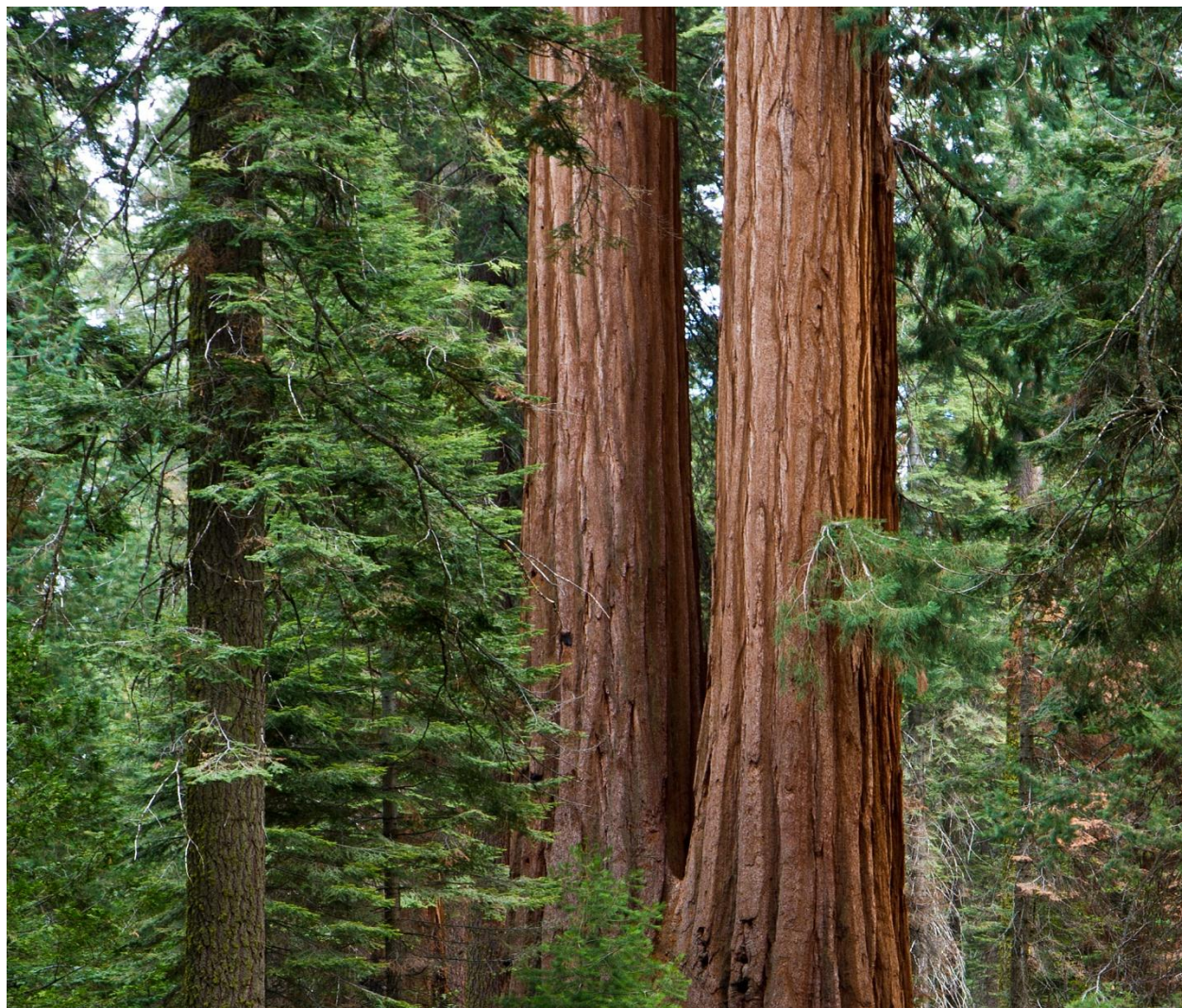




A Natural Resource Condition Assessment for Sequoia and Kings Canyon National Parks

Appendix 4 – Glaciers

Natural Resource Report NPS/SEKI/ NRR—2013/665.4



ON THE COVER

Giant Forest, Sequoia National Park
Photography by: Brent Paull

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Appendix 4 - Glaciers

Natural Resource Report NPS/SEKI/ NRR—2013/665.4

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This document contains subject matter expert interpretation of the data. The authors of this document are responsible for the technical accuracy of the information provided. The parks refrained from providing substantive administrative review to encourage the experts to offer their opinions and ideas on management implications based on their assessments of conditions. Some authors accepted the offer to cross the science/management divide while others preferred to stay firmly grounded in the presentation of only science-based results. While the authors' interpretations of the data and ideas/opinions on management implications were desired, the results and opinions provided do not represent the policies or positions of the parks, the NPS, or the U.S. Government.

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Contents

	Page
Figures.....	iii
Scope of Analysis	1
Critical Question	1
Data sources and types used in analysis	1
Reference Conditions.....	1
Analyses	3
Methods	3
Results.....	4
Assessment.....	7
Gaps in Understanding.....	9
Recommendations for future study/research	9
Literature Cited	11

Figures

	Page
Figure 1. Glaciers in SEKI classified by Basagic (2008) as perennial ice features. Basagic identified a subset of these as “true” glaciers based on size and potential for movement.....	2
Figure 2. Individual glacier chronology maps for (a) Goddard Glacier, (b) Darwin Glacier, (c) Lilliput Glacier, and (d) Picket Glacier	3
Figure 3. The total area lost (a) and fractional area lost (b) for the 7 study glaciers over the 104-year period between 1900 and 2004.....	4
Figure 4. A comparison between fractional area glacier change (top) and seasonal climate variables (bottom) over the past century	5
Figure 5. Darwin Glacier, in Kings Canyon National Park, was photographed by G.K. Gilbert on August 14, 1908 (top)	7

Scope of Analysis

Alpine glaciers provide ecological function through their effects on the hydrologic cycle, on terrestrial and aquatic microclimate, and on nutrient cycling. Sierra Nevada glaciers represent about 10% of total glacier area in the conterminous United States (Krimmel et al. 1998). Of Sierra Nevada glaciers, 469 of 1719 glaciers (27% of number), or 10.4 km² of 39.2 km² (27% of area) are in Sequoia and Kings Canyon National Parks¹. Alpine glaciers occupy high elevation mountain cirques, typically on north and northeast aspects (Figure 1). Glaciers are located between 3,090 and 4,148 m (Raub et al. 2006).

Glaciers delay peak runoff from spring to summer, when less water is available and demand is high, modulating seasonal variations in runoff (Fountain and Tangborn 1985). This is especially important in the Mediterranean climate of California where the bulk of precipitation falls between October and May, and the summer season is dry. Alpine glaciers also release nutrients and regulate water temperatures which effect aquatic and riparian flora and fauna (Brittain and Milner 2001, Dougall 2007).

Like most alpine glaciers over the 20th century, SEKI glaciers have been receding in response to a warming climate (Oerlemans 2005), altering alpine hydrologic cycles and contributing to global sea level rise. The shrinkage of glaciers results in earlier spring runoff and drier summer conditions. So, while SEKI glaciers are important locally and represent some part of the total population of conterminous U.S. glaciers, their condition as well as their existence is severely threatened by climate change.

This chapter will summarize recent work documenting Sierra Nevada glacier area loss, quantifying glacial retreat and determining which climate and topographic factors contribute most to Sierra Nevada glacial dynamics. This is intended to be brief, and provide an overview of what is known of SEKI glaciers.

Critical Question

Are the condition and extent of SEKI glaciers decreasing, and if so what factors are most influential?

Data sources and types used in analysis

This document is a summary of Hassan Basagic's M.S. thesis (Basagic 2008), which analyzed glacier area dynamics throughout the Sierra Nevada, and detailed area dynamics of a subset of glaciers in YOSE and SEKI.

Reference Conditions

Glacial extent has been documented in the Sierra Nevada since 1904 (Gilbert 1904, Farqahar 1920, Harwell 1931, Matthes 1939, 1940, Heald 1947, Harrison 1956, YOSE 1960, Curry 1969, White 1976, Tangborn et al. 1977, Chambers 1992), although most efforts have been focused on

¹ defined by Basagic (2008) as perennial snow and ice

one or a small subset of glaciers. The only comprehensive inventory of Sierra Nevada glaciers was conducted by Raub et al. (completed in 1980, but published in 2006).

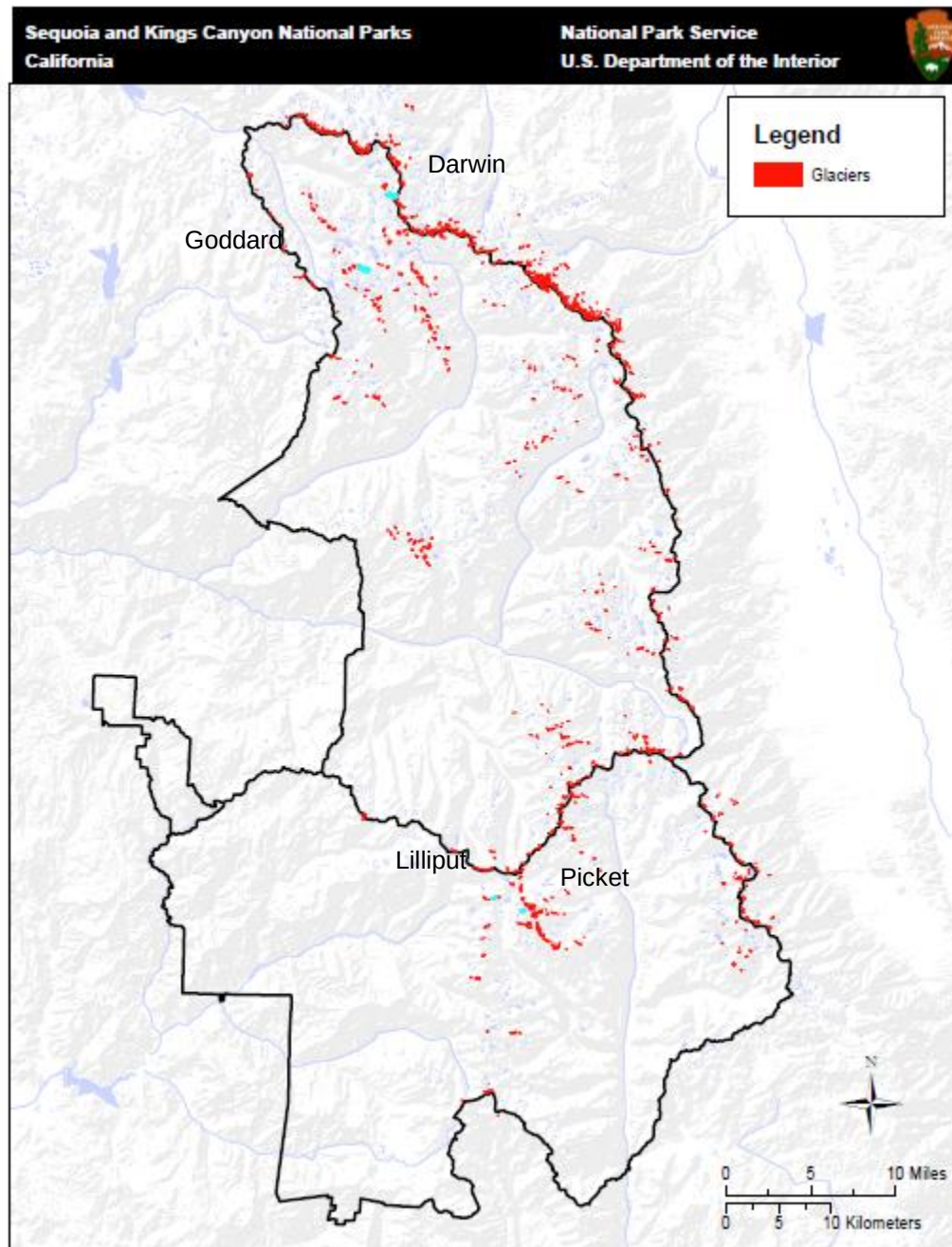


Figure 1. Glaciers in SEKI classified by Basagic (2008) as perennial ice features. Basagic identified a subset of these as “true” glaciers based on size and potential for movement. Of the true glaciers, Basagic chose 4 glaciers in SEKI for intensive study of glacial dynamics over time (highlighted in blue).

Analyses

Methods

Basagic (2008) digitally analyzed glacier area from 1:24,000 USGS topographic maps. From these maps perennial ice fields were identified, and a subset of true glaciers was determined using either of two criteria: 1) a size standard $> 0.01 \text{ km}^2$, or 2) a shear stress criteria indicating the ice moves, based on density, thickness, area and slope (Paterson 1999). For a subset of 14 true glaciers, in YOSE and SEKI,

Basagic reconstructed past and present extents using geologic evidence such as moraines, comparing historic and current photographs, and taking field measurements to quantify the magnitude of change. Seven of the 14 glaciers are in SEKI. He further estimated the rate of change for 7 study glaciers, of which 4 are in SEKI : Goddard, Darwin, Lilliput, and Picket (Figures 1, 2).

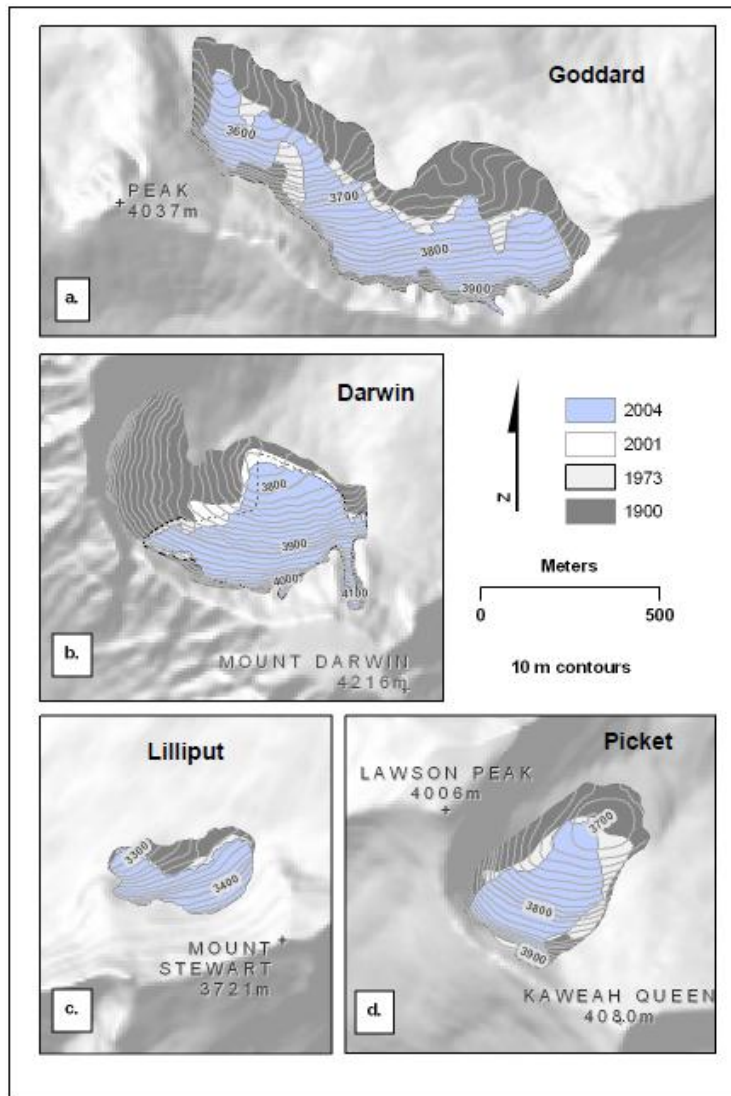


Figure 2. Individual glacier chronology maps for (a) Goddard Glacier, (b) Darwin Glacier, (c) Lilliput Glacier, and (d) Picket Glacier. The 1973 boundary of Darwin Glacier is dashed where the glacier was smaller than the recent extents.

Results

A pattern of glacier retreat – advance – retreat is evident from the past century's record (Figure 3). The time from 1850 to 1900 marks the end of the 750 year-long Little Ice Age (Grove 1988, Haeberli 1995). Since 1900, the magnitude of change for the subset of seven glaciers averaged 55% area loss, but in some glaciers was up to 78% loss (Figures 2, 3). The rate of change was categorized into four phases. In the Phase I (1900-1920) glacier area was constant. Phase II (1920-1950s) marked a rapid retreat. During Phase III (1950s-1980s) the retreat slowed and in some cases the glaciers advanced. In Phase IV (1980s onward) glaciers began retreat, and increased rates of retreat until present. The current retreat rate for the 1972 – 2004 period averaged $0.0012 \text{ km}^2/\text{yr}$. This value, if constant, indicate these glaciers will disappear in 250 years, ± 200 years (Basagic 2008).

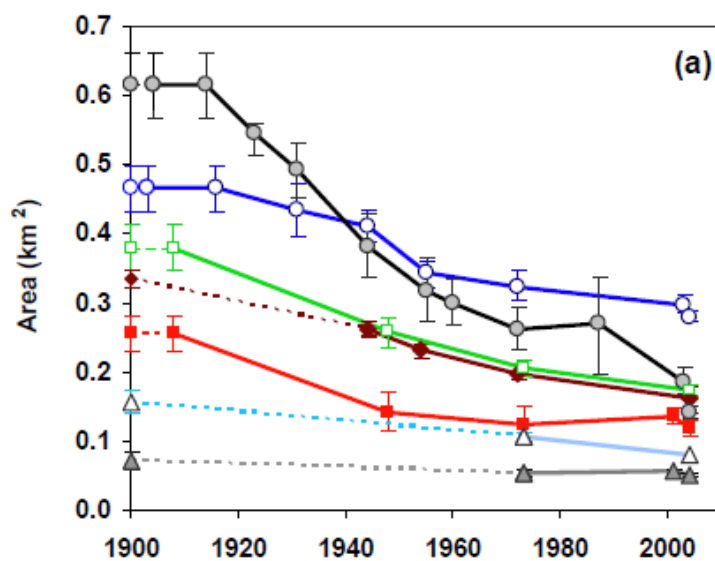
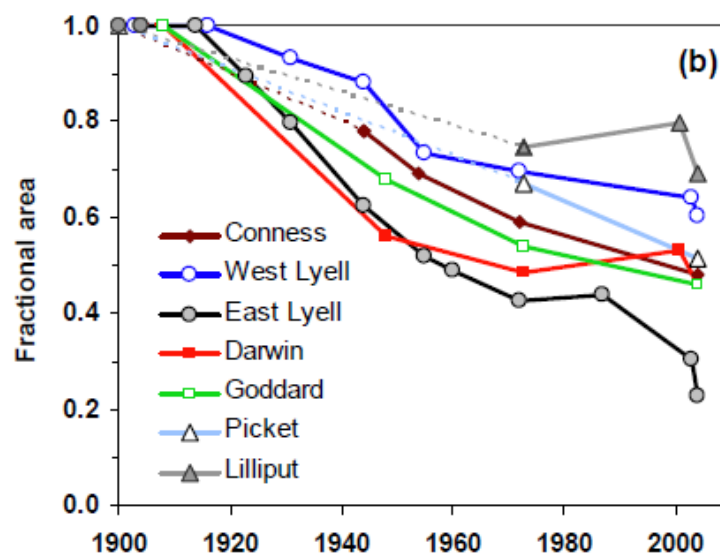


Figure 3. The total area lost (a) and fractional area lost (b) for the 7 study glaciers over the 104-year period between 1900 and 2004. Total area lost was 1.3 km^2 , or 56% of the original 1900 area of 2.3 km^2 . These data reveal rapid glacial retreat over the first half of the century, slowed retreat from late 1950s to 1980s, stabilization in the 1980s and early 1990s, before returning to a dramatic retreat in the late 1990s.



Using averages of the 7 study glaciers, Basagic reconstructed a “synthetic” average glacier that represents mean glacial dynamics through the 4 phases of glacial change. He then compared the trend in glacial extent to climatic variables from that time period and to topographic features such as slope (Figure 4).

The timing of the glacier phases appear to coincide with air temperature changes, especially winter and summer (Figure 4) and to high headwall cliffs. Winter temperatures do not directly influence ablation but may warm the snowpack such that less energy is required in the spring to warm the snowpack to melting temperatures. Glaciers with tall headwall cliffs presumably by decrease exposure to solar radiation and avalanche more winter snowfall onto the glacier surface, contributing to the mass gain and shade the surface in summer, which reduces melt.

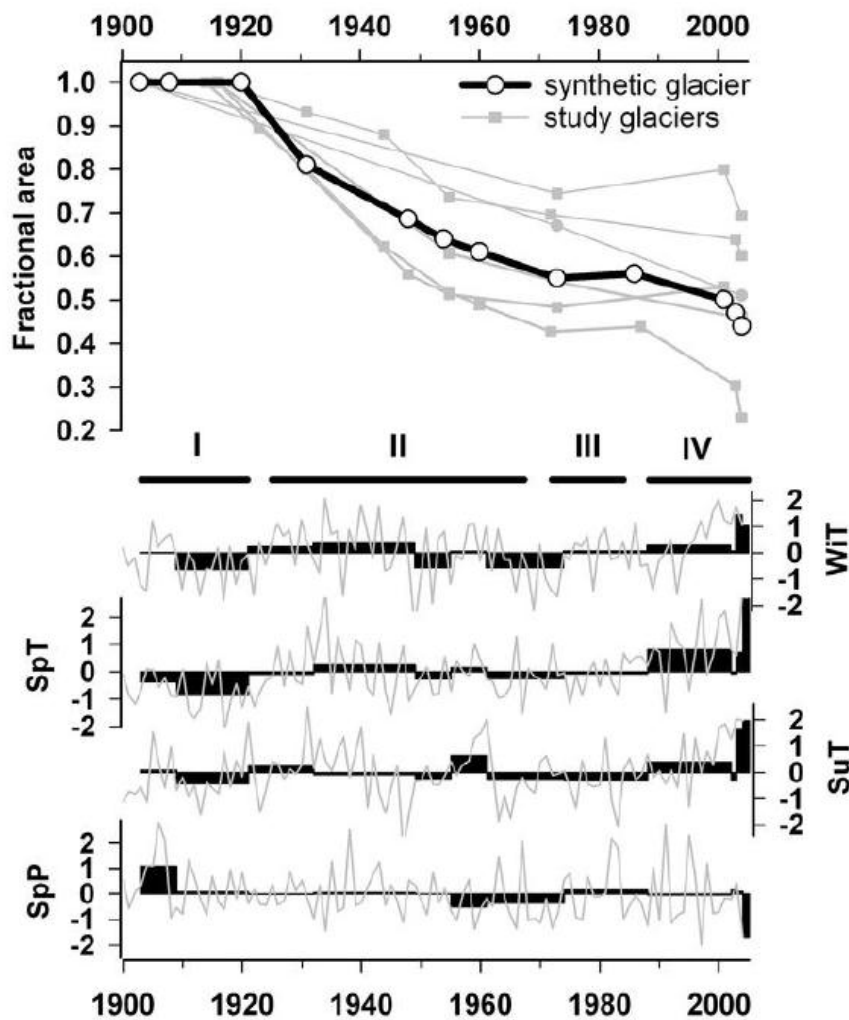


Figure 4. A comparison between fractional area glacier change (top) and seasonal climate variables (bottom) over the past century. Climate variables are normalized (light grey lines) and include winter (WiT), spring (SpT), and summer (SuT) temperatures, and spring precipitation (SpP). Black climate bars represent average conditions for time periods based on the synthetic glacier.

Assessment

The condition of alpine glaciers in Sequoia and Kings Canyon National Parks is poor relative to reference conditions in the early 1900's. Due to increasing spring temperatures, the last century has seen, on average, a 55% loss of glacier area in YOSE and SEKI, based on intensive study of a subset of 14 glaciers (see, for example, Figure 5).



Figure 5. Darwin Glacier, in Kings Canyon National Park, was photographed by G.K. Gilbert on August 14, 1908 (top). The glacier lost 54% of the original area by August 14, 2004 (middle, H. Basagic). The glacier has continued to shrink as observed on September 5, 2008 (bottom, H. Basagic).



The loss of glacier area has implications for local alpine hydrology. The glacier's ability to act as a frozen reservoir decreases with decreasing area, reducing the ability to buffer water quantity and temperature in ponds and streams, and thereby exacerbating increased summer droughts and warming (Fountain and Tangborn, 1985). Flora and fauna depend on available water resources

and have adapted to these conditions. Changes have already been documented in glacier-melt dependent systems in the Sierra Nevada including sub-alpine fir forests (Millar et al. 2004) and small mammal populations (Moritz et al. 2008).

Glaciers are a small, but locally important part of the Sierra Nevada hydroscape, which includes the extensive Sierra Nevada snowpack. In semi-arid regions like California, the loss of alpine glaciers and snowpack are among the most severe potential impacts of a warming climate for downstream human populations, because of the consequent result on water supply. Regional climate models predict as much as a 60% reduction in Sierra Nevada spring snowpack over the next 100 years, due a potential 3°C increase in regional temperature (Kim, 2001, Knowles and Cayan, 2002, Snyder et al. 2002).

Evidence for the worldwide retreat of many alpine glaciers during the past few decades has been shown from the world's major glaciated mountain ranges (UNEP 2008). Sierra Nevada glacier loss, in conjunction with other global glacial retreat, is a clear and unambiguous signal of global warming. The Intergovernmental Panel on Climate Change (2007) reports that globally, alpine glacier loss due to climate change is a serious threat to earth's human populations, especially to the more than one billion people directly dependent on water availability and hydropower potential supplied by melt water from earth's major mountain ranges (IPCC 2007).

Gaps in Understanding

Sierra Nevada glaciers lack volume change estimates. Volume measurements would quantify changes that area measurements alone miss, and could be more directly related to changes in climate. Improved high elevation estimates of precipitation inputs (timing, amount, and form) would better quantify glacier accretion terms, as the southern Sierra Nevada appear to be a zone where precipitation dominates over temperature to determine high elevation snow pack extent (Howat and Tulaczyk 2005).

Recommendations for future study/research

Increasing the number of study glaciers and interval between observations would improve statistical analyses of climate and topographic factors. The continuation of repeat photography and GPS mapping of glacier terminus is an important and cost-effective method of documenting change. Monitoring should be conducted at a minimum of every 5 years. Additionally, an updated glacier inventory is needed to fully document change throughout the entire range.

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