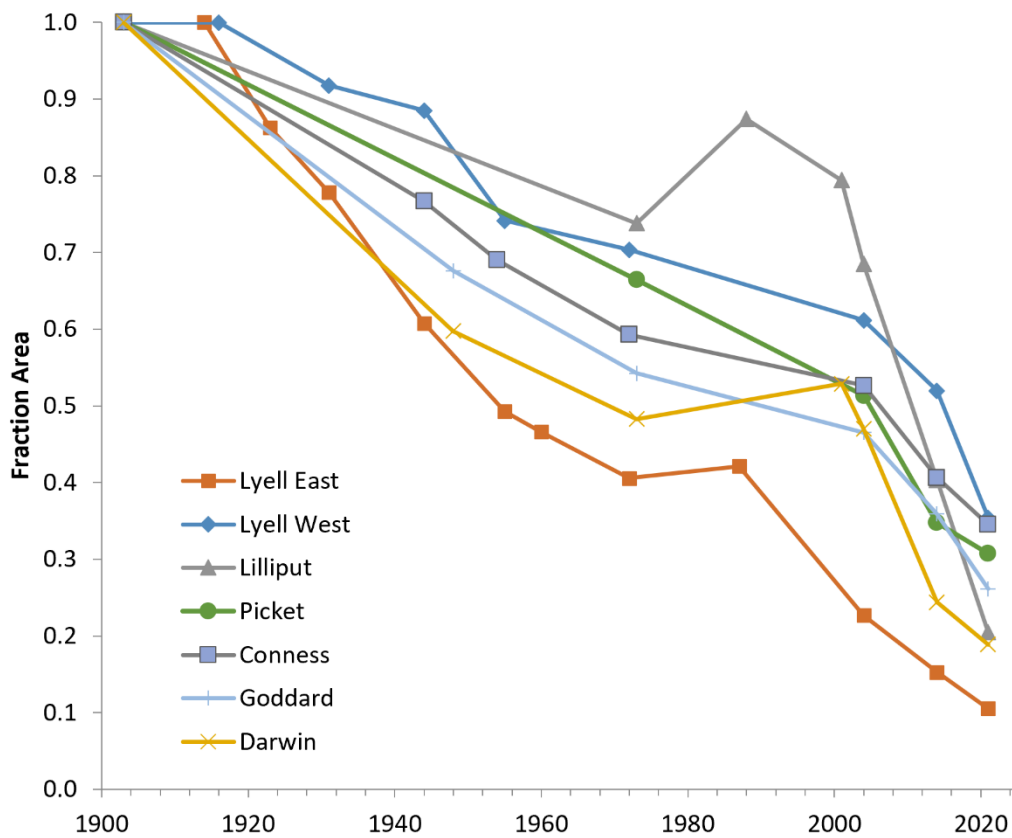


3.11 Glacier Change

Regionally and globally, glacier retreat is intensifying due to increasing temperatures. California reflects this broader trend, with the complete disappearance of the Trinity Alps glaciers and the continued decline of the Sierra Nevada glaciers.

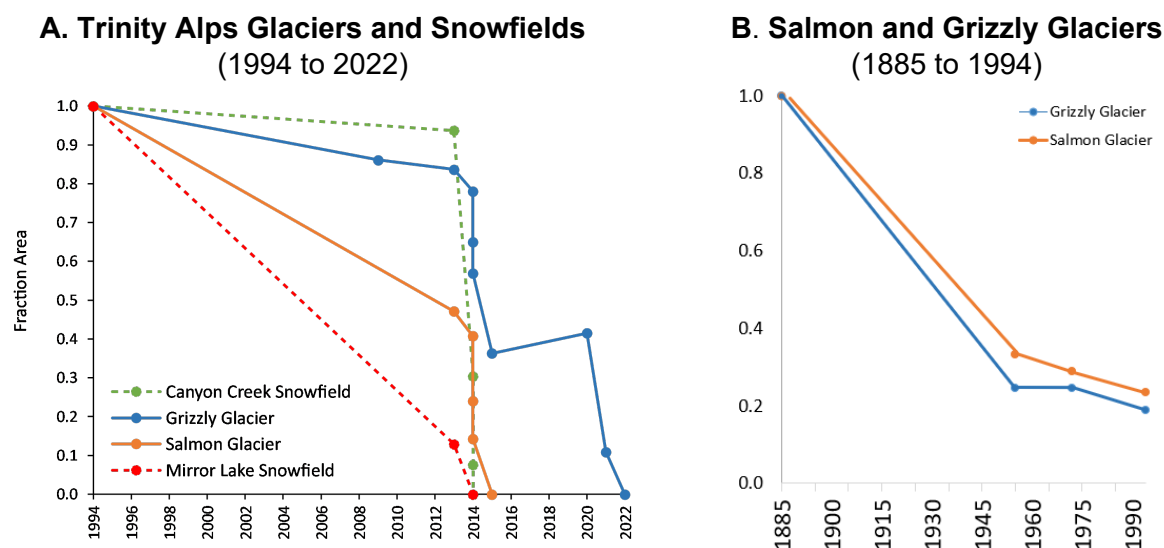
Figure 3.11.1. Change in Area of Sierra Nevada Glaciers.



The figure shows the change in area of Sierra Nevada glaciers as a fraction of the 1903 area. Source: Basagic and Fountain (2011, updated to 2021 by H. Basagic, unpublished data)



Figure 3.11.2. Change in Area of Trinity Alps Glaciers and Snowfields.



The figure shows: **A.** the fractional glacier area remaining relative to 1994 for two glaciers and two perennial snowfields in the Trinity Alps from 1994 to 2015 and subsequent measurements of Grizzly Glacier until its extinction in 2022 **B.** the changes in the areas of the Grizzly and Salmon Glaciers relative to their estimated areas around 1885; data prior to 1994 are not available for the Canyon Creek and Mirror Lake Snowfields. In 2015, Salmon Glacier disappeared entirely and the lower half of Grizzly Glacier broke apart into large ice blocks, leaving only the upper portion of the glacier intact (see historical and contemporary photographs in Appendix A).

Sources: Garwood et al. (2020 and 2026)

What does the indicator show?

A glacier is defined as a mass of perennial snow or ice that moves (Cogley et al., 2011). California's glaciers provide a stark illustration of the accelerating impacts of climate change. Selected glaciers and snowfields have experienced substantial reductions in area (see [Figure 3.11.3](#) for locations). [Figure 3.11.1](#) shows large declines in the seven Sierra Nevada glaciers relative to 1903. By 2021, the Sierra Nevada glaciers lost 65 to 89% (an average of about 75%) of their 1903 area, after having lost approximately half of their area since the 1970s (Basagic, unpublished 2021 data; methodology described in Basagic and Fountain, 2011). These findings are consistent with those from a separate study of 769 glaciers and perennial snowfields that were identified within the



Sierra Nevada in the 1970s and 1980s based on the US Geological Survey's 1:24,000-scale, topographic maps (Fountain et al., 2017). The largest 39 glaciers, free of rock debris mantling the surface, covered an area of 2.74 ± 0.12 square kilometers (km^2) in the 1970s and 1980s. By 2014, overall, they lost approximately 50% of their area. Measurements in recent years have been hindered by extensive snow cover (personal comm, Basagic, 2025 and Stock, 2026), although recent photographs capture Lyell and Maclure glaciers ([Figure 3.11.4](#) and [Figure 3.11.5](#)). Researchers project that these glaciers will be completely gone by the beginning of the next century, a profound environmental change occurring within a relatively short period of time (Jones et al., 2025).

Figure 3.11.3. Glaciers and Perennial Snow Regions in California.



Source: Garwood et al. (2020)



Figure 3.11.4. Lyell and Maclure Glaciers, 2024 and 2025.

A. Lyell Glacier in September 2024



B. Maclure Glacier in September 2024



C. Lyell Glacier in September 2025



D. Maclure Glacier in September 2025



E. Lyell Glacier in September 2025



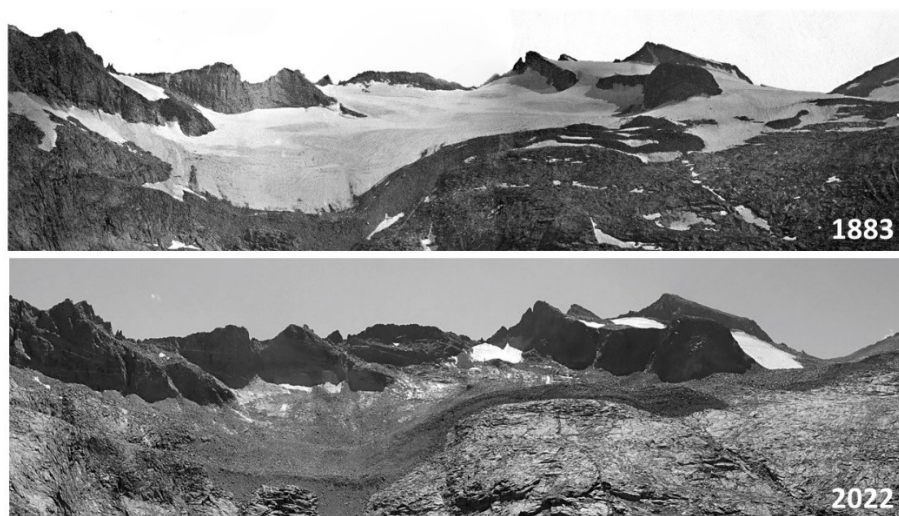
F. Maclure Glacier in September 2025



Source: Greg Stock (personal comm, 2025)



Figure 3.11.5. Lyell Glacier, 1883 and 2022.



Source: National Park Service

The Trinity Alps were a glaciated subrange of the Klamath Mountains in northwest California. Around 1885, at least nine Holocene glaciers existed in the Trinity Alps (Heermance et al., 2026). Grizzly and Salmon glaciers are the only two that persisted in the 21st century (Garwood et al., 2020). **Figure 3.11.2** shows substantial losses in the size of glaciers and snowfields in the Trinity Alps since 1994. All snowfields throughout the Trinity Alps and greater Klamath Mountains of southern Oregon and northern California disappeared by 2014 during an extended drought, and glaciers disappeared by 2022 (Garwood et al., 2020 and 2026; **Figure 3.11.2A**). Both glaciers had lost 70 to 75% of their area between 1885 and 1955; by 1994, approximately 20% of their 1885 area remained (**Figure 3.11.2B**). Between the fall of 2020 and the fall of 2021, Grizzly Glacier experienced a catastrophic 76% reduction in area. By the fall of 2022, after repeated annual drought conditions, the last remaining stagnant Grizzly Glacier ice had melted (Garwood et al., 2026) leaving the Klamath Mountains without glacial ice for the first time in centuries. This milestone marks the first time in nearly two decades of tracking California's climate change indicators that monitored glaciers from a distinct region have disappeared entirely.



Glacier loss in California reflects broader regional and global trends. Glaciers across the western United States have experienced rapid retreat in recent years (Abubakari and Ambinakudige, 2024), and glacier mass loss in North America has accelerated in response to rising air temperatures (Kääb and Røste, 2024; Williamson et al., 2025). On average, glaciers globally are projected to lose nearly 40% of their mass relative to 2020 by 2100, corresponding to a global mean sea-level rise of 113 mm, even if carbon emissions stop and temperatures stabilized at present-day conditions (Zekollari et al., 2025). The number of glaciers disappearing globally is projected to peak between 2041 and 2055, with up to approximately 4,000 glaciers disappearing annually (Van Tricht et al., 2026).

Why is this indicator important?

Tribal Connection 3.11.1

The loss and shrinking of these glaciers are grieved by California Tribes. Tribal Elder Dean Tonnenna explains the impacts the Mono Lake Kootzaduka'a experience from the shrinking glaciers in their territory including Conness, Lyell East and West, and Maclure: *"The glaciers in our area are an important component of our homeland. We are accustomed to looking up to the mountaintops no matter where we are along the Sierra Nevada and seeing the familiar glaciers. The glaciers have been around for countless generations, and they're mentioned in some of our traditional origin stories, especially the story of how pine nuts came to our region. The glaciers are also indicators of the future regarding water supply within our homeland and everything that's connected with water. We are concerned that if the glaciers dry up and vanish, that will correspondingly mean that our creeks and streams may no longer have enough water to last until the winter snows come again. With our streams and creeks drying up earlier in the year, that will have a cascading effect upon the vegetation community and our ability to gather plants for food, medicine, and cultural practices like basketry"* (Mono Lake Kootzaduka'a Tribe of California and Nevada, 2026).



Glaciers are important indicators of climate change. Because glaciers are sensitive to fluctuations in temperature, they provide visual evidence of warming. In addition, as warming causes snow and ice to melt, darker colored surfaces are exposed, albedo decreases, less solar energy is reflected out to space, and the planet warms even more. Deposition of black carbon from wildfire emissions can further darken snow and ice surfaces, contributing to additional albedo reductions (UCAR, 2026).

Glacier loss can also lead to cascading effects on hydrology and aquatic habitats, contribute to sea level rise, and impact recreation and tourism (USGS, 2021). Glacier shrinkage results in earlier peak runoff and drier summer conditions, affecting many aquatic species in alpine and subalpine environments that require cold water temperatures to survive. Species dependent on glacier environments are projected to face local extinction where glaciers disappear completely (Wilkes et al., 2023). Ice and persistent snow in the Trinity Alps create high-elevation cold-water habitats that support several endemic species, including the beetle, *Nebria praedicta*, and the coastal tailed frog (*Ascaphus truei*; see [Figure 3.11.6](#)), the latter of which is a California Species of Special Concern.

Three regional watersheds provide cold glacial and snowmelt flows to streams supporting small populations of spring Chinook salmon (*Oncorhynchus tshawytscha*) and summer steelhead (*Oncorhynchus mykiss*). Rapid declines in glacial ice and snowpack threaten these cold-adapted species and their resilience (Garwood et al., 2020). For information on increasing river water temperatures and impacts on Chinook salmon populations, see the *Salmon Water River* and *Chinook Salmon Abundance* chapters.



Figure 3.11.6. Coastal Tailed Frog.



The Coastal tailed frog (*Ascaphus truei*) ranges from British Columbia to northern California, from near sea level in Humboldt County up to elevations of 2150 meters in the Trinity Alps.

Source: CDFW (2016); Photo credit: Thompson et al. (2016)

What factors influence this indicator?

A glacier is a product of regional climate, responding to the combination of winter snow and spring/summer temperatures. Winter snowfall nourishes the glaciers; winter temperature determines whether precipitation falls as rain or snow, thus affecting snow accumulation and glacier mass gain. Spring and summer air temperatures affect the rate of snow and ice melt.

In recent years, increasing winter and spring temperatures across North America have led to less snowpack in spring and early summer (Mote et al., 2018). Based on their assessment of glacier studies in various parts of the world, the Intergovernmental Panel on Climate Change (IPCC, 2021) concluded that human-induced warming likely contributed substantially to widespread glacier retreat during the 20th century. Local variations in topography and climate either enhance or reduce the magnitude of change so that each glacier's response is somewhat unique.

Sierra Nevada

The glacier retreat in the Sierra Nevada occurred during extended periods of above average spring and summer temperatures; winter snowfall appeared to be a less important factor (Basagic and Fountain, 2011). Glacier area changes at East Lyell and



West Lyell glaciers were found to be significantly correlated with spring and summer air temperatures. In the past century, average annual temperatures in the Sierra Climate Region warmed by almost 3 degrees Fahrenheit (°F), or 1.7 degrees Celsius (°C) with summer and fall having warmed the most, at 3.6 (2°C) and 3.4°F (1.9°C), respectively (WRCC, 2026).

As seen in **Figure 3.11.1**, the seven glaciers studied have all decreased in area. However, the magnitude and rates of change are variable, suggesting that factors other than regional climate influenced these changes. One of these factors is glacier geometry. A thin glacier on a flat slope will lose more area compared to a thick glacier in a bowl-shaped depression, even if the rate of melting is the same. In addition, local topographic features, such as headwall cliffs, influence glacier response through shading solar radiation, and enhancing snow accumulation on the glacier through avalanching from the cliffs.

Trinity Alps

Grizzly and Salmon Glaciers and Canyon Creek and Mirror Lake Snowfields in the Trinity Alps occurred at 2,460 meters, an elevation far lower than other glaciated areas in California. The high latitude region has a particularly wet climate during the winter months due to its proximity to the Pacific Ocean (Garwood et al., 2020). Although a marginal climate for glaciers, these glaciers persisted into the 21st century due to topographic features where tall headwalls increase shading and enhance localized snow accumulation through avalanching and wind transport.

Although large data gaps exist, clearly the largest amount of ice loss in the Trinity Alps occurred during the first half of the 20th century with a combined area loss of 72% for Grizzly and Salmon glaciers (Garwood et al., 2020; see **Figure 3.11.2**). Since then, the glaciers receded at a much slower but steady rate and persisted even while winter precipitation in the Trinity Alps was below the long-term average (using 1895 to 2015 as baseline) in nine of 20 years from 1996 to 2015, and summer temperatures exceeded the long-term average in 18 years of the same period. Scientists attribute the recent glacial retreat in the Trinity Alps (see Appendix A, **Figure 3.11.A-1** and **Figure 3.11.A-2**) largely to unprecedented and consistently high summer temperatures



coincident with record low winter precipitation in the region during the 2012-2016 drought (Garwood et al., 2020) and persisted through 2021 (Garwood, unpublished data). During the severe drought, snowpack was at an all-time low—no other year since 1950 reported an April 1st snowpack of less than 34% of the historical average in the Klamath Mountains (Garwood et al., 2020).

Technical considerations

Data characteristics

Sierra Nevada

To quantify the change in glacier extent, seven glaciers in the Sierra Nevada were selected based on the availability of past data and location: Conness, East Lyell, West Lyell, Darwin, Goddard, Lilliput, and Picket glaciers (Basagic and Fountain, 2011). Glacier extents were reconstructed using historical photographs and field measurements. Only late summer photographs, largely snow free, were used in the interpretation of the ice boundary. Early 1900 extents were based on ground-based images and evidence from moraines (loose sediment and rock debris deposited by glacier ice). To obtain recent glacier areas, the extent of each glacier was recorded using a global positioning system (GPS) in 2004. The 2014 outlines were derived from aerial photographs acquired by the US Department of Agriculture National Agricultural Imagery Program, 1-meter ground resolution. The 2021 imagery was acquired from [DigitalGlobe WorldView © 2021 Maxar](#), 0.5-meter ground resolution.

Trinity Alps

Long-term changes in glaciers and perennial snowfields were quantified using clearly defined moraines; vertical aerial orthophotos (photographs geometrically corrected such that the scale is uniform); high-resolution satellite images; and GPS mapping (Garwood et al., 2020; Garwood, unpublished data). The 1885 outlines were generated by mapping the ridgelines of prominent Holocene moraines coupled with mapping the near vertical bedrock headwalls at the upper extent of the glaciers.

To examine the response of glaciers and perennial snowfields in the Trinity Alps to variations in climate, changes in glacier area were compared to winter precipitation and summer air temperature from the PRISM re-analysis data (Daly et al., 2008; PRISM



Climate Group 2018), employing a similar analysis as Sitts et al. (2010), using data for the 4 km × 4 km PRISM grid cell centered on Thompson Peak for the period of January 1895 to September 2015.

Strengths and limitations of the data

This indicator relies on data on glacier change based on photographic records, which are limited by the availability and quality of historical photographs. The use of both aerial photographs and satellite images provides high-quality visual data for measuring changes in glacier area. Detailed information about uncertainties associated with mapping the area of glaciers can be found in the methods section of Garwood et al. (2020). A limitation in relying on satellite and photographic images is that change in glacial volume cannot be assessed.

Increasing the number of glaciers studied and the number of intervals between observations would provide a more robust data set for analyzing statistical relationships between glacier change and climatological and topographic parameters. Additionally, volume measurements would provide valuable information and quantify changes that area measurements alone may fail to reveal.

OEHHA acknowledges the expert contribution of the following to this report:



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Appendix A. Historical and Contemporary Glacier Photographs

Historical glacier responses preserved in photographs are important records of past climates in high alpine areas where few other climate records exist. Repeat photographs – paired historical and contemporary images – for selected glaciers are presented below. Additional photographs of the Sierra Nevada, Trinity Alps and other western glaciers can be viewed at the “Glaciers of the American West” [web site](#) (PSU, 2021).

Figure 3.11.A-1 Historical and Contemporary Late Summer Photographs of Two Sierra Nevada Glaciers

Dana Glacier



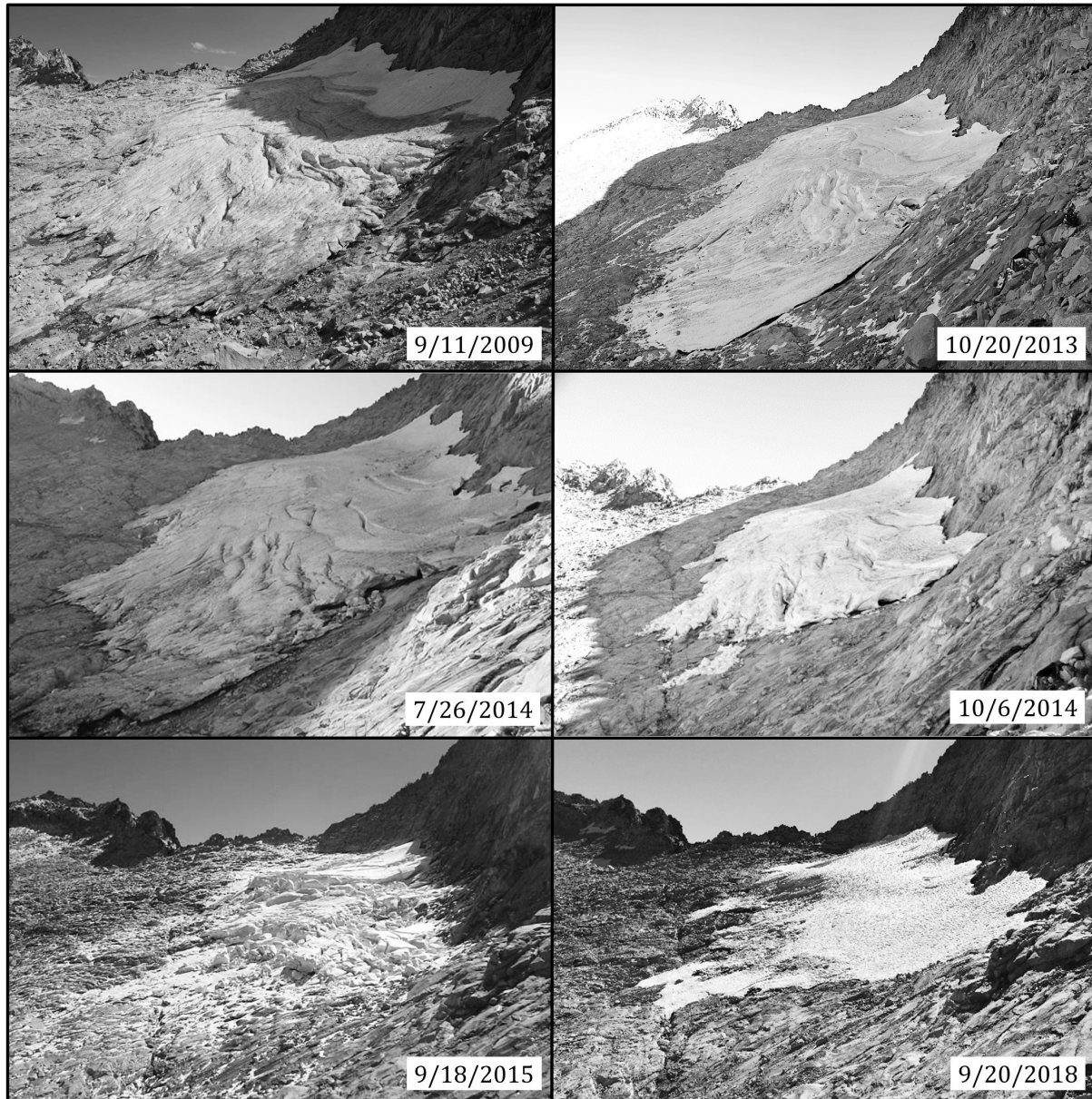
Credit: US Geological Service, photo station ric046: I.C. Russell, 1883 (left); R. Hallnan (right)

Conness Glacier



Credit: National Park Service, photo station Conness 5555 (left); H. Basagic (right)



Figure 3.11.A-2 Grizzly Glacier, repeat photographs

Credit: All photographs taken by J Garwood, with exception of October 2013 by K. Lindke and October 2014 by J. Barnes

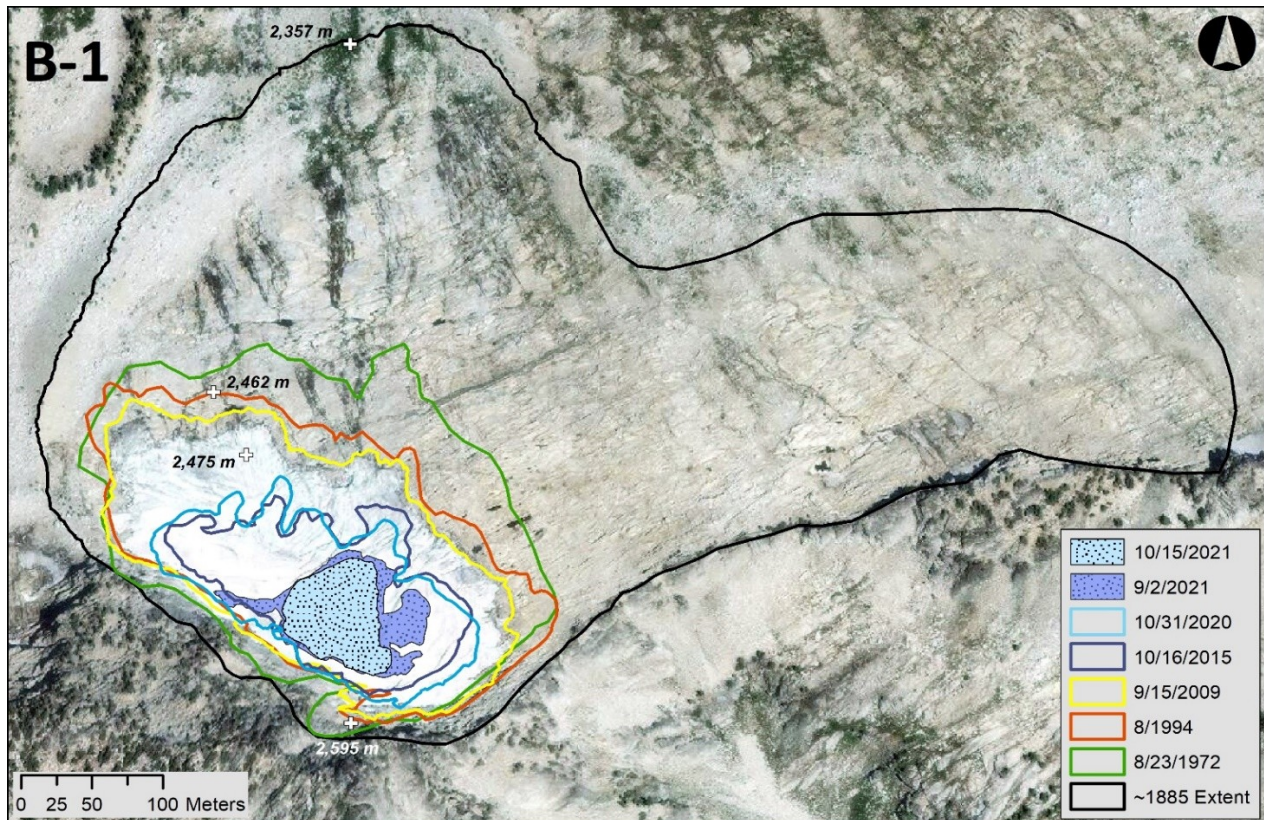
Repeat photographs of Grizzly Glacier were taken between September 2009 and September 2018. The lower half of the glacier broke apart in the fall of 2015. A thin layer of fresh snow visible in the September 2015 image accumulated during a brief storm that occurred two days prior to the image date. This snow cover visually exaggerates the actual glacier size beyond the visible pile of scattered ice debris visible in the photo; a result of extreme calving, which is when chunks of ice break off at the



end of a glacier, in the lower half of the feature during the summer of 2015 (Garwood et al., 2020).

Appendix B. Glacier area loss for the Trinity Alps, California

Figure 3.11.B-1 Grizzly Glacier, digitized outlines

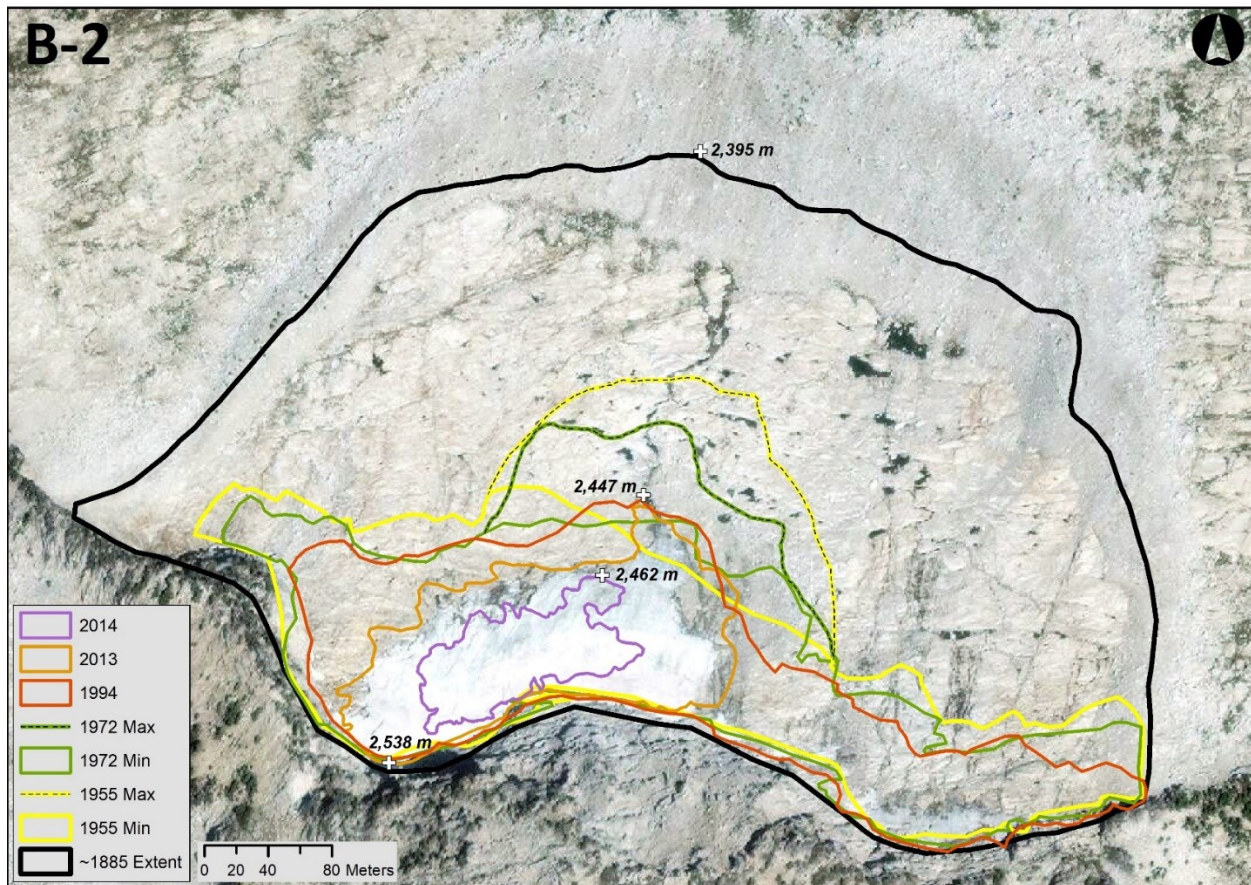


Digitized outlines of Grizzly Glacier (B-1) and Salmon Glacier (B-2) from approximately 1885 to 2021. Salmon Glacier disappeared completely by the fall of 2015 while Grizzly Glacier maintained a similar area between 2015 and 2020 before losing 76% of its 2020 area during the summer and early fall of 2021. The 1885 outlines were generated by mapping the ridgelines of prominent Holocene moraines coupled with mapping the near vertical bedrock headwalls at the upper extent of the glaciers. The 1885 outlines represent the most recent Little Ice Age glacial advance. Due to extensive residual snow cover on Salmon Glacier in 1955 and 1972, outlines include a minimum estimated area (solid colors) and additional maximum estimated area (dotted regions). Satellite base image date is from 26 July 2014. Approximate surface elevations are noted at four locations at each glacier.

Source: Garwood et al., 2020 (updated 2021; J. Garwood, unpublished data)



Figure 3.11.B-2 Salmon Glacier, digitized outlines



Source: Garwood et al., 2020

