

Sierra Nevada Rock Glaciers: Alpine Water Reserves and Biodiversity Refugia in a Warming World

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PROBLEM STATEMENT

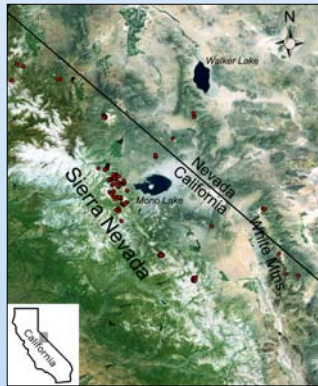
Increases in western North America temperatures have been twice the global average over the past 50 years; mountain regions experienced accelerated warming above lowland averages. The Sierra Nevada (SN), CA, lies in a Mediterranean climate where warming climates are anticipated to impose significant ecological stress on already marginal alpine habitats. For example, the American pika, *Ochotona princeps*, endemic to alpine talus slopes, is the first animal species to be petitioned for listing as endangered by climate change (CBD 2007).

SIERRA NEVADA ROCK GLACIERS AND ROCK-ICE FEATURES (RIFs)

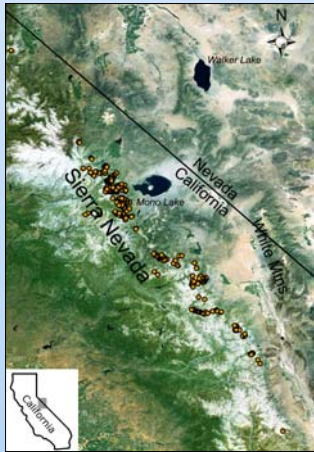
Although considerable research has documented rapid melting of glaciers, diminishing snowpacks, and earlier stream runoff, rock glaciers have been mostly overlooked. Modern and Pleistocene RIFs and their till are abundant in the high SN from the Tahoe Basin southward. Due to rock mantling and unique cold-air circulation patterns, RIFs in other parts of the world have been shown to be in disequilibrium with climate change, to lag in response to warming, and to retain permafrost more than 1000m below the regional levels. We propose that SN RIFs respond similarly to climate change and thus provide important and overlooked sources of water in alpine regions and refugial habitat for cold- and wetland-dependent alpine species.

Previously, we mapped and classified RIFs of the Sierra Nevada (Fig. 1A) into 6 categories, 3 of which are relevant here: Cirque Rock Glaciers (Fig. 2), Valley Wall Rock Glaciers (Fig. 3), and Boulder Streams (Fig. 4) (Millar and Westfall in press).

Fig. 1. A) Distribution of Rock-Ice Features (RIFs) mapped in the Sierra Nevada (Millar & Westfall in press); B) Distribution of American pika sites collected in the Sierra Nevada and W Great Basin



B. Pika



A. Rock-Ice feature



Fig. 2. Cirque Rock Glacier (RCG) in Gibbs Canyon



Fig. 3. Valley Wall Rock Glacier (RGV) in Francis Cr Canyon



Fig. 4. Boulder Stream (BSC) on the Kuna Crest

STUDY GOAL

Investigate the role of RIFs for their water-retention, wetland supporting, and biodiversity refugial values in alpine areas of the Sierra Nevada, California.

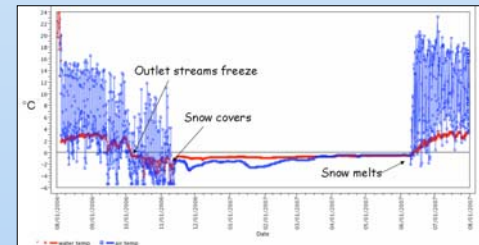


Fig. 5. Temperature curves from iButtons placed in RIF outlet stream and adjacent rock shelter (air) Analysis: J. Lundquist, UW

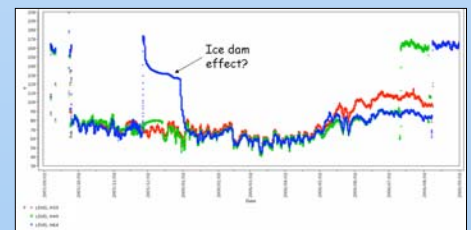


Fig. 6. Water depth curves from solinsts (Level Loggers) placed in 3 RIF outlet streams

RIFs AS PERSISTENT ALPINE WATER SOURCES

To determine whether RIF outlet streams run persistently in the warm season, we placed paired temperature mini-dataloggers (iButtons) in outlet streams near RIF snouts and in adjacent rock shelters exposed to air. We also placed solinsts (Level Loggers) in outlet streams to measure water depth.

From the data collected, we interpret the temperatures to indicate that RIF streams do not dry in the warm seasons, and persistently hold either water or ice (Fig. 5). iButton temperatures during summer and fall in the stream remained persistently low and never showed diurnal fluctuations of the air. Winter temperatures remained stably below 0°C and indicate that snow covered both streambed and air iButton locations, thermally protecting them from external air temperature fluctuations. After snowmelt, the streams again ran persistently. Similarly, RIF outlet stream water depth remained stable and persistent through the year (Fig. 6), with only a slight increase in spring and no peak run-off as is typical for non-RIF stream profiles.

RIFs SUPPORT ABUNDANT WETLAND HABITAT AND PROVIDE REFUGIA FOR PLANT SPECIES

A striking feature of Sierran RIFs is the abundant, high-quality wetland habitat below their bases (Fig. 7). Persistent water source, stable outflow, and widely distributed discharge through rocky matrices result in water retention in the cirques, allowing rich wetlands to develop. This contrasts with non-RIF canyons where water from snow- and ice melt flows rapidly down-canyon, leaving the upper cirques at best with narrow riparian strips. RIF wetland environments support Alpine Wetland, Subalpine Meadow, and Subalpine Wetland Shrub plant communities, with abundant wetland species (Tbl 1, Sawyer & Keeler-Wolf 1995). Combining field and map methods, we measured the extent of wetland habitat of 40 RIFs. Average area of wetland habitat is about twice the RIF area for all classes except BSC (Tbl 2).

As future snowpacks and soil moisture diminish, RIFs will support increasingly rare wetland habitats and provide key refugia for wetland-dependent plants.



Fig. 7. Wetlands surrounding base of late Pleistocene relict Parker Cirque Rock Glacier

RIFs AS CRITICAL HABITAT AND REFUGIA FOR AMERICAN PIKA (*OCHOTONA PRINCEPS*)

1. Distribution, RIF Association, and Elevation

Pikas are reported to be declining as temperatures rise (CBD 2007). We documented pika habitat in the SN and W Great Basin (GB) ranges during the summer 2007 as locations where we observed or heard pika or found recent sign. Sampling was opportunistic and not systematic.

We recorded 165 pika locations; 133 in the SN and 32 in the GB (Fig. 1b). All but 15 are vouchered by pellet samples. Pika locations were abundant in the SN from Carson Pass to Rock Cr and abundant in the Sweetwater, Leviathan, Bodie, Wassuk, Glass, and White Mtn ranges of the GB. Pika sites ranged in elevation from 1840m to 3770m (6036' to 12,362').

Pika sites occurred overwhelmingly on RIF environments: 85% of our sites were associated with RIFs (Fig. 8), most commonly on BSC, RGC, and RGV landforms. The remaining 15% were talus rock-slides, eroding bedrock, or anthropogenic sites.

2. Climate Relationships

We used the PRISM model (Daly et al. 1994) adjusted to 1600 m² resolution, to calculate climate of pika locations. Annual precipitation was 250-1650mm (Fig. 9). Mean minimum temperatures were -3.8°C (annual), -10.7°C (Jan), and 5.5°C (July) (Figs. 10A, 10B, 10C). Mean maximum temperatures were 8.7°C (annual), 1.1°C (Jan), and 19.2°C (July) (Figs. 11A, 11B, 11C). Minimum temperatures show truncation of the warmer values relative to an assumed equilibrium normal distribution of temperatures, suggesting extirpation of the warm sites faster than the species can adjust. Maximum temperatures, by contrast, show a wide range in nearer-normal distribution. Given that minimum, but not maximum, temperatures have been rising over the past century in this region, this pattern corroborates previous reports of pika sensitivity and response to warming.

Despite this sensitivity, minimum temperatures of pika locations have very low and non-significant correlation to elevation (Figs. 12A, 12B, 12C), while maximum temperatures have strong and significant negative correlations (Figs. 12D, 12E, 12F). This suggests that pika habitat, mostly RIFs, exists within and creates microclimates in disequilibrium with regional climatic conditions and lapse rates, a finding we have previously reported (Millar & Westfall in press).

Table 1. Plant species occurring in RIF wetland habitats

<i>Achillea millefolium</i>	<i>Lupinus</i> spp
<i>Aconitum columbianum</i>	<i>Mertensia ciliata</i>
<i>Allium validum</i>	<i>Mimulus primuloides</i>
<i>Angelica lineariloba</i>	<i>Oxyria digyna</i>
<i>Apocynum androsaemifolium</i>	<i>Pedicularis groenlandica</i>
<i>Calamagrostis breweri</i>	<i>Poa cusickii</i> ssp <i>epilis</i>
<i>Castilleja lemmonii</i>	<i>Potentilla gracilis</i>
<i>Castilleja nana</i>	<i>Salix arctica</i>
<i>Carex integra</i>	<i>Salix boothii</i>
<i>Carex spectabilis</i>	<i>Salix orestera</i>
<i>Cornus sericea</i>	<i>Salix jepsonii</i>
<i>Delphinium polycladon</i>	<i>Sambucus racemosa</i>
<i>Dodecatheon</i> spp.	<i>Senecio triangularis</i>
<i>Epilobium angustifolium</i>	<i>Sphencosadium capitellatum</i>
<i>Gentianopsis holopetalola</i>	<i>Spiraea densiflora</i>
<i>Hackelia velutina</i>	<i>Swertia radiata</i>
<i>Kalmia polifolia</i>	<i>Vaccinium caespitosum</i>
<i>Ledum glandulosum</i>	<i>Veratrum californicum</i>

Table 2. Average wetland area from 12 relict and 28 modern RIFs

Age	Class	n	R _G Area (ha)	Wetland Area (ha)
Pleistocene	RGC	12	100	252
Modern	RGC	11	10	20
	RGV	8	2	5
	BSC	9	16	10

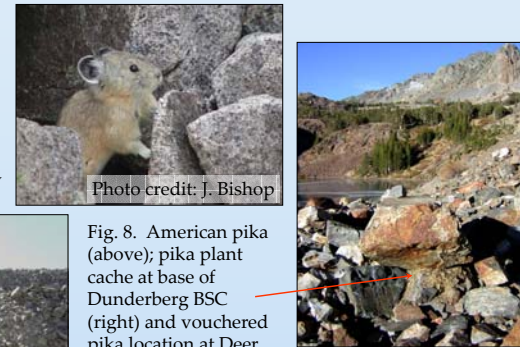


Fig. 8. American pika (above); pika plant cache at base of Dunderberg BSC (right) and vouchered pika location at Deer Lk RGC (left)

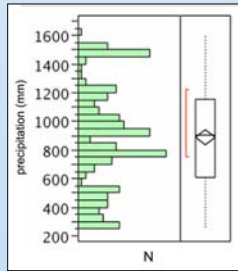


Fig. 9. Pika climate distributions from adjusted PRISM model; all locations. A) Annual precipitation.

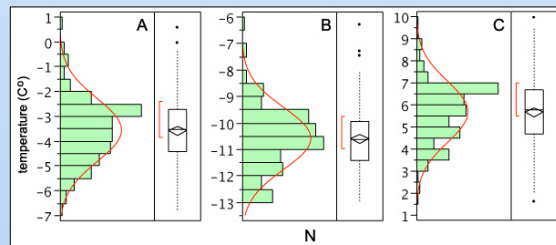


Fig. 10. Pika climate distributions from adjusted PRISM model; all locations. A) Annual minimum temperature. B) January minimum temperature. C) July minimum temperature

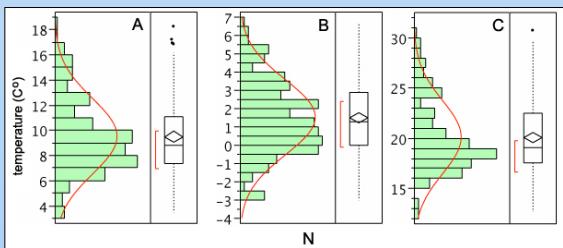


Fig. 11. Pika climate distributions from adjusted PRISM model; all locations. A) Annual maximum temperature. B) January maximum temperature. C) July maximum temperature

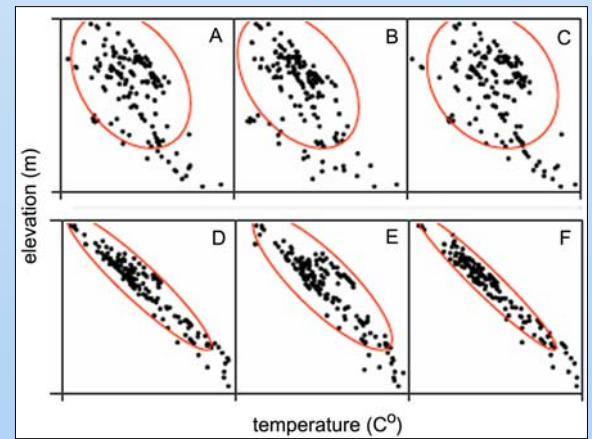


Fig. 12. Correlations of pika site elevations with temperature; all locations. Adjusted PRISM model. A) Annual minimum. B) January minimum. C) July minimum. D) annual maximum. E) January maximum. F) July maximum

3. RIFs as Refugia for Pika

We propose that RIFs provide superb habitat for the life requirements of pika, including (Fig. 13):

- * Deep, open, and extensive rock matrices that exclude soil development due to freeze-thaw processes, provide abundant subterranean conditions for pika territories, and impede penetration by predators;
- * RIF-specific air circulation that maintains cold interstitial air in summer and warm air circulation in winter (Delaloye & Lambiel 2005);
- * Persistent and diverse wetland shrub and forb habitat directly adjacent to the rock landforms with ready source of summer and winter pika dietary needs;
- * Widespread RIF distribution conducive to effective pika metapopulation structure and refugial options under future warming climates.



Fig. 13. Typical RIF illustrating features conducive to prime pika habitat

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