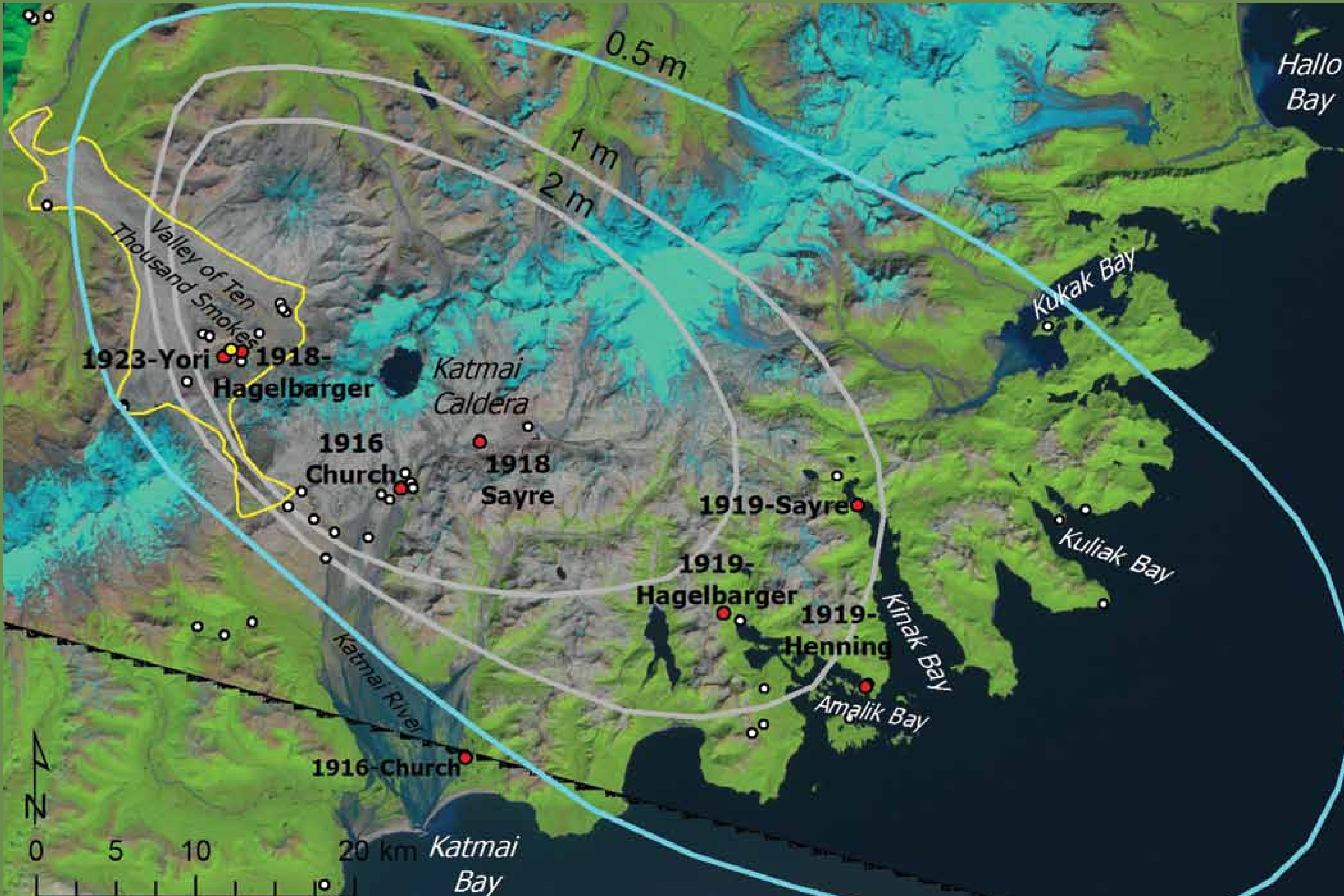


0.5 m
1 m
2 m
Hallo Bay
Valley of Ten Thousand Smokes
1923-Yori
1918-Hagelbarger
Katmai Caldera
1916 Church
1918 Sayre
1919-Sayre
Kukak Bay
Kuliak Bay
1919-Hagelbarger
1919-Henning
Kinak Bay
Amalik Bay
Katmai River
1916-Church
Katmai Bay
N
0 5 10 20 km

Ecological Recovery After the 1912 Katmai Eruption as Documented Through Repeat Photography

By M. Torre Jorgenson, Gerald V. Frost, Alan J. Bennett, Amy E. Miller

Introduction

The eruption of Novarupta in 1912 in Katmai National Park and Preserve was the largest in recent history and devastated a large mountainous and coastal region. Although scientific inquiries along the coast began almost immediately after the eruption, the sensational discovery of the center of the eruption in the Valley of 10,000 Smokes by Robert F. Griggs in 1915 catalyzed a decade of scientific expeditions in the region. The expeditions left a rich legacy of historical photographs that documented the barren landscape. The National Geographic Society (NGS) supported multiple expeditions between 1915 and 1919 to map and investigate the affected volcanic terrain (*Clemens and Norris 1999*). In 1916, Griggs led an expedition of four men, including photographer D.B. Church, that made it into the Valley of 10,000 Smokes. Subsequent NGS expeditions between 1917 and 1919 produced photographs by Church, Griggs, Paul Hagelbarger, Paul Henning, Emery Kolb, and Jasper Sayre. Additional photos were taken by Walter Smith during U.S. Geological Survey (USGS) expeditions in the early 1920s (*Smith 1925*). In 2004, the National Park Service initiated an effort to acquire, relocate, and rephotograph some of these scenes as part of a larger effort to document changes in the landscape throughout the park lands of southwestern Alaska (*Jorgenson et al. 2006*).

Figure 1. Location of all repeat photos (white dots) and a subset of repeat photos presented here (red dots) in the areas affected by the ash flow in the Valley of 10,000 Smokes (yellow line) and by the ash fall (gray isopachs show ash depth) from the eruption of Novarupta (yellow dot) in 1912.

The eruption of the Novarupta volcano took place over a 60-hour period during June 6-8, 1912 (*Martin 1913, Hildreth and Fierstein 2003*). At least 4.1 cubic miles (17 km^3) of fall deposits and 2.6 mi^3 (11 km^3) of ash-flow tuff (ignimbrite) were produced, a volume larger than that erupted by Krakatau (Indonesia) in 1883. Novarupta is known to have been exceeded by only four eruptions in the last 1,000 years: Tambora (Indonesia) in 1815, Laki (Iceland) in 1783-84, Kuwae (Vanuatu) in 1452, and Baitoushan (Korea-China) in 1050 (*Hildreth and Fierstein 2003*). The eruption caused 810 square miles (2,100 km^2) of mountainous terrain around the volcano to be covered as deep as 300 ft (91 m) in ash and pumice and created thousands of high-temperature fumaroles in the Valley of 10,000 Smokes, many of which lasted for more than 20 years.

Methods

Historical photographs were obtained from archives at the NGS, USGS Photographic Library, the Lake Clark-Katmai Studies Center of NPS, the University of Alaska Anchorage, and the University of Alaska Fairbanks. Approximately 4,800 Griggs expedition photographs were reviewed at the NGS archives, of which 344 were acquired. Additional photographs were acquired from archives at the NPS Alaska Regional Office and online sources at USGS and the Alaska Volcano Observatory.

A subset of the photographs were retaken using methods described by Hall (*2002*). In cases where the original vantage point could not be precisely triangulated, no longer existed (e.g., a river cutbank), or was obscured by vegetation, a nearby location was used. GPS coordinates, camera height, and azimuth were recorded at each site to facilitate future monitoring. Dominant plant species and estimated cover were recorded, where possible. In 2004, Gerald Frost (ABR) and Tahzay Jones (NPS) hiked to access photo points in the Valley of 10,000 Smokes, upper Knife Creek, Mageik Creek, and the middle Katmai River. In 2005, Torre Jorgenson and Alan Bennett used a helicopter to access additional photo points distributed throughout Katmai.

Results and Discussion

Recovery by Impact Zone

Repeat photographs of the Katmai landscape devastated by volcanism reveal a range of geomorphic and ecological processes affecting the recovery of the region. Photographs were sorted according to four zones of disturbance-intensity, radiating from the 1912 Novarupta eruption site (*Figure 1*).

Landsat satellite images from 2000 and 2002 (*Figure 1*) show that revegetation of the ash flow in the valley has been negligible, and in adjacent areas with heavy ash fall (>6.6 ft/2 m) only ~5% of the area has revegetated. As ash depths decrease at greater distances from the eruption site, vegetation cover increases, such that in the areas of lowest ash fall about 70% of the area shows strong vegetation recovery. Impacts from the eruption extended as far as Hallo Bay (*Jorgenson et al. 2006*) and Kodiak Island (*Griggs 1918*), and these areas have a nearly complete cover of vegetation today.

Repeat photographs taken in 2004 and 2005 provide more detailed views of vegetation recovery and are generally consistent with the Landsat imagery (*Figures 2-9*). Photos from the ash flow in the valley show very little recovery nearly 100 years after the eruption (*Figures 2-3*). In most of the area, vegetation cover, primarily willows, remained at <1% (visually estimated from photographs). In the >6.6 ft (2 m) ash fall zone, vegetation in 2004 covered 10-30% of the landscape (*Figures 4-5*). Alder has recovered in isolated patches on the valley slopes, primarily in areas where the ash had been eroded from the hillside by landslides and fluvial processes. Floodplains, however, had <1% cover in 2004 due to active channel migration and scouring (*Figure 5*). Willows were more abundant in protected drainages, but growth on thicker ash fall deposits remained negligible. In the 3.3-6.6 ft (1-2 m) zone, vegetation that survived the moderate impact covered 10-40% of the landscape soon after the eruption and then increased to cover 70-90% of the landscape by 2005 (*Figures 6-7*). In the 1.6-3.3 ft (0.5-1 m) zone along the coast, vegetation in 1919 covered 10-40% of the landscape and increased to 90-100% of the landscape by 2005 (*Figures 8-9*). In the latter two zones, present-day vegetation is dominated by alder scrub and bluejoint-herb meadows. Substantial ecological impacts also occurred beyond the 1.6 ft (0.5 m) isopach; vegetation in 1919 covered only 10-40% of the landscape and increased to nearly 100% of the landscape by 2005, with the exception of active floodplains (*Figure 9*). While meadows and shrublands have recovered in areas of moderate and low impact, trees that were once common at lower elevations, particularly cottonwood on river floodplains, have shown little recovery.

Photograph courtesy of P. Hagelbarger, copyright NGS

Photograph courtesy of G. Frost

Figure 2. Novarupta in the Valley of 10,000 Smokes in 1918 and 2004, with only scattered vegetation comprised of willows and wood-rushes. The surficial covering of fine ash evident in 1918 is gone by 2004 due to water and wind erosion

Photograph courtesy of C. Yori

Photograph courtesy of G. Frost

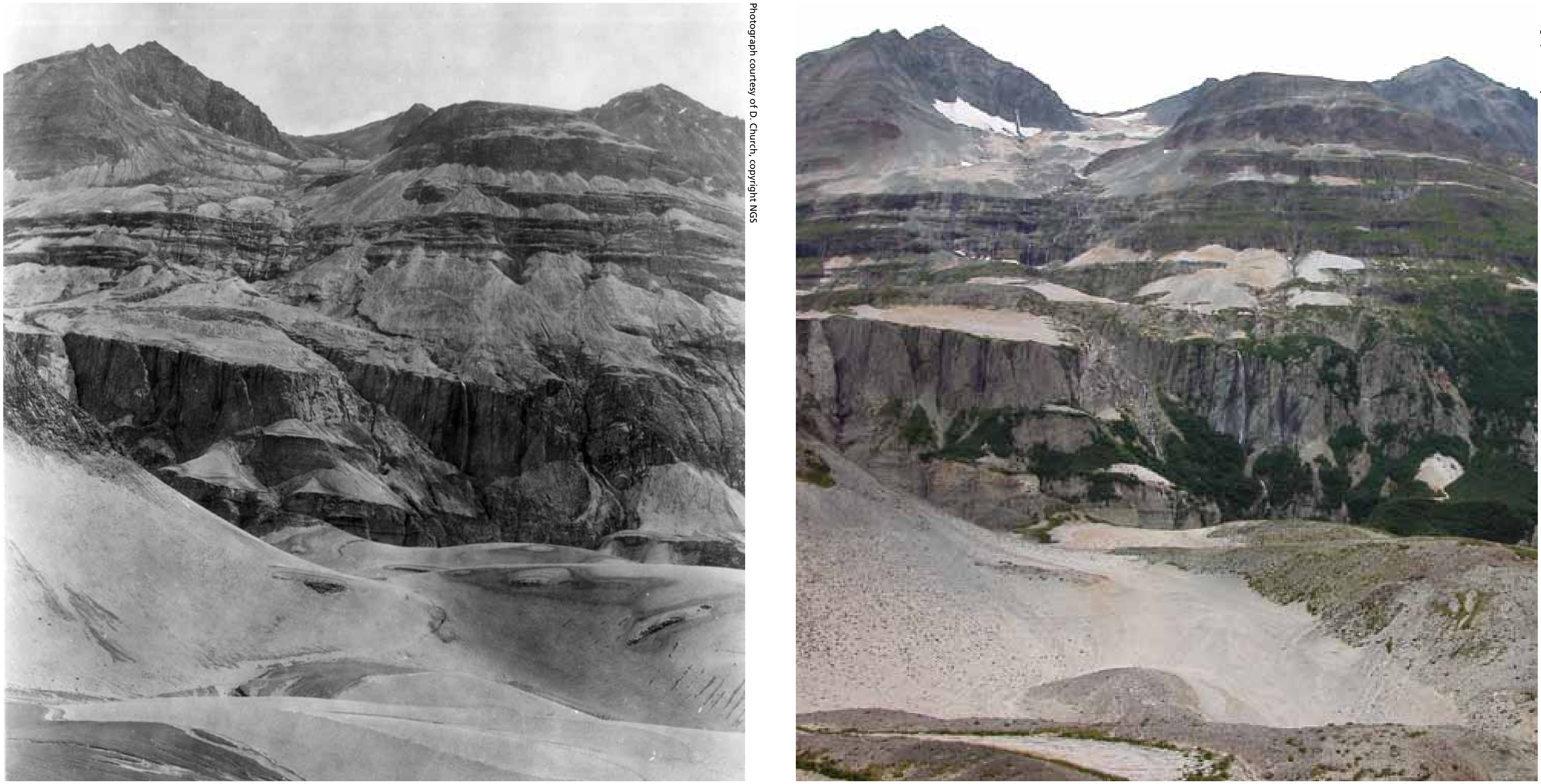
Figure 3. Falling Mountain (left), Mt. Cerberus (center), and the upper Valley of 10,000 Smokes in 1923 and 2004. The parallel depressions are probably concussion fissures that formed during the eruption, followed by moderate gully erosion of the surface (foreground) and sparse willow establishment .

Recovery of Main Vegetation Types

Vegetation recovery was dominated mainly by four vegetation types: partially vegetated barrens, bluejoint-herb meadows, willow scrub, and alder scrub. Other uncommon vegetation types that recovered well after the eruption included Sitka spruce forests that expanded into areas disturbed by the ash fall, dwarf ericaceous scrub at higher elevations, and halophytic wet meadows on tidal flats.

Partially vegetated and barren areas (<30% vegetation cover) remained widespread in areas of ash flow and heavy ash fall. In the Valley of 10,000 Smokes, common colonizing plants included scattered willows (*Salix barclayi and S. alaxensis*), rushes (*Luzula spp*), and bluejoint grass (*Calamagrostis canadensis*). A few mosses and liverworts were found colonizing the bare soil shortly after the eruption (*Griggs 1933*) and are still present today. Sitka alder (*Alnus viridis ssp. sinuata*), however, was virtually absent from the ash flow. Near the coast, common colonizers included grasses (*Deschampsia caespitosa, Leymus mollis*) and forbs (*Chamerion angustifolium, Lupinus nootkatensis, Artemisia tilesii*).

Bluejoint-herb meadows were common on slopes interspersed with the alder thickets along the



Photograph courtesy of D. Church, copyright NGS

Photograph courtesy of G. Frost

Figure 4. The south wall of Katmai Canyon in 1916 and 2004 shows that most of the ash has been eroded from the steep slopes, while ash remains prevalent on the lower gentle terrain. Alder was nearly absent soon after the eruption but has recovered somewhat around the margins of the ash.

coastal mountains in zones with thinner ash fall. The vegetation was dominated by bluejoint grass, umbels (*Heracleum lanatum, Angelica genuflexa*), fireweed (*Chamerion angustifolium*), and other forbs (*Geranium erianthum, Achillea borealis, Sanguisorba canadensis*).

Tall and low willow scrub was common in drainages and in the mountains near the coast. Willows were predominantly *Salix barclayi*, but included *S. sitchensis, S. alaxensis* and *S. glauca*. Numerous dwarf shrubs (*Vaccinium vitis-idaea* and *Empetrum nigrum*), bluejoint grass, and forbs (*Chamerion angustifolium, Trientalis europaea, Sanguisorba stipulata, Lupinus nootkatensis*) were common.

Alder tall scrub was abundant in the coastal mountains affected by moderate to light ash fall. Early photographs showed scattered, live tall shrub thickets on many of the steeper mountain slopes where ash cover did not persist. By 2005, Sitka alder and various willows (*Salix barclayi, S. sitchensis,* and *S. alaxensis*) up to 15 ft (4.5 m) tall were co-dominant in the overstory. Scattered Sitka spruce (*Picea sitchensis*) and black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) occasionally were present. The initial survival of scattered alder patches in the coastal mountains undoubtedly aided recovery through expansion of surviving shrubs and by providing a seed source for new recruitment. The understory of alder scrub has most of the plants found in bluejoint herb meadows.

Figure 5. Mt. Katmai seen from the Katmai River floodplain in 1918 and from a nearby vantage point in 2004. Channel migration has prevented vegetation from establishing on the floodplain, while vegetation has colonized the margins of the ash along the lower hillsides. Trees that were originally present remain absent across most of the landscape.

Sitka spruce woodlands appear to have expanded into new habitats in a few locations. In 1919, Sitka spruce was observed on a peninsula in Kuliak Bay and a small islet at the mouth of Amalik Bay (*Griggs 1934*). By 2005, spruce forest had increased markedly in Kukak Bay where they were not previously evident (live or dead) in 1919 (*Jorgenson et al. 2006*). Sitka spruce has also spread quickly on Kodiak Island due to the early presence of trees that provided a seed source and the occurrence of a mineral seedbed following the eruption, where plant competition at the seedling stage was minimal (*Griggs 1918*, *Tae 1997*).

At Hallo Bay, salt marshes received 4-12 in (10-30 cm) of ash and subsequently were covered by silt from tidal flooding and eolian sand. Today the coastal landscapes now support productive salt marshes on narrow tidal flats and dunegrass meadows on beaches.

Factors Affecting Recovery

The ecological recovery of the areas disturbed by ash flow and fall has been greatly affected by geomorphic

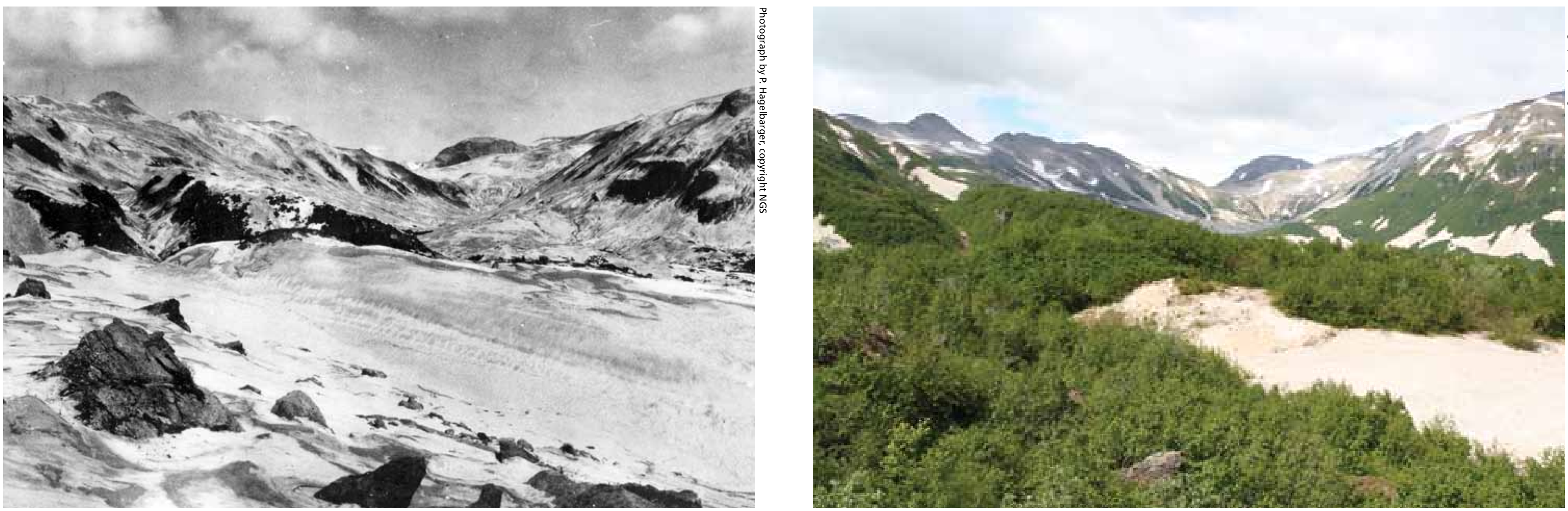
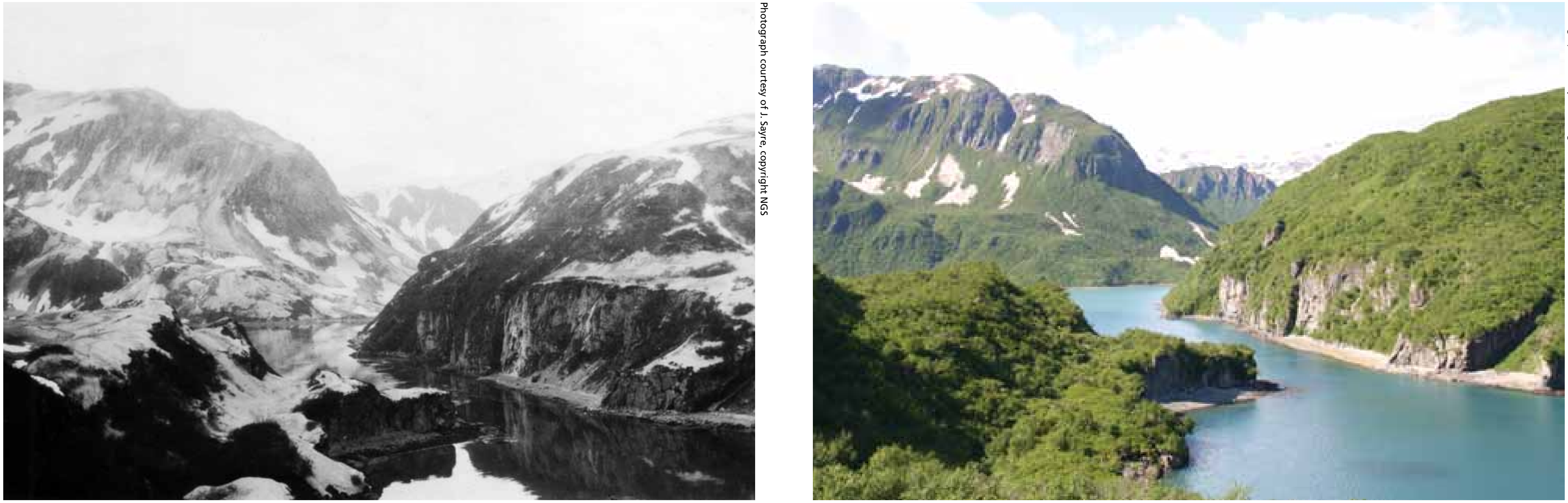


Figure 6. Mountains north of Geographic Harbor in 1919 and 2005 that received 3.3-6.6 ft (1-2 m) of ash fall. Some alders on steeper slopes survived the eruption and shrub cover later expanded across most of the area, although many thick ash deposits remain bare.



Photograph courtesy of J. Sayre, copyright NGS

Photograph courtesy of T. Jorgenson

Figure 7. Hidden Harbor, which had 3.3-6.6 ft (1-2 m) of ash fall, in 1919 and 2005. Alder and willow thickets partially survived as conspicuous as dark patches on the pale ash deposits and later recovered across most of the area.

Photograph courtesy of W. Henning, copyright NGS

Photograph courtesy of T. Jorgenson

Figure 8. Entrance of Amalik Bay in 1919 and 2005. Numerous alder patches survived the ash fall, and by 2005 alder scrub and bluejoint-herb meadows covered nearly the entire land surface.

Photograph courtesy of D. Church, copyright NGS

Photograph courtesy of T. Jorgenson

Figure 9. Katmai village cemetery seen in 1916 and at a nearby location in 2005. Channel migration and extensive deposition of ash-rich alluvium by the braided Katmai River has left no trace of the cemetery and village. Recovery of tall alder scrub is evident on the slopes of Mt. Pedmar in the background.

processes and the chemical properties of the ash deposits (*Griggs 1919, 1922, 1933*). On slopes, much of the ash has been removed through landslides, slumping, fluvial erosion, and wind erosion (*Figure 4*). High winds that cause severe surface abrasion, particularly in the Valley of 10,000 Smokes, are common and undoubtedly retard plant establishment. Gully formation is prevalent in flat areas of the valley where the original drainage patterns were obliterated by the ash flow (*Figure 3*). Floodplain dynamics were greatly affected as heavy ash fall immediately increased suspended- and bed-loads within the channel, and heavy sediment input probably continued for many years after the eruption (*Griggs 1919*). Within a decade, the upper reaches of high-energy, braided floodplains had been mostly cleared of fine-grained cover deposits of ash (*Figure 5*), but lower reaches and deltas continue to have very active channel migration in the highly mobile sandy materials (*Figure 9*).

Soil chemistry and low nutrient-availability are major factors contributing to the slow recovery of vegetation on thick ash deposits. Katmai ash is mainly comprised of rhyolite and dacite, which are dominated by quartz and potassium- and sodium-rich feldspars (aluminum- and silica-rich). Griggs (*1933*) attributed the slow revegation to the very low nitrogen concentrations (<0.02% total nitrogen) in unmixed ash. These nutrient-limited ash deposits favor species with symbiotic nitrogen-fixing bacteria, such as alder and legumes. While alder has recovered well in areas with light to moderate ash deposits, alder has not shown much recovery on thick ash fall and especially on the ash flow in the Valley of 10,000 Smokes. Katmai ash also has very low phosphate concentrations (0.4% phosphoric acid), which also strongly limits plant growth. Finally, aluminum oxide concentrations are high (13.9% Al_2O_3) (*Griggs 1933*), which suggests high aluminum solubility, and consequent toxicity, may be a factor in acidic soils formed from rhyolite. Low soil moisture in coarse-grained pumice deposits may be a factor in limiting seedling establishment, but seedling establishment and recovery typically are rapid on other newly exposed gravelly substrates that are common in Katmai, such as landslides, glacial moraines, and riverbars. The astonishing lack of recovery of the ash deposits over much of the area after nearly 100 years warrants more detailed investigation.

Acid rain and highly corrosive sulfuric acid gasses likely affected vegetation even where ash fall was very light. Photographs of granitic outcrops west of the eruption along Lake Grosvenor in 1919 document white, barren bedrock outcrops, which have subsequently become nearly entirely covered by crustose and fruticose lichens (*Jorgenson et al. 2006*). Acid rain from the eruption was reportedly so strong that it caused clothing to disintegrate on clotheslines in Vancouver, Canada (*Geology Fieldnotes, http://www.nature.nps.gov/geology/parks/katm*). Recent investigations of widespread vegetation damage near Chiginagak Volcano on the Alaska Peninsula attributed the heavy mortality to a gaseous flow of sulfuric acid aerosols generated by catastrophic drainage of the crater lake (Schaefer et al. 2008).

In summary, the 1912 eruption at Katmai devastated a large area of southwestern Alaska through ash fall and pyroclastic flows, and its impacts extended globally. The spectacular effects of the Katmai eruption created a unique natural laboratory in which to study ecological recovery along a gradient of disturbance levels and ecosystem types, ranging from primary succession on the sterile soils of the Valley of 10,000 Smokes, to secondary succession after ash fall. Repeat photography offered an effective and highly engaging technique to monitor this recovery over a centennial time-scale. Ecological recovery occurred remarkably quickly in many areas, but the otherworldly landscape of the valley remains almost entirely barren a century after it was created. The amazing lack of revegetation in some areas that had thick pyroclastic flows and ash deposits warrants more research into what factors are limiting plant recovery.

Acknowledgements

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For additional images visit: http://science.nature.nps.gov/im/units/swan/index.cfm?theme=repeat_photos

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