons learned here can be relevant in other disturbance settings.

In 1982, Congress designated the area as a National Volcanic Monument within the Gifford Pinchot National Forest. This designation, with its emphasis on research and the specification that natural processes would unfold substantially uninterrupted, along with support from the PNW Research Station, the National Science Foundation, and other institutions, has made Mount St. Helens a hub of volcanic research.

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KEY FINDINGS

- Extensive research has occurred at three volcanoes worldwide: Krakatau (erupted 1883), Surtsey (1963), and Mount St. Helens (1980). A comprehensive review of the ecological research at these sites is enabling scientists to identify universal themes in ecosystem response to disturbance versus responses that are related to the nuances of a specific eruption or the biota of that location.
- Mount St. Helens is the most studied volcano. This is a result of a dedicated effort by many. The protocols developed at Mount St. Helens are now being applied at volcanic sites around the world.
- For every hour of fieldwork and data collection, about 3 hours are needed to properly archive that data so it will be accessible to future researchers.

A RESEARCH HUB EMERGES

The raw power of the Mount St. Helens eruption riveted the nation. Within days, scientists were in helicopters to begin documenting the ecological status of the disturbed ecosystems. Within weeks, they had found life within this profoundly disturbed area, legacies of the pre-eruption forest, lakes, and streams that somehow managed to survive.

The May 18, 1980, eruption occurred at 8:32 a.m. in a year when snow still blanketed upper elevations, forming a protective cover over herbs, shrubs, and saplings. Ice-covered lakes shielded aquatic organisms. Nocturnal animals had retreated to their dens and underground burrows, and migratory song birds had not yet arrived for the season. These details, the scientists later realized, played a critical role in both the pace and pattern of ecosystem assembly. Surprising components of the pre-eruption landscape managed to survive, whether under snow, belowground, or ferried away by mudflows. The role of biological legacies in the regenerating landscape was an early major theme of research. “Mount St. Helens galvanized the importance of biological legacies,” explains Crisafulli. “It formalized many ideas that were more loosely defined in previous decades.”

“When volcanoes erupt explosively, they create complex mosaics of disturbance,” says Crisafulli. “They leave a lot behind; this is what governs the pace and pattern of

Charlie Crisafulli

Post-eruption landscape following the 2008 eruption of Chaitén, in Chile. The disturbance mechanisms following an eruption also are found in nonvolcanic disturbances. Heat and burial (from the blast cloud and tephra fall) caused the forest mortality shown above, while the river corridor was scoured and buried by lahars (mudflows). The ecological research underway on Chaitén has been modeled on protocols developed on Mount St. Helens.

ecosystem response. These disturbance gradients create exemplary arenas for ecological inquiry." Recognizing this, Crisafulli and the initial cadre of scientists established study sites on Mount St. Helens along a gradient of disturbance intensity. This approach facilitates comparison of responses to other eruptions and other disturbed sites. It also makes it possible to test hypotheses about the movement of organisms into a disturbed area. They may move from the edge, or outward from hotspots of biological legacies, or arrive as invading organisms. This is just one of the methods developed during studies on Mount St. Helens that has been adopted at other volcanic sites in Alaska, Argentina, Chile, Costa Rica, Indonesia, and Russia.

THE BIG 3: KRAKATAU, SURTSEY, MOUNT ST. HELENS

Three years ago, Crisafulli and his team of researchers decided to fully assess the body of work that comprises volcano ecology. "After 30-plus years of ecological research at Mount St. Helens, numerous lessons had emerged on ecosystem responses to disturbance, and I wanted to know to what extent these lessons were universal versus idiosyncratic and related to nuances of the Mount St. Helens eruption or its biota," Crisafulli explains.

The team gathered all the scientific publications they could find published between 1883 and 2015 related to volcano ecology. They documented which sites around the world have been studied by ecologists and the focus and extent of those studies. The result is an extensive bibliographic database which they are using to synthesize the current state of knowledge and to identify gaps in knowledge about volcano-ecology interactions. These gaps become starting points for developing a research strategy that will lead to new insights and understanding about volcano ecology.

The team found that of the 1,551 terrestrial volcanoes in the Smithsonian Global Volcanism Program database, 404 have erupted since 1883—the formal beginning of the study of volcano ecology following the eruption of Krakatau in Indonesia. Of these 404, 76 have been studied to some extent, and these efforts have resulted in 715 published ecological studies. Mount St. Helens represented almost 40 percent of these scientific papers.

Well-studied volcanoes are in the Americas from the Aleutians to Patagonia, Japan, and New Zealand. Under-studied volcanoes are in Africa, the South Pacific, Papua New Guinea, Indonesia, and the western Pacific.

Volcanoes in forest ecosystems are the most studied. Plants and animals have received about equal attention, but only a small percentage of volcanoes have had both studied. Invertebrates and vertebrates have been about equally studied, but within vertebrates, birds and mammals have received more attention than reptiles, amphibians, or fish.

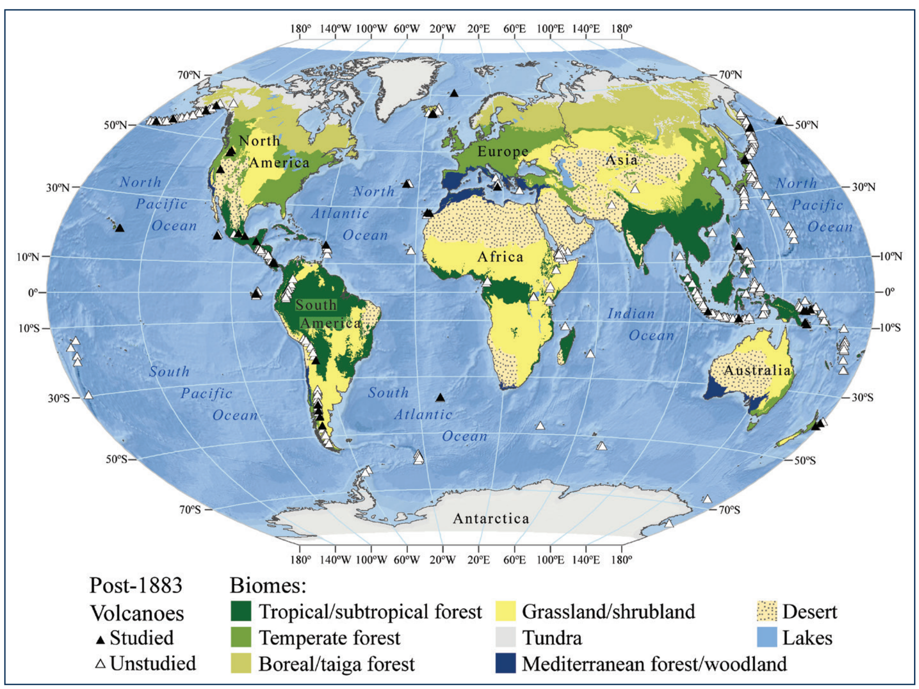
After this initial cataloging, Crisafulli explains that they then looked at the intensity of studies: How many have been sites of long-term research where scientists have examined multiple groups of plants and animals and ecological processes? Three rose to the top: Krakatau, Surtsey—an eruption in 1963 that formed a new island off the coast of Iceland—and Mount St. Helens.

"These are iconic locations of volcanic research," Crisafulli says, "Research at these three volcanoes has profoundly influenced our understanding of ecosystem dynamics following volcanism."

On one hand, ecologically these three volcanic sites are very different. Krakatau is on a tropical island and Surtsey emerged from the northern Atlantic Ocean as a sterile island, while Mount St. Helens is in temperate coniferous forest in a continental setting. But these differences form a useful mesh through which to sift the findings. "We can ask, 'Is there anything interesting that we see across these volcanic settings with respect to the pattern and pace of ecosystem response?' It gives us the opportunity for cross-site and cross-biome comparison, and to compare continental versus oceanic settings. We can tease out idiosyncrasies of individual eruptions versus overarching generalities," explains Crisafulli.

Looking at biological assembly, for example, says Crisafulli, "We can ask, 'what paths do living organisms take to disperse, become established, and form communities in the new environment—particularly a sterile environment devoid of carbon and nitrogen that are necessary for microbial and plant growth?'"

On Mount St. Helens, the Pumice Plain was a sterile expanse formed during the eruption by superheated pyroclastic flows that deposited pumice many tens of feet deep. Prairie lupine, a wildflower that's a member of the legume family, was first observed growing on the otherwise barren plain 2 years later. Each lupine plant created a microhabitat that was hospitable to several other plant species. Like other legumes, lupine chemically improves the soil for other plant species by "fixing" atmospheric nitrogen.



Crisafulli et al. 2015

World map of the 404 volcanoes that have erupted above the ocean surface since 1883. Black triangles mark volcanoes that have received ecological study. Most of these studied volcanoes are in forest biomes.

The lupine plants physically trap other wind-blown debris and attract insects, many of which ultimately die on or around the plant. As these bits of organic matter decompose, they also enrich the soil. Researchers found that soils under lupines have much higher total nitrogen, organic material, and microbial activity than adjacent bare areas. Within a few years, the lupine patches on the Pumice Plain became biological hotspots facilitating the colonization of other plant species and attracting numerous insects, birds, and small mammals, in what had been a barren landscape.

On Surtsey, seabirds profoundly influenced the development of plant and invertebrate communities. Once gulls had colonized the new island, the number and variety of plants growing on the island increased exponentially. The birds' guano, full of marine-based nutrients from the fish they had consumed, became a fertile medium for seeds blown in or washed ashore. Insects and land birds colonized the gull-mediated plant communities, leading to increased biodiversity.

Fruit bats were key to the ecological development on Krakatau. They traveled across expanses of sea from undisturbed islands to Krakatau where they were instrumental in dispersing seeds and creating a soil medium hospitable to germination.

"Here we have three different mechanisms of nutrient enrichment—plant, bird, mammal—creating islands of fertility," says Crisafulli.

Borgþór Magnússon, Icelandic Institute of Natural History

Surtsey, a volcanic island formed by an eruption in 1963 off the coast of Iceland, has also been the focus of long-term ecological research. Seabirds were instrumental in the development of plant communities on the island, which then attracted insects and land birds.

"We can see there are parallels in community assembly between oceanic and mainland habitat islands. We can tease out the idiosyncrasies of individual eruptions and biological players versus overarching generalities. The biological agents may vary but the ecosystem processes may be quite similar."

Krakatau, Surtsey, and Mount St. Helens stood apart from the other 73 volcanoes where ecological research has occurred because the persistence of research has been long term and includes numerous taxonomic groups and ecological processes. On Mount St. Helens, this momentum is maintained, in part, through gatherings held every 5 years when researchers from around the country convene at the volcano to revisit study plots and gather the next increment of data. The last two gatherings of these "science pulses" also have focused on bringing in the next generation of researchers. At Mount St. Helens, the original cadre of researchers following the 1980 eruption have either retired or are approaching retirement, and they are looking for new faces willing to inherit the long-term studies.

ARCHIVING ANSWERS FOR TOMORROW'S QUESTIONS

Libraries and museums are priceless repositories of knowledge. The advent of digital files and online databases makes materials available to minds around the world. Cataloging, documentation, keywords: these are some of the elements that differentiate a library or curated museum collection from a well-stocked attic. These elements made it possible for Crisafulli and his team to track down 715 articles published around the world over 132 years without leaving their offices. Now Crisafulli is working to archive data and specimens from Mount St. Helens so they will be accessible to generations of researchers around the world.

"We have hundreds of thousands of physical specimens and also reams of plot-based data. We are working to get all these long-term data and samples properly archived so they'll be safeguarded from loss and available for future generations. For every hour spent gathering data, count on 3 hours to manage the data. It's a tremendous effort in cost and time. This might be why so many datasets aren't archived and thus become unavailable," says Crisafulli.

Charlie Crisafulli

Specimens from Mount St. Helens, such as these butterflies, are being preserved in museums around the country so they will be accessible to future generations of researchers.

Some of the small mammal specimens and their data are now archived at the Burke Museum on the University of Washington campus. Jeff Bradley is the mammalogy collection manager at the Burke and explains why he was excited to add the Mount St. Helens specimens to the collection.

"The Mount St. Helen's eruption is a big part of Washington's natural and cultural history," says Bradley. "We have pre-eruption specimens from the region as well as specimens killed during the eruption—elk and deer skeletons, for example—collected in the months following the eruption. The Burke is a perfect place to be a repository of all the Mount St. Helens stories."

Small mammal sampling on Mount St. Helens is done by live trapping—the shrews, voles, and ground squirrels, for example, are trapped, weighed, measured, and released. Occasionally, however, some die in the trapping process, and these are what are sent to the Burke. At the museum, the frozen carcasses are turned into museum samples. "We make a study skin, skeleton, and archive tissue samples frozen at -80 °C. For the Mount St. Helens specimens, we also collect and preserve fecal samples," says Bradley.

"We anticipate that these specimens will be very valuable to scientists in the future, to anyone wishing to study species response to altered and reconstituting environments," says Bradley. "Lots of these questions are being answered now, but looking into the future, the specimens here at the Burke become really important, particularly as technology changes. Researchers will be able to apply new technology to specimens to ask new questions that you couldn't ask today."

Bradley continues, "Now it's very common to use DNA to do genetic research, but DNA analysis hasn't really been around that long. What's going to be the technology of the 21st century that might allow researchers to ask new questions? To ask different questions and fill in pieces of the puzzle that maybe genetics couldn't do alone. Will it be some factor or protein that hasn't even been described yet? People will be able to extract whatever that is from these specimens stored at the Burke."

These specimens also hold potential for research on microbiomes. "The microbiome is an area of research that's really hot right now, both in health science and wildlife science," says Bradley. "People are realizing these microbes on our skin, in our gut, all over our bodies are more important than thought before. Two hundred years from now, scientists will be able to extract and investigate these things we currently can't even dream of because these specimens are archived here in our collection."

Crisafulli also has sent arachnid collections to the Burke Museum, Smithsonian National Museum of Natural History, American Museum of Natural History, and the California Academy of Sciences. Small mammal collections, as well as grasshopper, beetle, and earwig collections have been deposited in the Museum of Southwestern Biology in New Mexico.

Amphibian collections were accessioned in the Museum of Vertebrate Zoology in California and in the Burke Museum. Plant specimens were given to the Intermountain Herbarium in Utah. More specimens will eventually be deposited in various other museums and repositories, preserving answers to as of yet unasked questions.

"A library implies an act of faith which generations, still in darkness hid, sign in their night in witness of the dawn."

—Victor Hugo, French poet, 1802–1885

LAND MANAGEMENT IMPLICATIONS

- Understanding ecosystem responses at Mount St. Helens provides valuable lessons on nature's resiliency following a range of disturbance intensities and offers insights on whether restoration activities are necessary at other disturbed sites (e.g., wildfire, strip mines, or dam removal).
- Carefully documenting natural processes following disturbance can inform land management decisions based on lessons such as the role of biological legacies, patterns and rates of biotic assembly, and biodiversity of large, slowly regenerating landscapes in pre-forest condition.
- Preserving data and samples has value for answering questions of the future. Efforts are underway to archive Mount St. Helens samples and data at museums and databases so it is available in perpetuity.

FURTHUR READING

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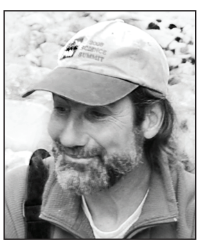

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