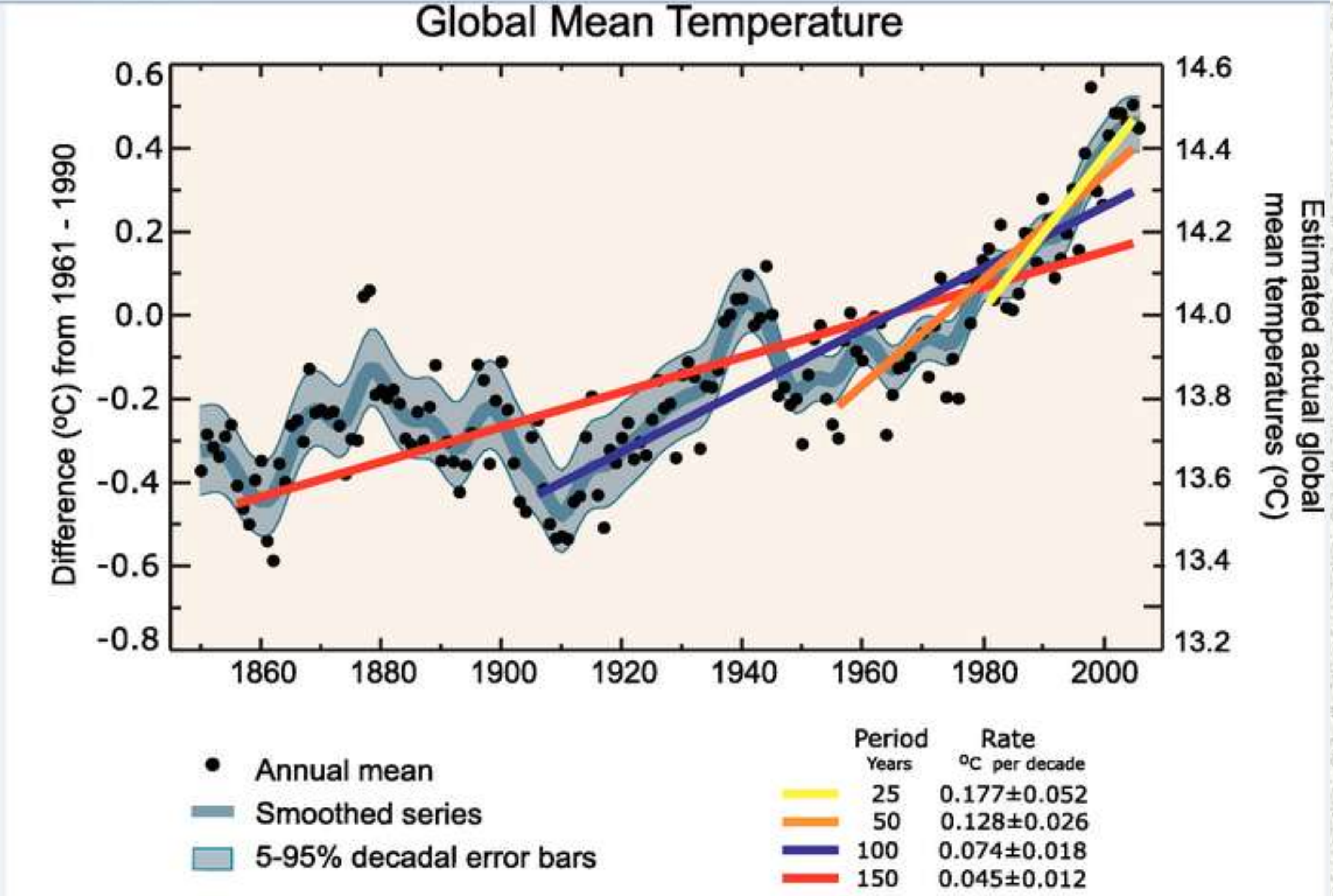
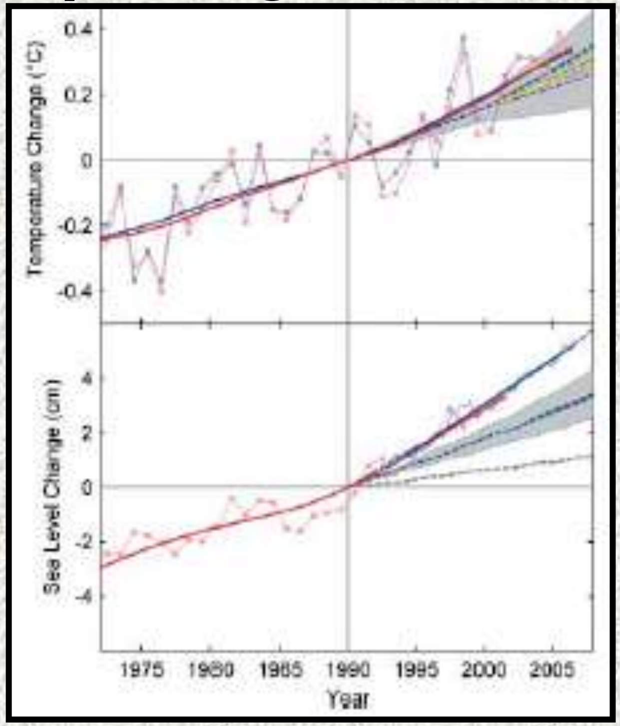


Does 'velocity' of climate change matter for wildlife?

Increasing rates of change in abiotic parameters

Temperature change
Sea-level rise

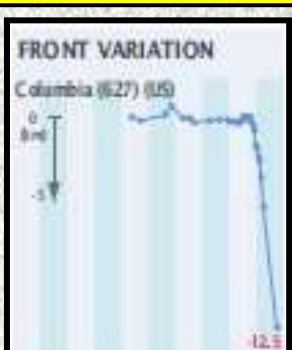
Rahmstorf et al. 2006



Glacial mass balance

UNEP-WGMS 2008

Extent of glaciers



UNEP-WGMS 2008

Changes in 1 Apr SWE

Mote et al. 2003

1930s to 1990s			1945–55 to 1990s		
Observed SWE	VIC SWE	Precip.	Observed SWE	VIC SWE	Precip.
−13.6%	+1.3%	+3.5%	−29.2%	−15.5%	−4.6%
+10.8%	+2.2%	+8.6%	−15.8%	−8.8%	+0.5%
+2.9%	−13.8%	+10.4%	−2.2%	−24.6%	−1.1%
+8.9%	−6.4%	+10.1%	−21.6%	−18.2%	+2.1%

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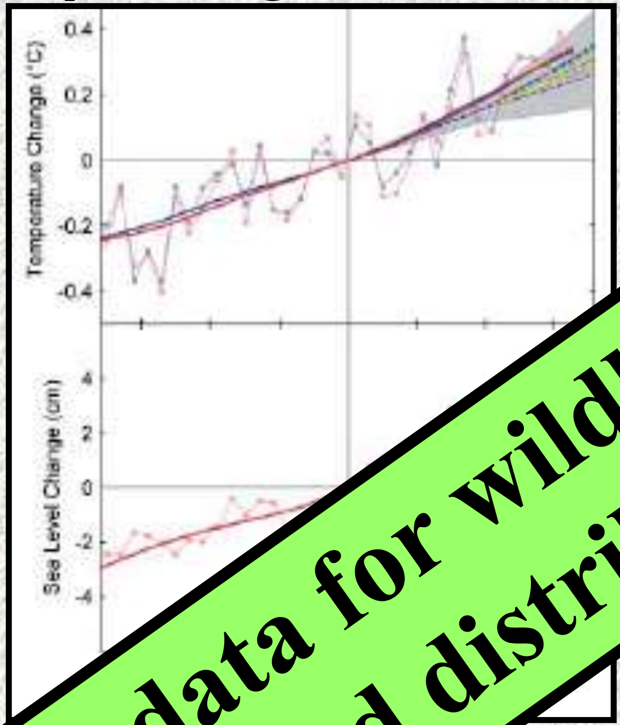

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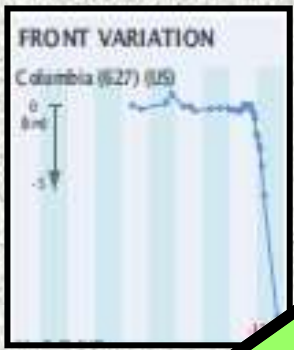

UNEP-WGMS 20

003

Changes in 1 Apr SWE

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+8.9%	−6.4%	+10.1%	−21.6%	−18.2%	+2.1%

Much fewer data for wildlife, esp. for local extinction and distributional change

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Conserving wildlife in mountain ecosystems:

importance of a broad-scale perspective

Erik A. Beever

USGS Northern Rocky Mtn. Science Center

U.S. Department of the Interior
U.S. Geological Survey

Overview: *The Big Picture*

- **Montane ecosystems and their wildlife**
- **Critical importance of mechanisms**
- **Sage-obligate phenology: birds, bugs, flowers**
- **Am. pikas (change vs. current, changing pace)**
- **New technologies, approaches**
- **Context-dependency: *it all depends …***

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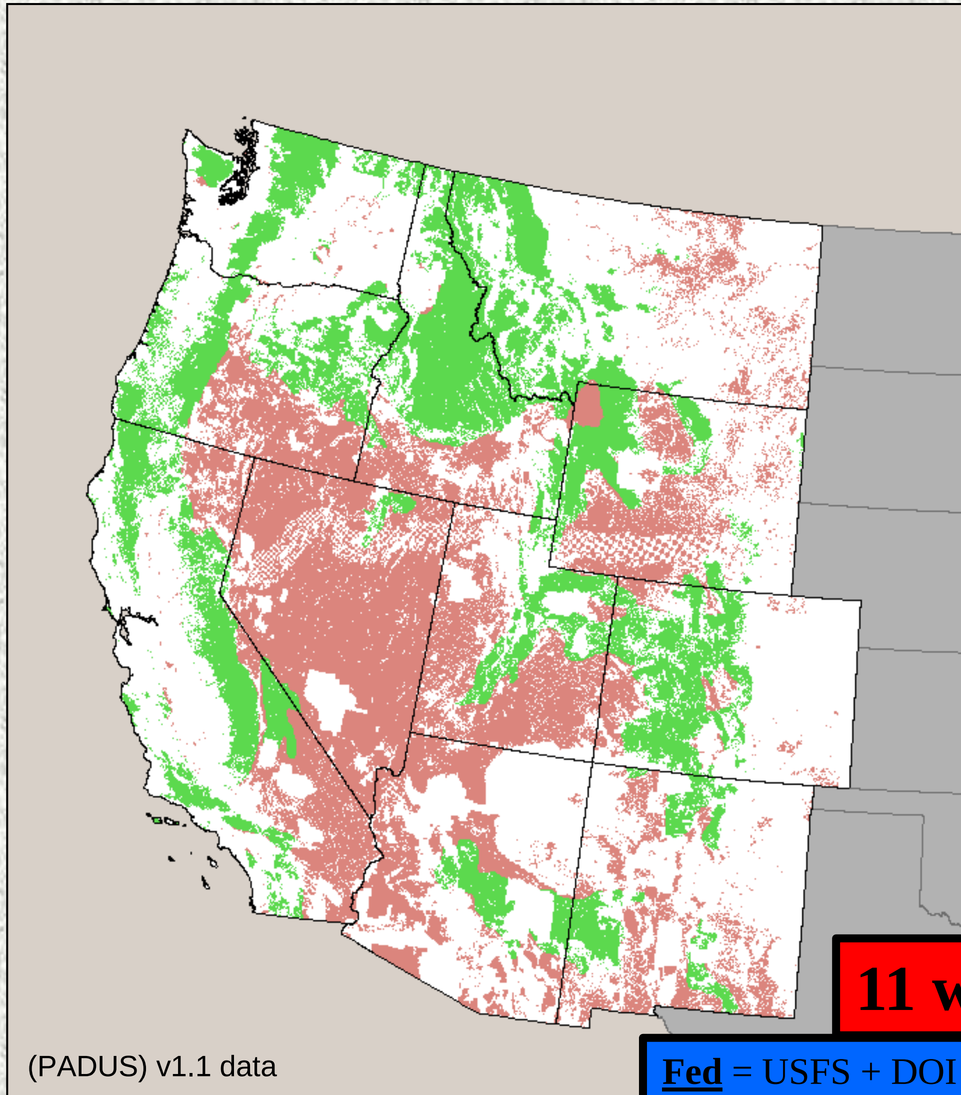
Montane ecosystems …

- ***Higher*** **PPT, % as snow, UV radiation, wind**
  - **Greater variability in climate**
- ***Lower*** **ambient T, atmosph. P, O_2**

- **Pronounced veg. zonation, fires**
- **Lower intensity & diversity of many human land uses**
- **Poorly developed soils, lower NPP, shorter growing season**
- **Higher proportion of wilderness, conservation areas**

Mountain ecosystems are disproportionately federal



Lt. green **Purple**

- **56% of mountainous landscapes are federally managed**
- **39% of non-mountainous landscapes are federally managed**

11 western U.S. states

Fed = USFS + DOI lands
Non-fed = all other lands
Mountainous = Categories C5, C6, & D3-6 from Hammond's (1970) classes of land-surface form

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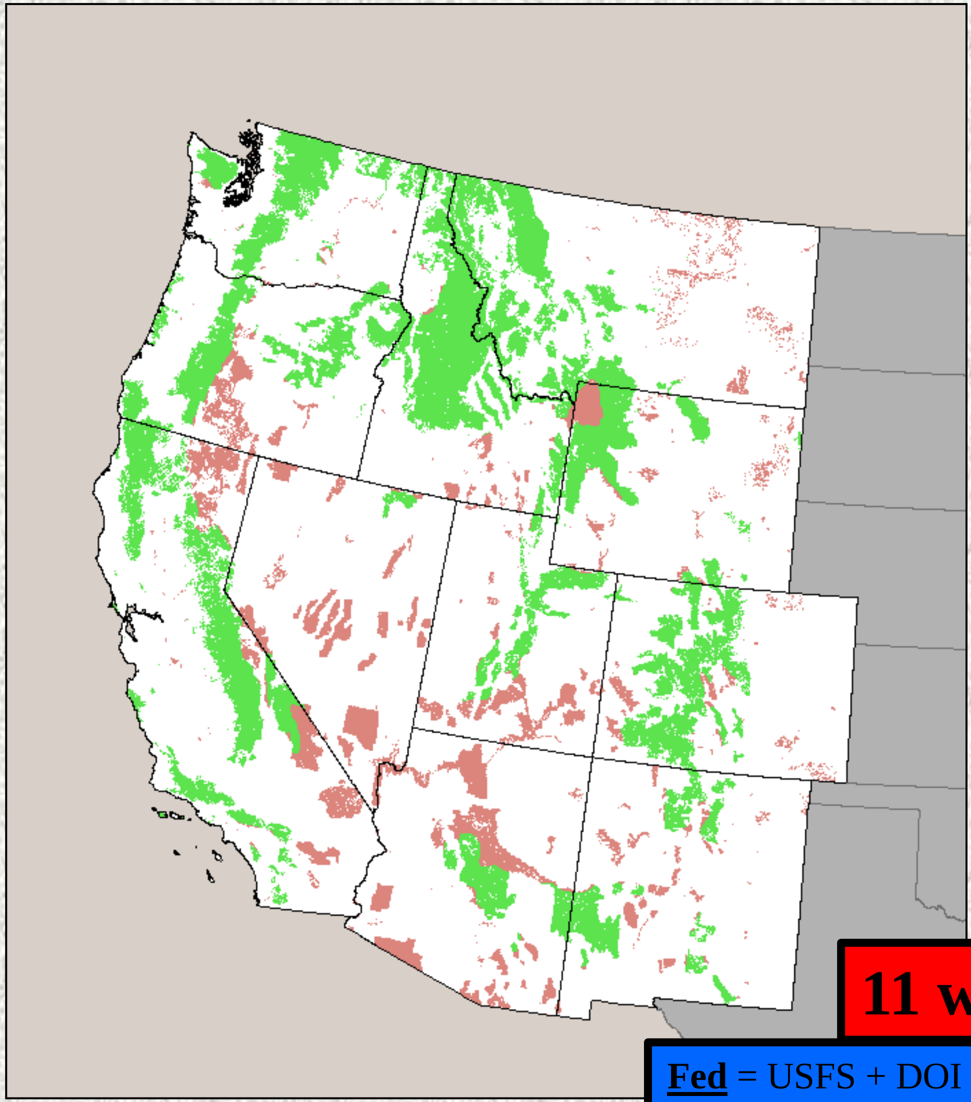
Most-protected lands are mostly mountainous



Lt. green Purple

- 72% of strictest-conservation federally managed lands are mountainous
- 9.9% of non-mountainous landscapes are federally managed under strictest conservation

11 western U.S. states

Fed = USFS + DOI lands
Non-fed = all other lands
Mountainous = Categories C5, C6, & D3-6 from Hammond's (1970) classes of land-surface form

… and their montane wildlife

- less biogeographic connection to other montane pop'ns
- high flexibility in reproduction, behavior, seasonality
- variability across latitudinal, elevational, and PPT clines
- Diverse life-history responses to harshness:
  - seasonal ranges, migration (elevational)

  - subnivean activity, year-round

  - torpor, hibernation, or estivation to over-winter

Potential mechanisms of GCC on montane spp.

- Altered food abundance
- Altered community structure
- Habitat fragmentation → species-area losses
- Exceeding (narrow) physiological tolerances
  - Acute heat stress
  - Chronic thermal stress
  - Winter cold stress (melted snow, insulation)

Potential mechanisms of GCC on montane spp.

- **Increased vulnerability to crepuscular/nocturnal predators**

- **Increased susceptibility to disease, pests, parasites**
- **Altered snow/ice cover, precipitation, streamflow, humidity, soil moisture, insolation**
  - **Increased water stress**
- **Mtn. ecosystems & their climates & wildlife are poorly understood**

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Phenological mismatches for migr. birds

- Red Rock Lakes NWR – establ. 1935, for trumpeter swans and migratory birds
- on W edge of GYE; long history w/humans
- 66% wilderness; elevations 1,900 - 3,100 m

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Phenology: *the stage & actors*

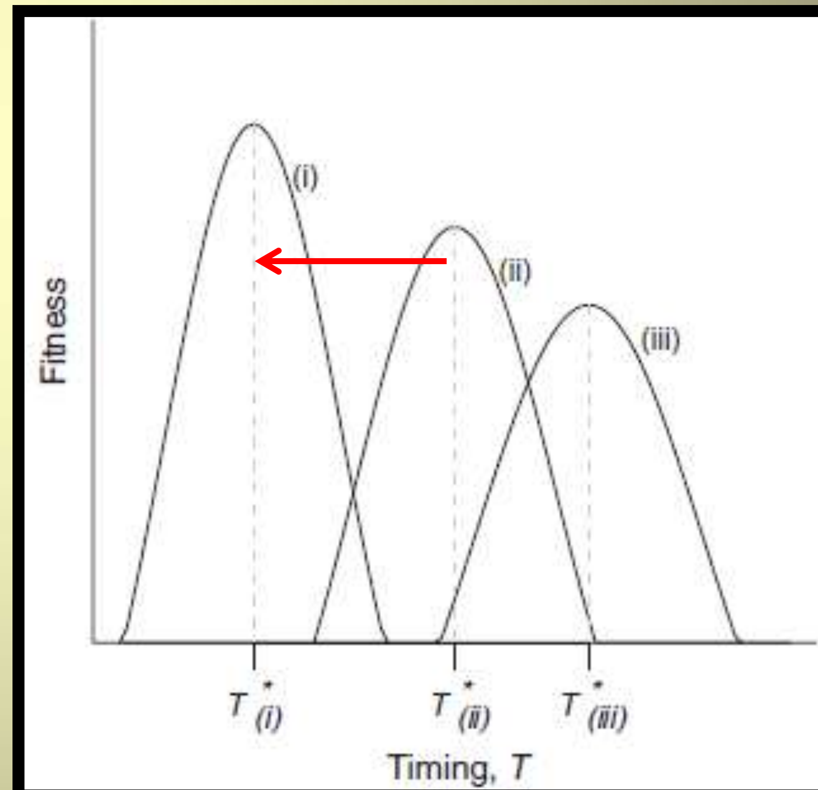
- **Migratory passerines eat plants, insects**
- **Encompass elevational gradients (space-t)**
- **Pre- and post-breeding**
- **Birds, bugs, plants, climate**
- **Energetics affect fecundity**

<u>Vesper sparrow</u>
Broadly distributed
<10% decline, last 10 yrs
1 ssp. Of Concern

<u>Brewer's sparrow</u>
Sage-obligate
Significant ↓, last 10-20 yrs
S2 – S5; of cons. interest

What is phenological mismatch?

- Migration timing ⟶ day length
- Insect emergence ⟶ degree-days
- Birds arrive after insect emergence passed
- Climate has warmed



Phenology: *objectives*

- Identify absolute & relative timing of bird arrival, insect emergence, & plant flowering;
- Characterize the shape of the temporal change in these events throughout the snow-free season;
- Compare above across areas experiencing different magnitudes of climate change;
- Quantify fitness consequences of birds consuming plants vs. insects;
- Compare mismatch in specialist vs. a more-generalist bird species

Phenology: *results to date*

- **Seasonal changes in body mass differed between spp.**
- **In Brewer's sparrows, mass declined on recently grazed areas, slightly increased on areas w/ 7 yrs rest**

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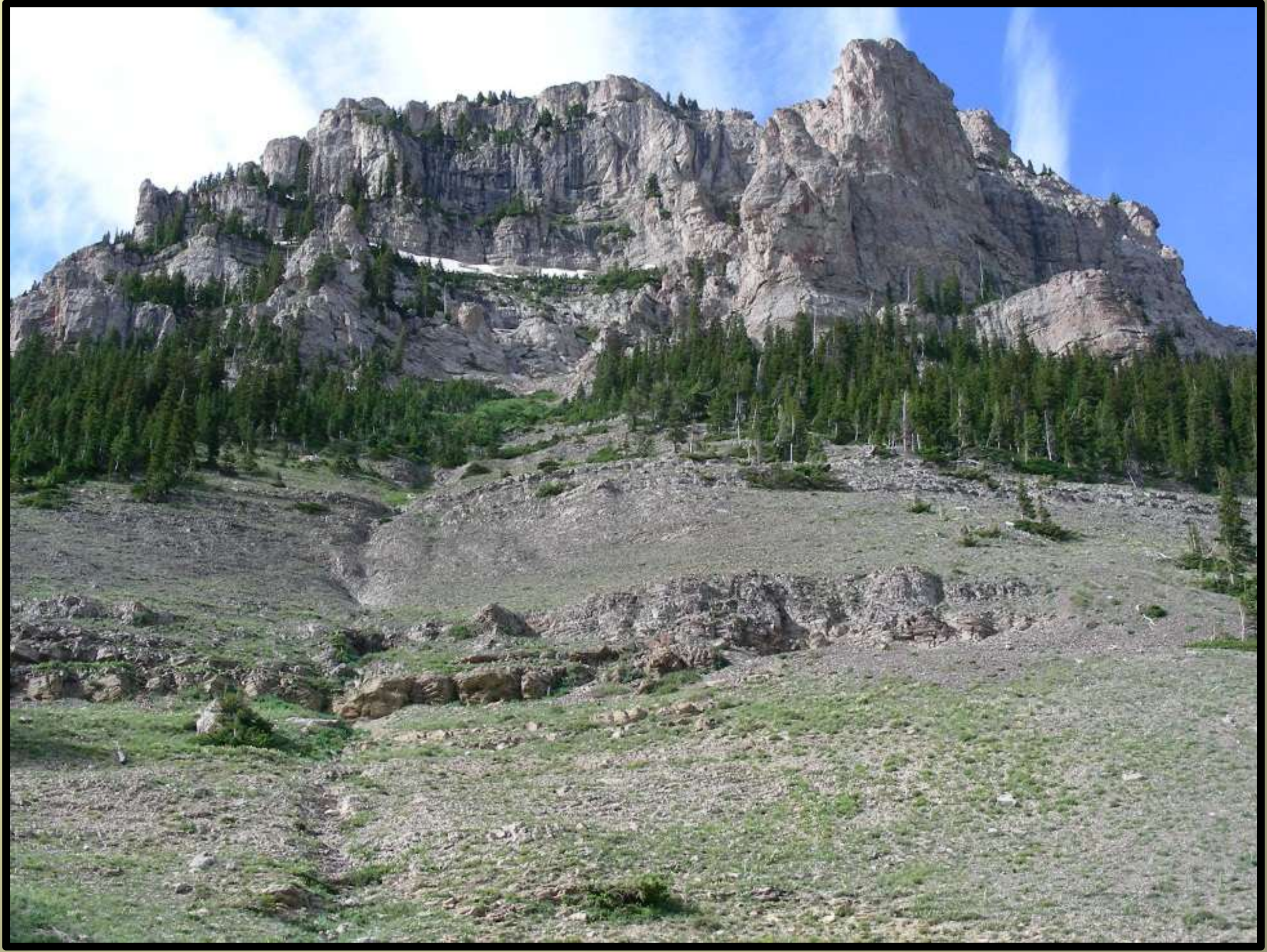
Phenology: *results to date*

- **Seasonal changes in insect abundance differed between size classes**



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Phenology: *results to date*

- Territorial males captured from arrival through pre-breeding & egg-laying periods
- Declines in insect contribution to diet throughout season
- Decline sharper in Brewer’s sparrows

Phenology: *collaborators*

- **Red Rock Lakes NWR**
- **The Nature Conservancy**
- **Montana Fish, Wildlife, and Parks**
- **University of California, Santa Cruz**
- **University of Montana-Western**
- **University of Rhode Island**
- **U.S. Geological Survey**

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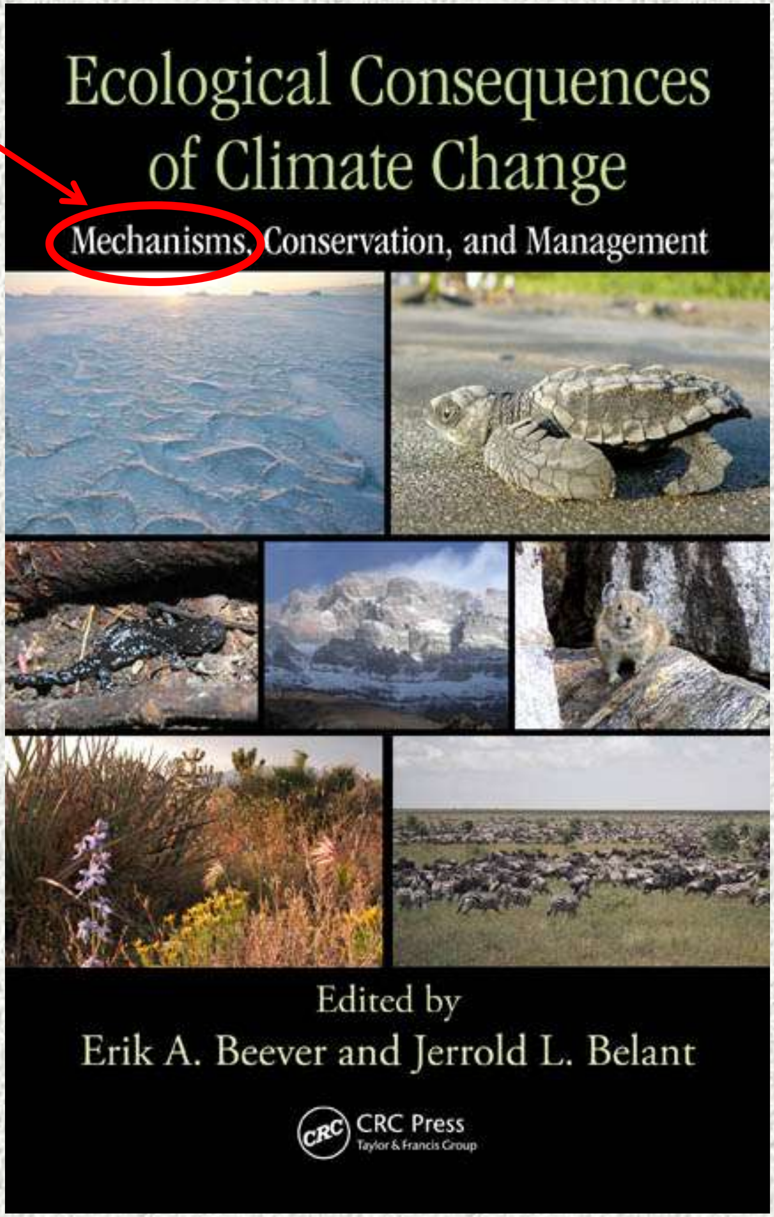
Mechanisms are *very* important !

- **Help understand *why* and *how* behind who, where, what**

- **Essential for adaptation, mitigation mgmt & conservation strategies**



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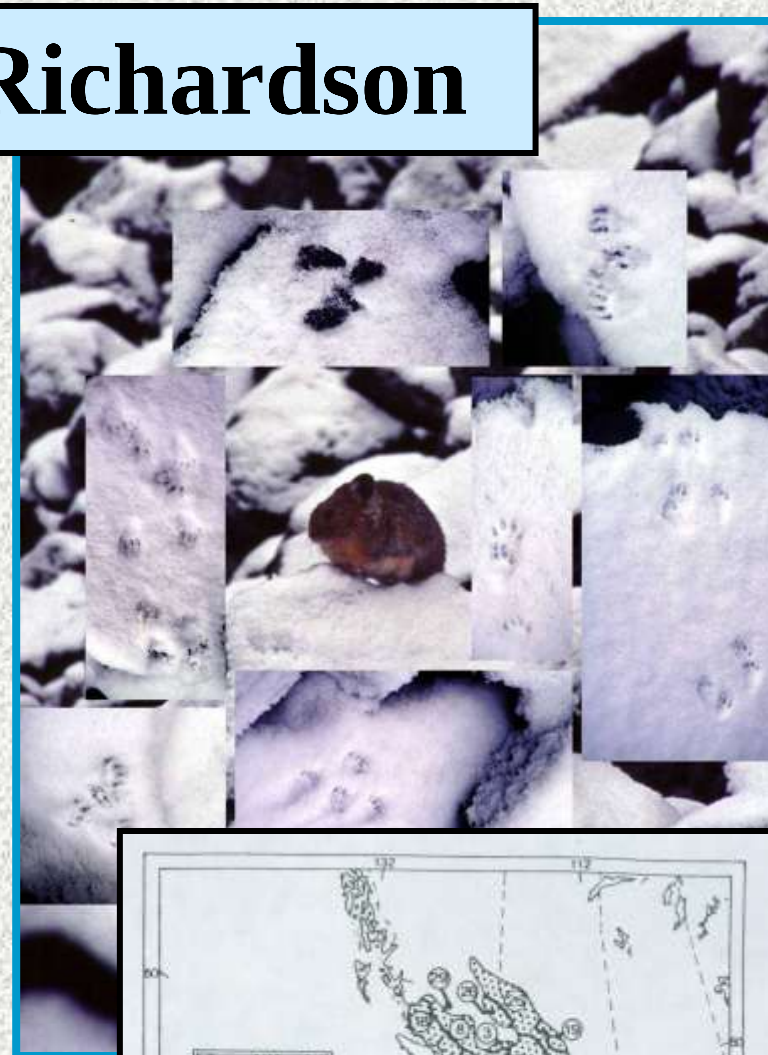
Ochotona princeps Richardson

- **Coprophagous** (to conserve H_2O)
- **Territorial** (cheek-gland rubbing)
- Broad repertoire of **vocalizations** (7)
- **Active** year-round (rare for montane)
- Inhabit **only talus** and talus-like areas
- **Don't move** very far → radiation



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Pikas as model sp. for ecological-niche testing

- Locally abundant; rare 4 mammals
- Relatively stable population sizes
- Highly detectable (haypiles, calls)
  - Monitoring, research are less expensive
- Easily defined habitat, NOT changing over time
  - losses ***not*** confounded by habitat change
- HSTal records & 15 yrs of recent data indicate a changing distribution

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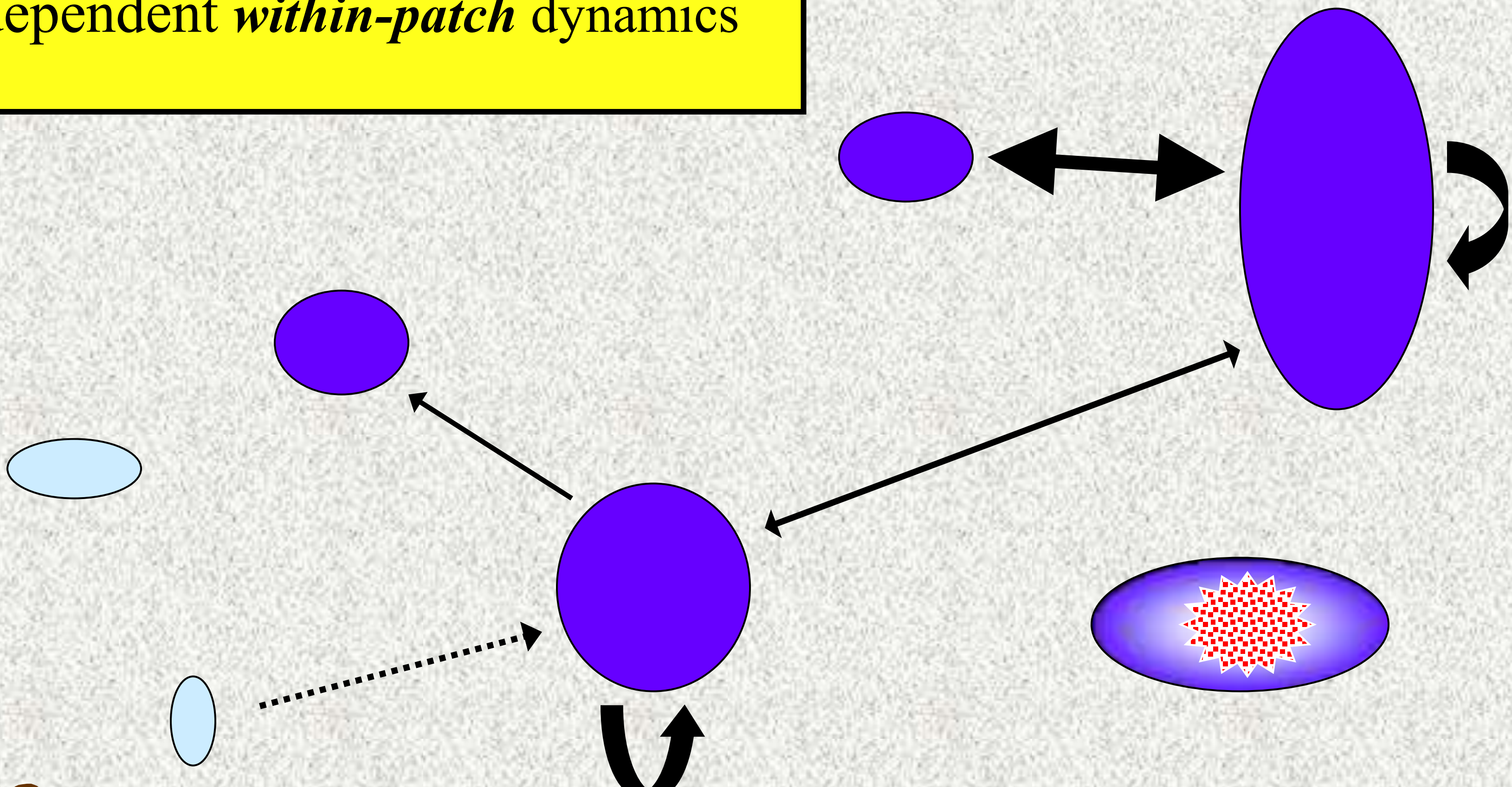
Dynamics of metapopulations

- Extinction-colonization dynamics
- Low dispersal frequency
- Independent ***within-patch*** dynamics



Questions ⇒ Hypotheses

- **Have there been any distributional changes since historical specimen records?**
- **What combination of factors was responsible for changes (if any)?**
- **Did the pace and drivers of losses differ between 20th Century and last decade?**
- **Across broad domains, is pattern of site-level losses best predicted by magnitude of change in climatic attributes, or by relative status of climatic attributes?**

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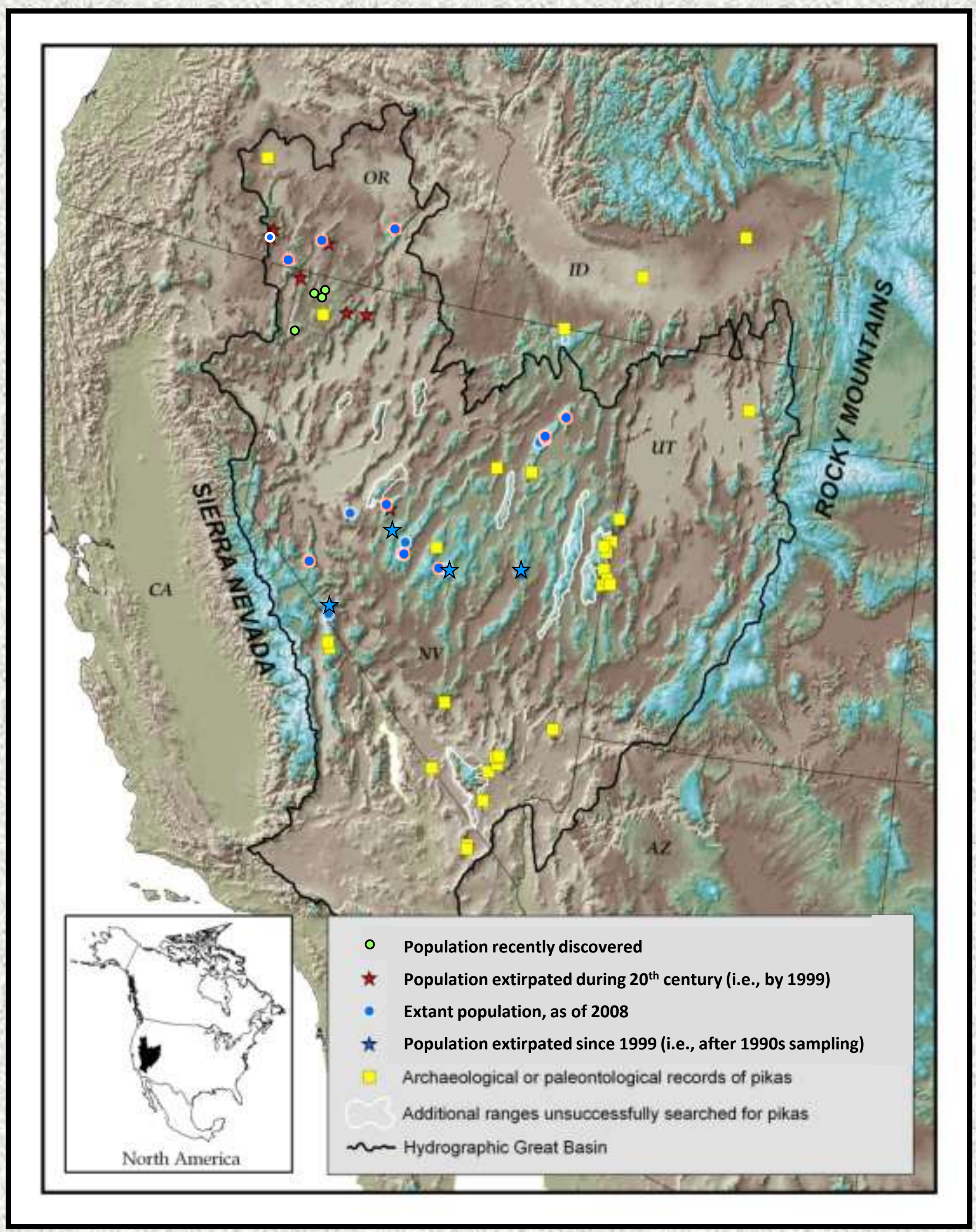

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Study sites

within the Great Basin

(blue areas: >2,286 m)

3 periods of sampling

Historic	**1898-1956**
Recent_1	**1994-1999**
Recent_2	**2003-2008**

Pika evidences

Sighting

Call (AKA 'vocalization')

Active haypile, sighting

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Pika industry

Old evidences of pikas

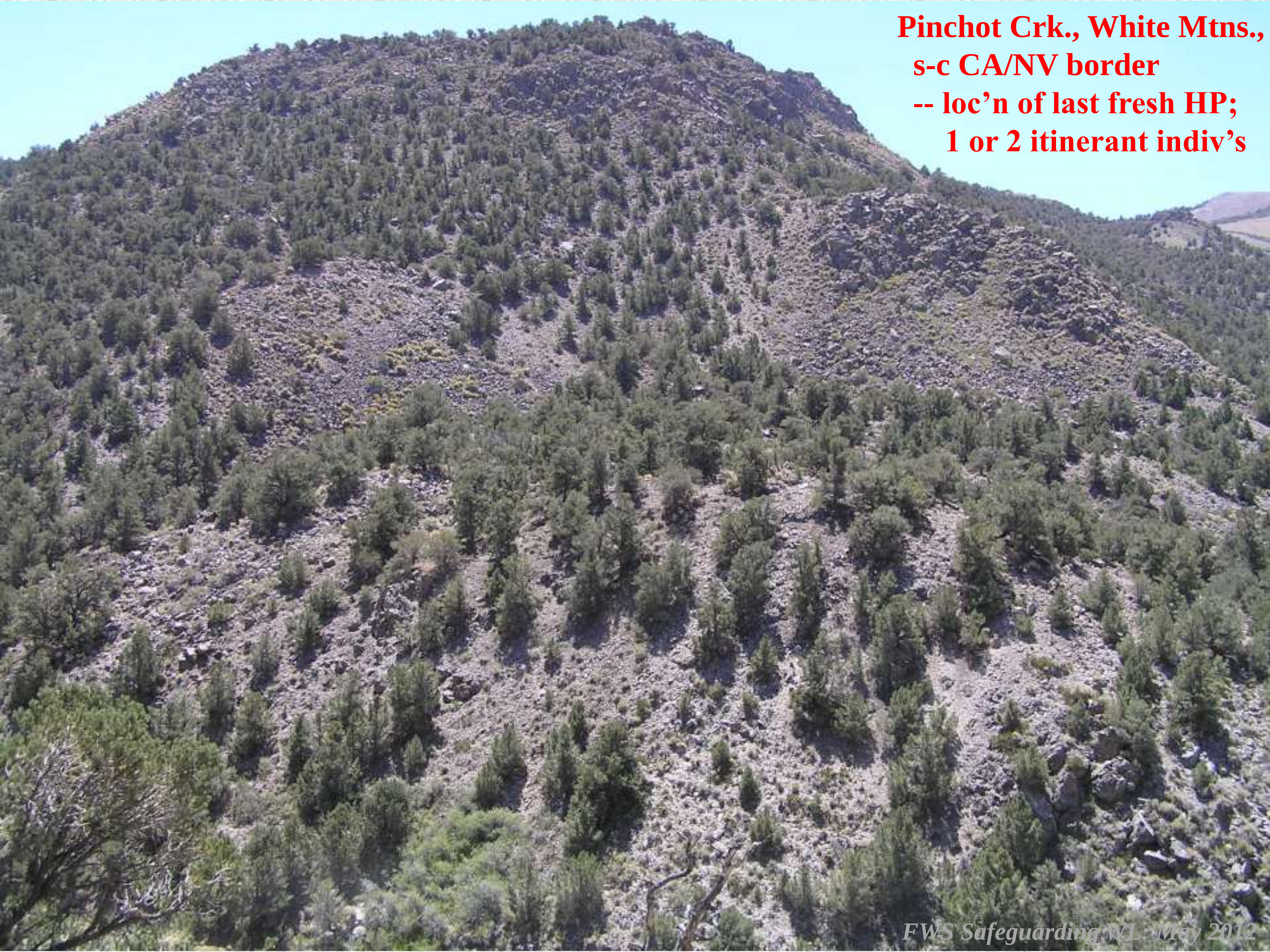
Feces: dry

Old haypiles

Feces: moist

Three Lks. (Lamoille Cnyn), Ruby Mtns., ne NV
(classic pika habitat)

Long Cnyn, Ruby Mtns., ne NV
(pikas remain at site, but lowest taluses unoccupied)


Pinchot Crk., White Mtns.,
s-c CA/NV border
-- loc'n of last fresh HP;
1 or 2 itinerant indiv's
FWS Safeguarding WL: May 2012


Greenmonster Cnyn., Monitor Range, central NV
last stronghold within site; loc'n of type specimen
FWS Safeguarding WL: May 2012

Peterson Crk., Shoshone Range, central NV
(recent local extinction; multi-scale patchiness of talus habitat)

Anatomy of a decline: *persistence*

- **6 local extinctions from historic to end of my 1st sampling (once every 10.7 yrs)**
- **4 add'l local extinctions from 1st to end of my 2nd sampling (once every 2.2 yrs)**
- **Old evidences**

3 periods of sampling

Historic	1898-1956
Recent_1	1994-1999
Recent_2	2003-2008

***N* = 25 historical locations**

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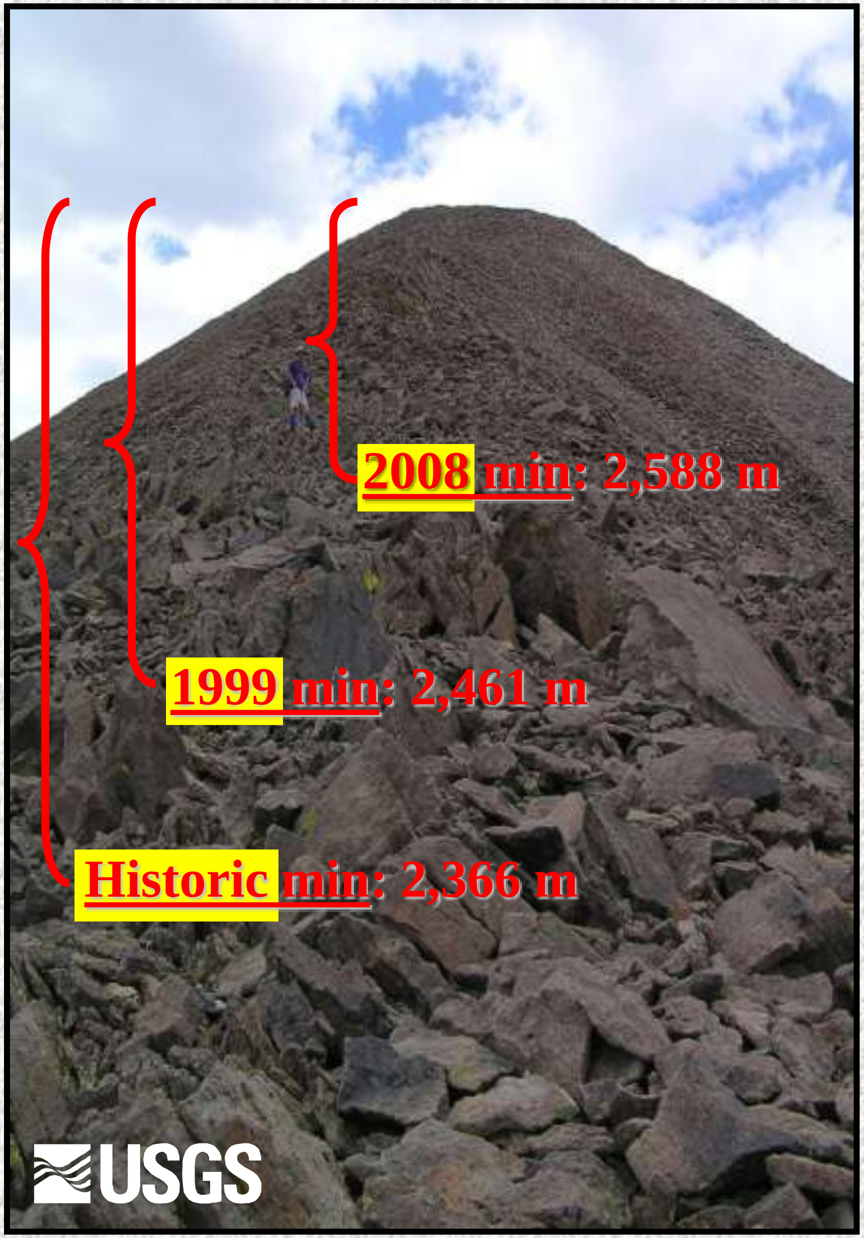
Anatomy of a decline: *upslope migrations*



- **Minimum elevation of detections, Historic to my first (1990s) sampling: 13.2 m per decade**
- **Minimum elev. of detections, 1st to 2nd sampling: 145.1 m per decade**
  - **Parmesan & Yohe (2003) meta-analysis: 6.1 m per decade**
- **No Δ in max, mean, or median elev, at most sites**
- **At lower-elevation margins, apparent: a) loss of animals on S-facing slopes, and b) reduced animal densities**

Other species are shifting, too …

- **Observed across diverse taxa**

Evidence from Single Species Studies for Upward Shifts in Elevational Distributions Linked to Climate Change

Species and Evidence for Range Shift	Location (Lat°)	References
Extinction of Low Elevation Historical Populations		
Euphydryas editha (butterfly)	Western North America (30–53N)	Parmesan 1996, 2005
Ochotona princeps (pika)	Western USA (38–43N)	Beever et al. 2003
Ovis canadensis (sheep)	California, USA (33–38N)	Epps et al. 2004
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Upper Elevation Expansion		
Thaumetopoea pityocampa (moth)	Italy (46N)	Battisti et al. 2005, 2006
Changes to Elevational Distribution/Abundance Patterns		
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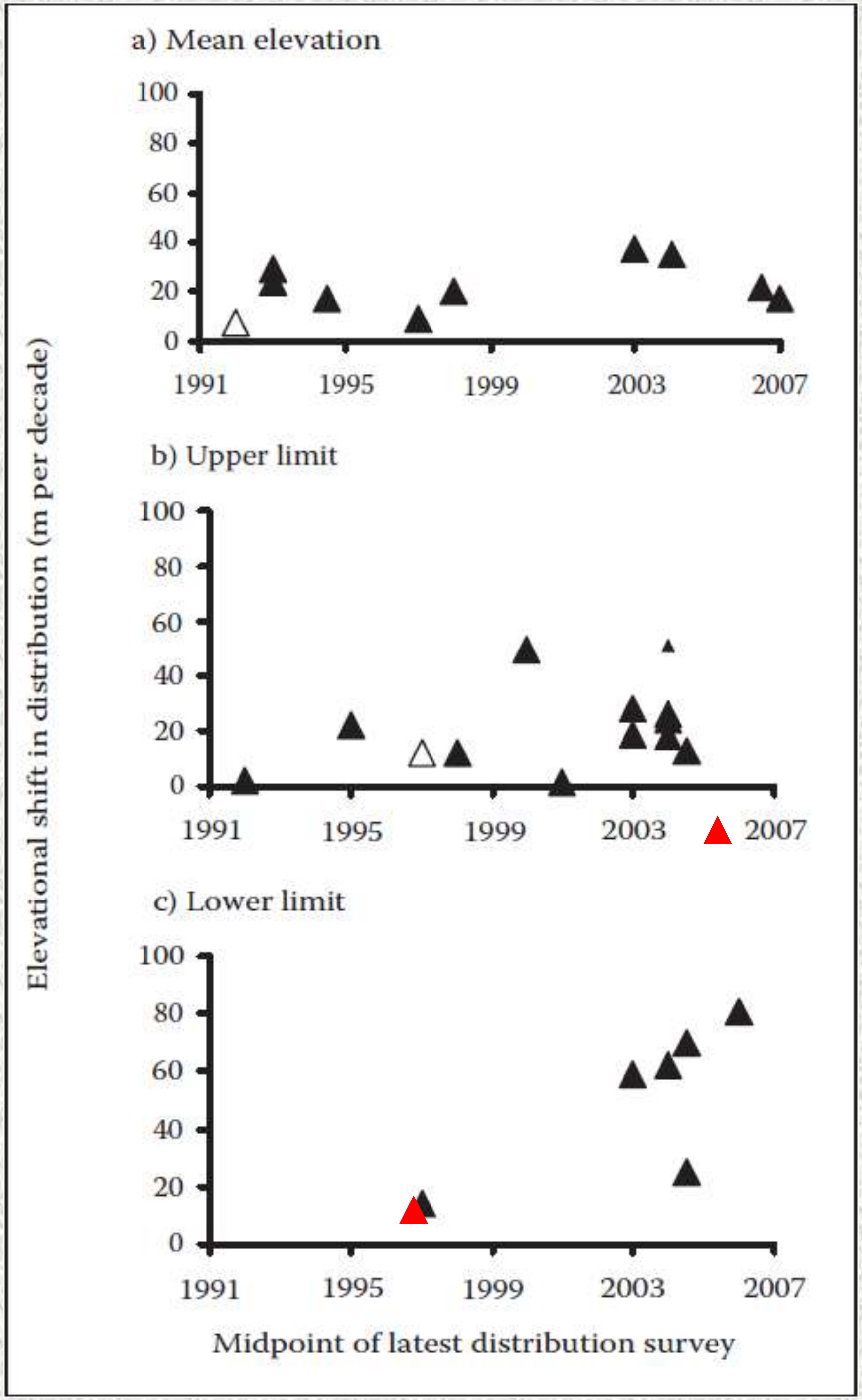

Wilson & Gutiérrez 2012

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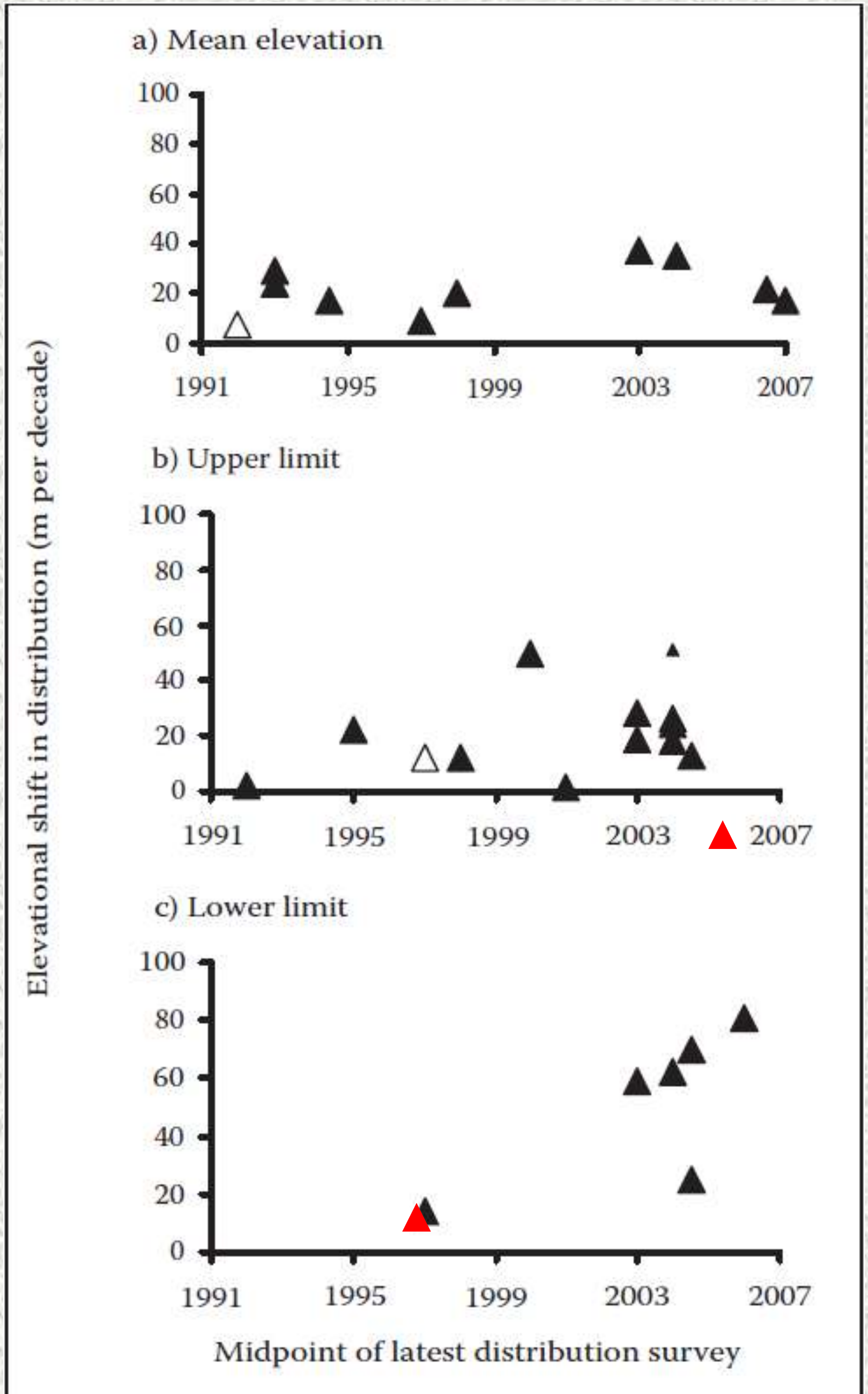

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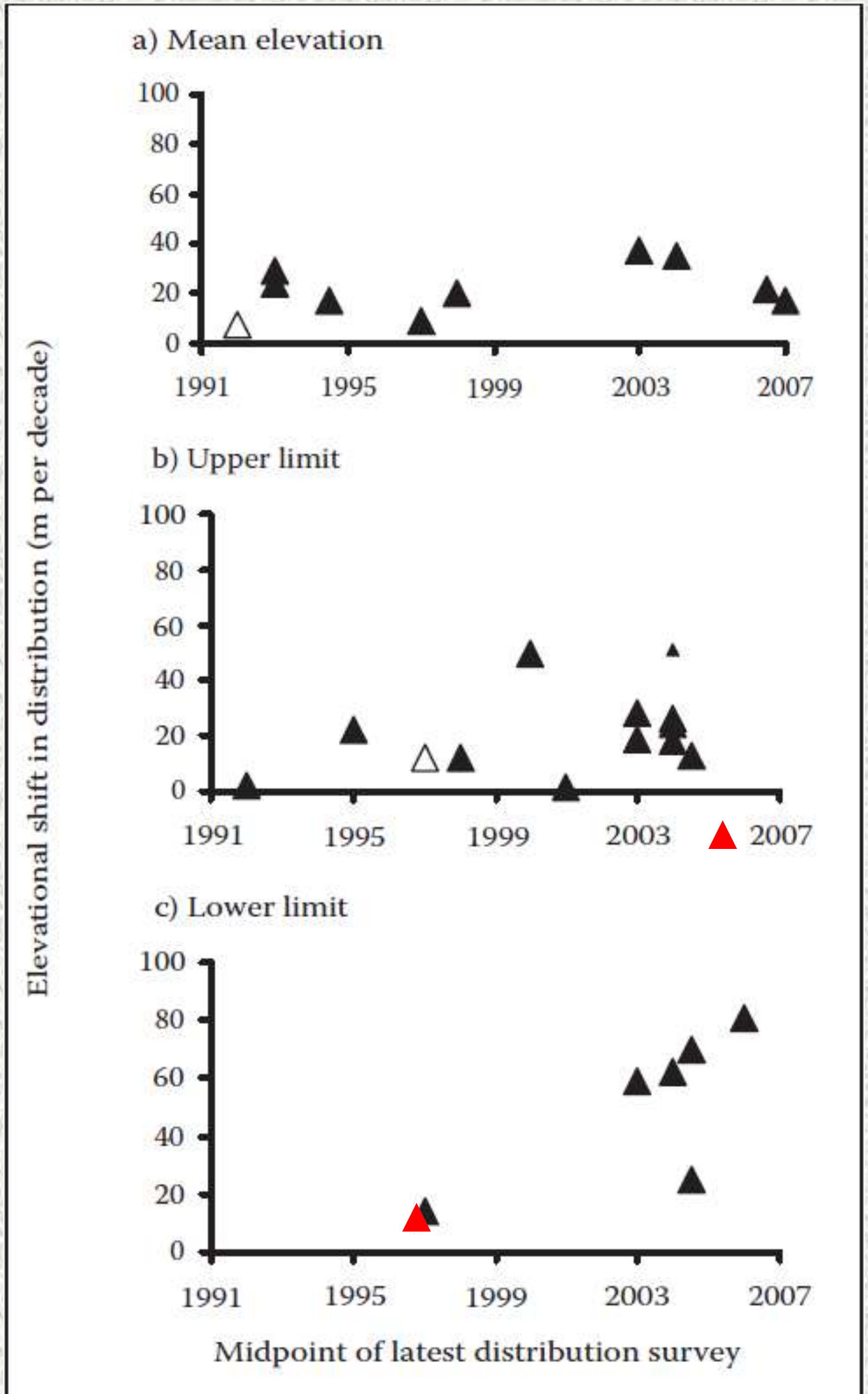

Wilson & Gutiérrez 2012

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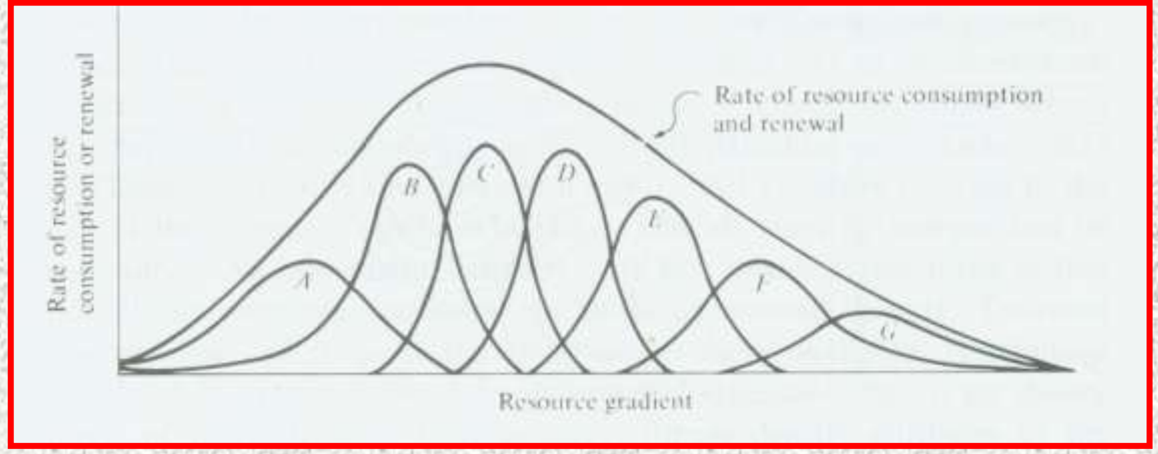
Ecological-niche models

- **Forecasting future responses to climate change**
- **Relate to niche concept**
  - **Most assume niches are conserved**



- **Many sources of uncertainty**
- **Often rely on *coarse-scale* data, analysis**
- **Frequently *presence-only* data, modeling**

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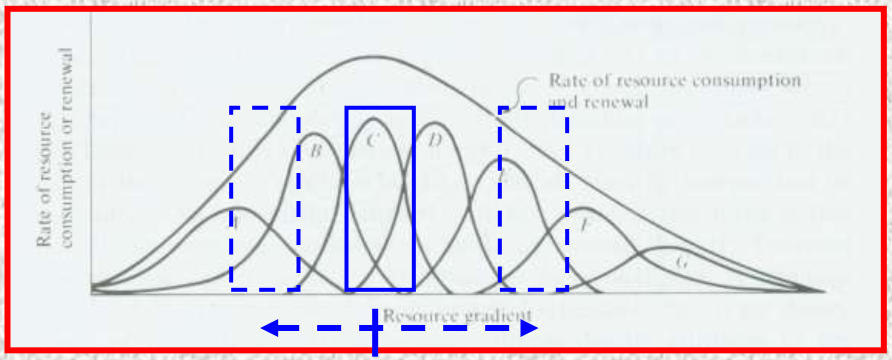
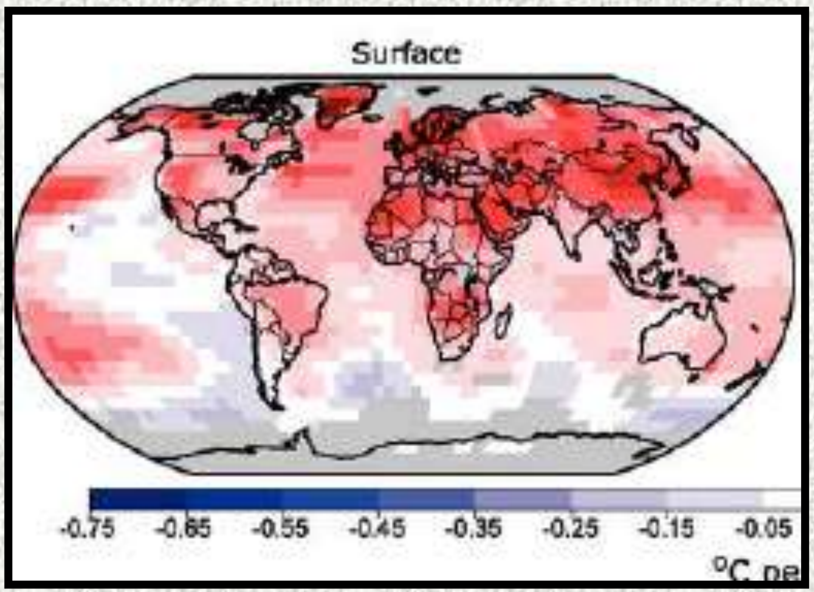
Modeling changes in species distributions

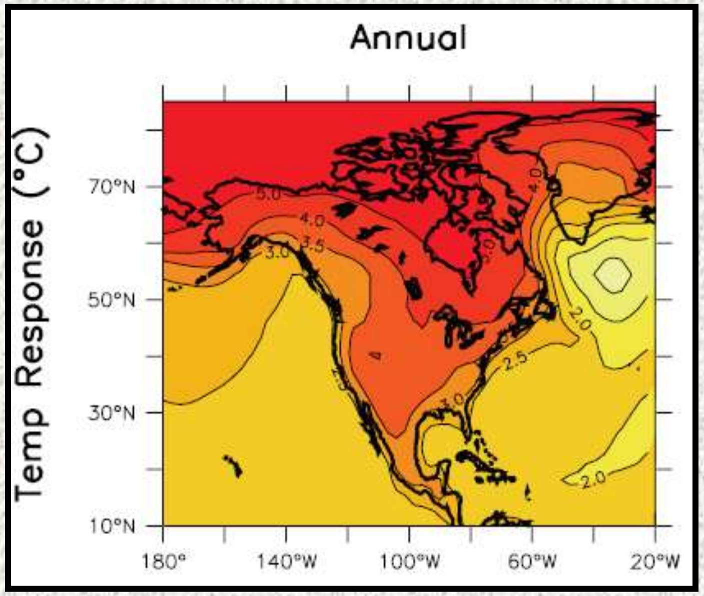
- **Observed evol'n in thermal performance**
- **Sufficient genetic diversity for local adapt'n**
- **Pika extirpations latitudinally distributed**

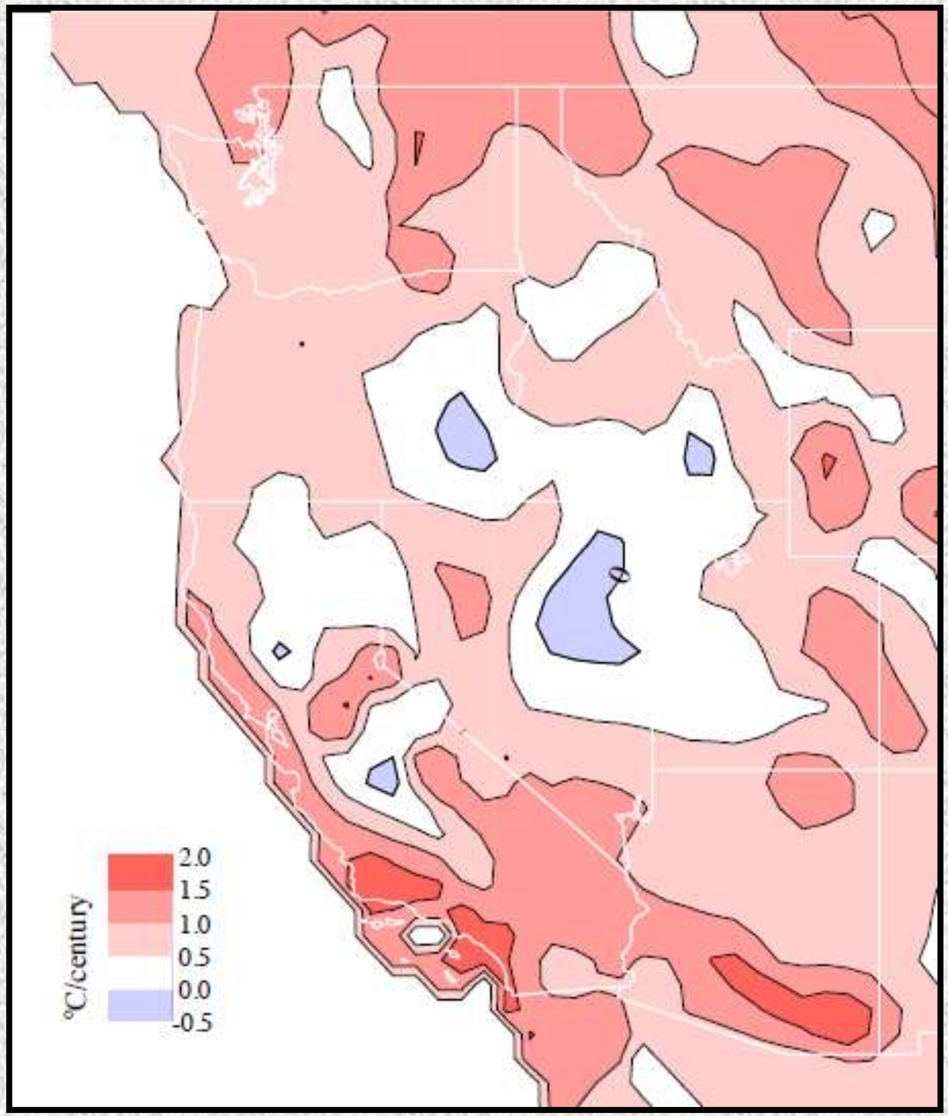
Local adaptation: Losses determined by ***how much climate has changed***



Modeling changes in species distributions: *spatial heterogeneity in amount of climate changes*







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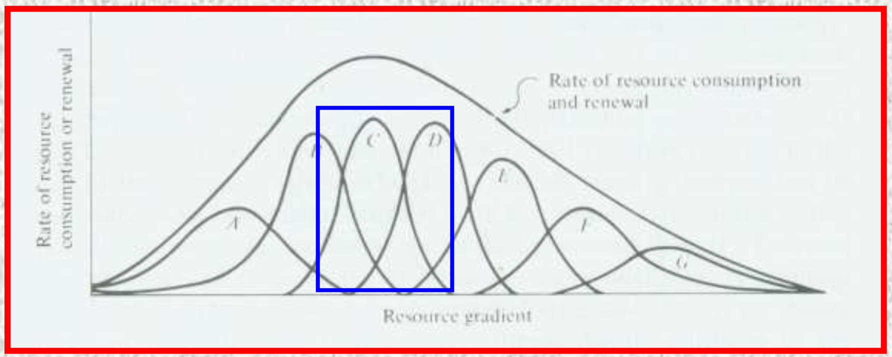
- **Observed evolution in thermal performance**
- **Sufficient genetic diversity for local adaptation**
- **Pika extirpations latitudinally distributed**
- ***HOWEVER …***

Modeling changes in species distributions

- Observed evol'n in thermal performance
- Sufficient genetic diversity for local adapt'n
- Pika extirpations latitudinally distributed
- ***HOWEVER …***



- **Most species' losses at S. edge of range**
- **Rate of climatic change has been RAPID**
- **Energetic, physiological constraints**

Fixed-dimensions niche: Losses determined by *proximity to edge of bio-climatic niche* (i.e., relative status of climate)

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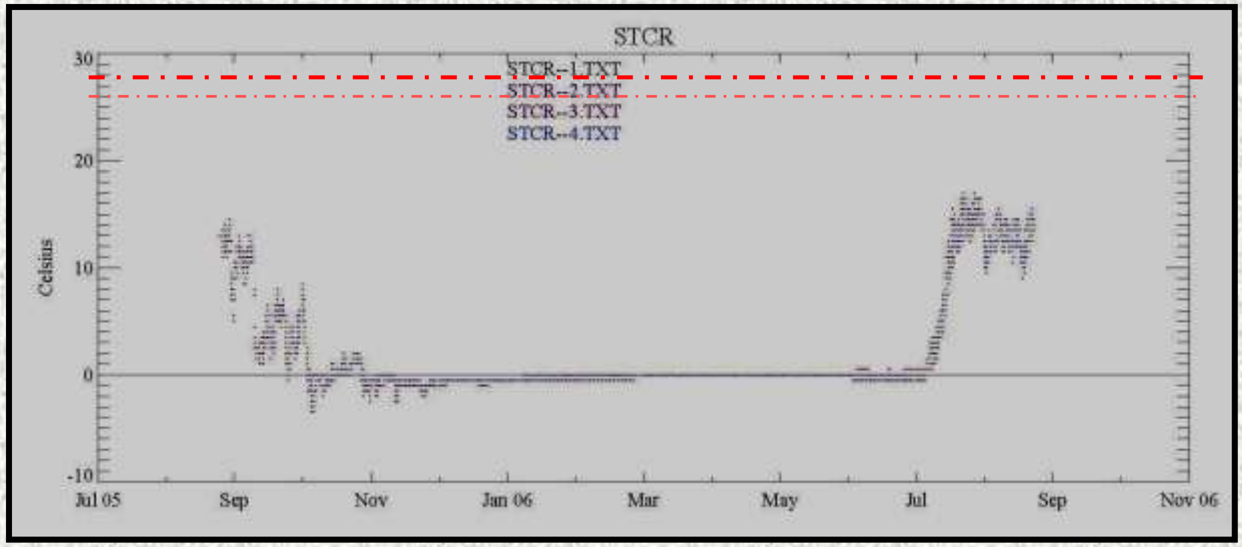
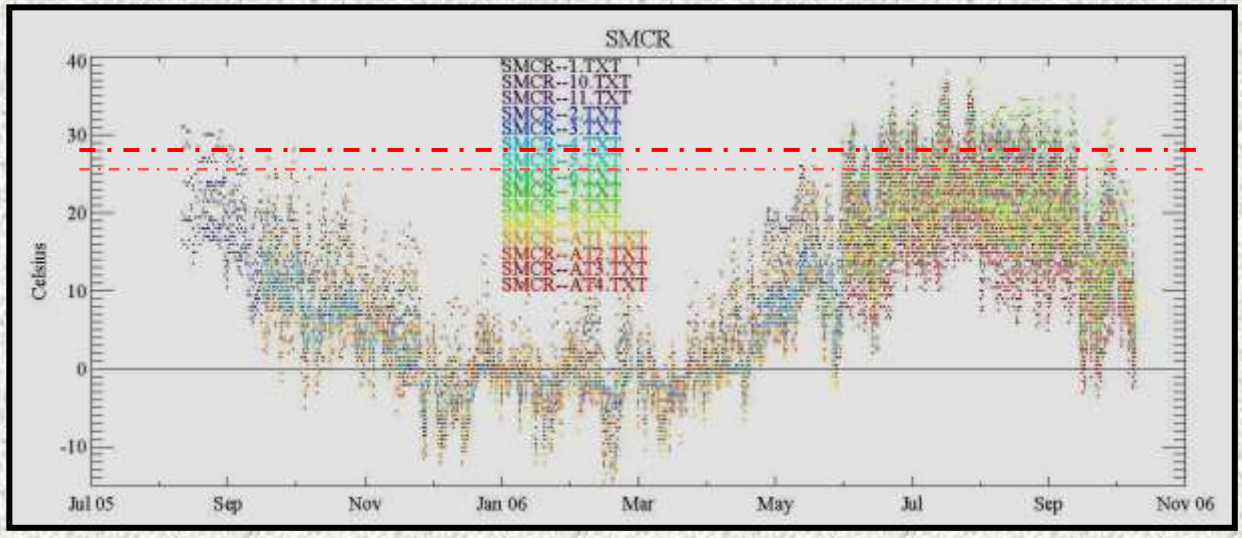
Potential mechanisms of GCC on montane spp.: *summer heat stress*

- **Pika-occupied** sites rarely had within-talus temps above pika-lethal thresholds



Beever et al. 2010, *Ecol. Appl.*

- **Locally-extinct** sites more often had within-talus temps above pika-lethal thresholds



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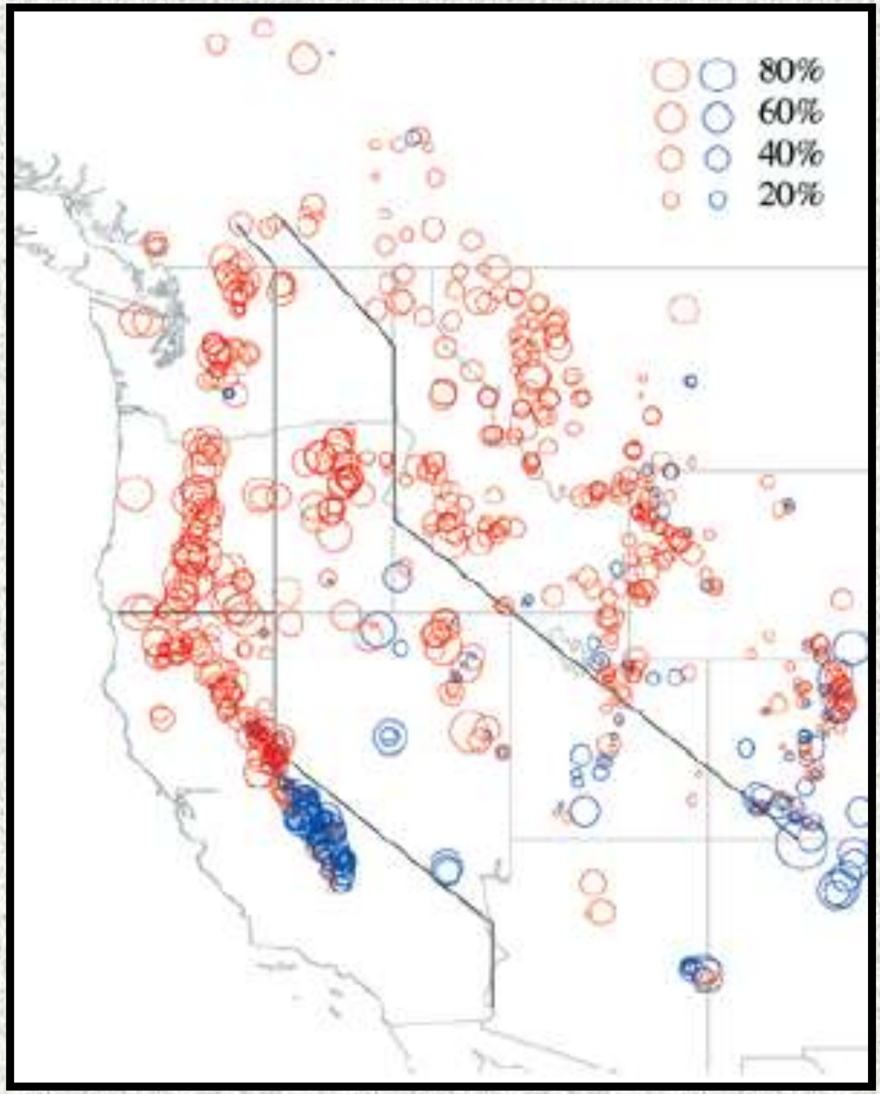
Potential mechanisms of GCC on montane spp.: *winter cold stress*

- **Decrease in snowpack (SWE) across 924 snow-course sites in western N. America, 1950-1997 (April 1)**



Mote et al. 2003

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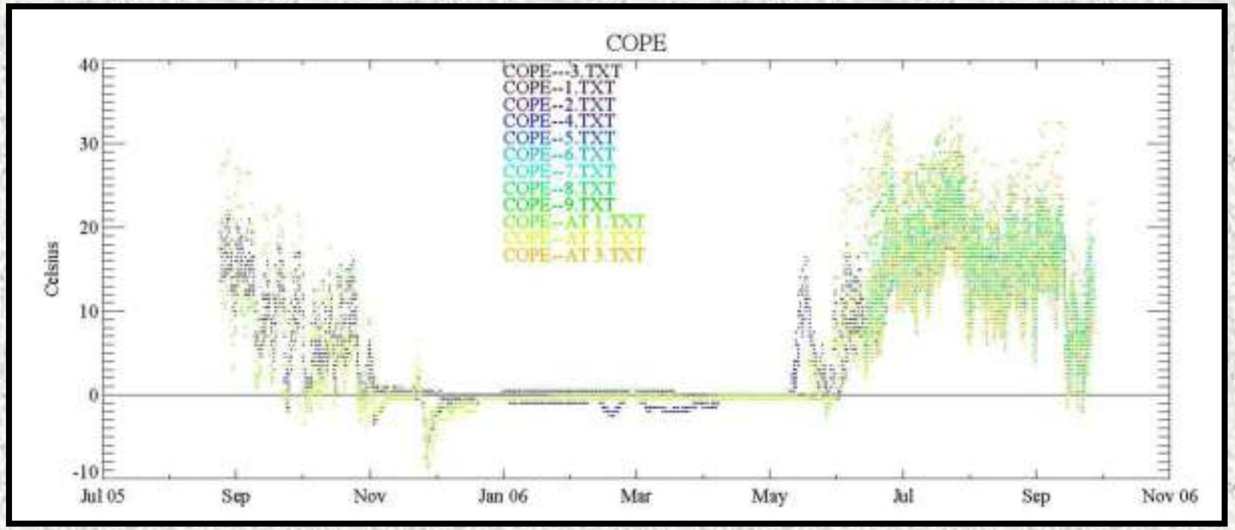
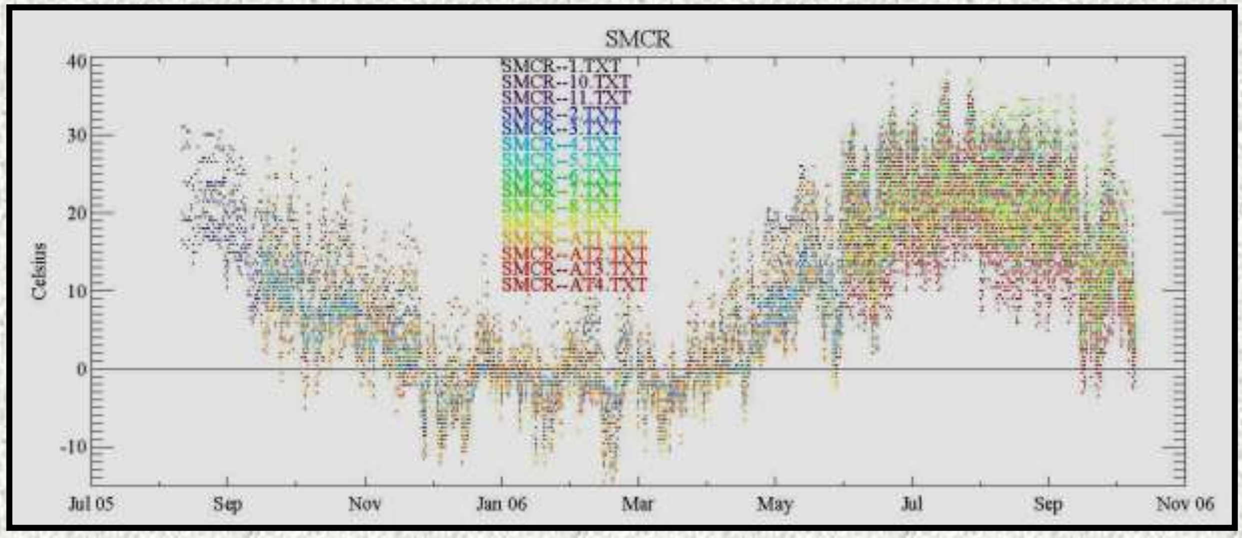
Potential mechanisms of GCC on montane spp.: *winter cold stress* (cont'd.)

- Most **pika-occupied** sites snow-covered 0.5 – 8.2 months/yr



Beever et al. 2010, *Ecol. Appl.*

- 8 of 10 **locally extinct** sites never had snow cover >2 weeks



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Testing: *field and analytical methods*

- **~200 iButtons set in previously pika-occupied taluses (7/05-Present)**
- **Status of site and talus occupancy checked ≥ 5 times, 2005-2008**
- **Metrics for 3 mechanisms of direct thermal stress**
  - **Acute heat stress: # d > 28° C**
  - **Chronic heat stress: average summer (JJA) temperature**
  - **Winter cold stress: #d < 0 or -5° C**
- **Central hypothesis: comparison of data fit between A) field conditions in 2005-06 (i-button data) and B) *magnitude of change* from 1945-1975 to 1976-2006; also investigated *total stress* (1945-2006 avg.)**

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Top models for patterns of persistence

Beever et al. 2010

Model	−2 × log(*L*)	*K*	AIC_c	ΔAIC_c	Akaike weight	Evidence ratio^{-1}
Mean summer temperature (2005–2006)	22.559	2	27.104	0.000	0.148	1.000
Days below −5°C (1945–2006) and mean summer temperature (1945–2006)	20.330	3	27.473	0.368	0.123	0.832
Days above 28°C (2005–2006)	23.337	2	27.883	0.779	0.100	0.677
Mean summer temperature (2005–2006) and days above 28°C (2005–2006)	20.774	3	27.916	0.812	0.099	0.666
Mean summer temperature (1945–2006)	23.954	2	28.500	1.396	0.074	0.498

- **Recent variables prominent among top models**
- **Importance of types of stress not previously well appreciated**
- **No clear-cut most-plausible single model**

Importance of different variables for persistence

Beever et al. 2010

Predictor	Mean Akaike weight per model	Sign of effect
Recent mean summer temperature (°C)	0.0629	6−
Long-term mean summer temperature (°C)	0.0530	6−
Recent no. days above 28°C	0.0530	6−
Cumulative no. days below −5°C	0.0491	4−
Recent no. days below 0°C	0.0271	2−, 2 +
Cumulative no. days above 28°C	0.0263	6−
Recent no. days below −5°C	0.0252	3−, 1+
Cumulative no. days below 0°C	0.0207	3−, 1+
Change in no. days above 28°C	0.0037	6−
Change in no. days below 0°C	0.0034	4−
Change in mean summer temperature (°C)	0.0022	1−, 5+
Change in no. days below −5°C	0.0014	3−, 1+

- **“Climate-change” variables *very* poorly predicted patterns of loss**
- **Acute heat stress a relatively poor predictor (behavior)**
- **Concern @ historic low-temp variables**

Evidence of climatic influence on pikas

- **EXPERIMENTAL: Vulnerability to direct heat stress** (Smith 1974)

- **Hotter, drier macroclimates at extirpated vs. extant sites**
  - **PRISM-modeled data, AND iButtons in taluses across Basin**

	iButton field data, 2005-2006			
	# Days > 28˚C	Avg summer temperature (˚C)	# Days < 0˚C	# Days < -5˚C
Pika-extant sites (*N* = 15 sites)	2.8 ± 1.0	12.05 ± 1.01	204.4 ± 13.2	15.0 ± 4.6
Pika-extirpated sites (*N* = 10)	10.9 ± 4.0	17.02 ± 0.72	159.6 ± 9.7	28.7 ± 7.8

Beever et al. 2010, *Ecol. Appl.*

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Evidence of climatic influence on pikas

- **Within mixed-occupancy sites, extirpated patches 2.5°C warmer during summer than occupied patches**

- **Extant sites received 1.43x greater PPT during 1961-1990 than did 6 sites initially lost, & 1.75x greater PPT during 1971-2000 than 4 sites of recent loss (PRISM)**

- **Change in population-size index most negative at southernmost sites**

- **Loss of pikas from low-elevation sites in 4 ranges even though higher-elevation populations in the same range persisted**

Different drivers of extirpation? (a)

- **Compare identity and rank of top models from extirpations during 20th Century, last decade**

Different drivers of extirpation? (a)$_1$

- Compare identity and rank of top models from extirpations during 20th Century, last decade

- 'Local Refuge' (MaxElev) alone best predicted persistence from historic records through 1999
- However, for 1999-2008, null model was plausible for describing patterns w/Local Refuge
- Residual variable that accounts for site latitude alone strongly predicted pattern, and appeared in 26/28 of plausible models, across all 3 periods

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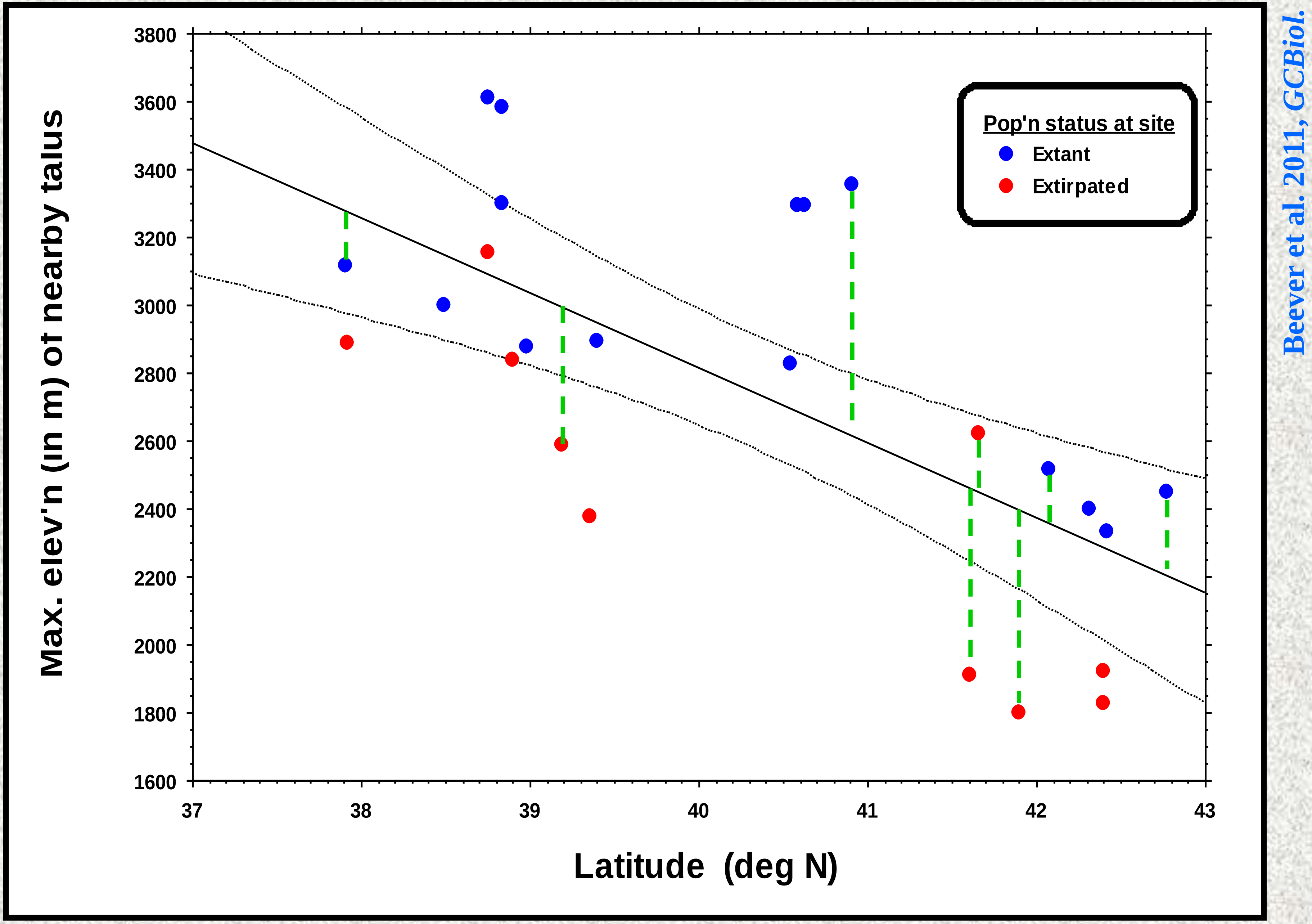

Beever (1999): ***integrative*****, latitude-adjusted local migrational ceiling**

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Different drivers of extirpation? (a)$_2$

- Compare identity and rank of top models from extirpations during 20th Century, last decade

- **0/8 models plausible with using Local Refuge for 20th-Century persistence appeared in Recent top models; 8/10 of 20th-Century top models plausible with using residual appeared in Recent top models, but ranks differed**

Different drivers of extirpation? (b)

- **Ranks of variable weights shifted dramatically, last decade vs. during 20th Century**

	'20th Century' (historic to 1999)	'Recent' (1999 to 2009)
(a) Maximum elevation of habitat within upper bound of dispersal distance		
Predictor variable (listed in order of decreasing weight per model	***MaxElev***	**AugMaxT**
	RngHab	RngHab
	AugMaxT	DistRd
	DistRd	GrzPost99
	GrzPre99	***MaxElev***
Sites correctly classified*	24/25	16/19
Average of |(weighted P[occ] – occupancy status)|†	0.123	0.276
(b) Residual of Maximum elevation of local habitat on latitude		
Predictor variable (listed in order of decreasing weight per model	RngHab	***MaxElevR***
	MaxElevR	**AugMaxT**
	DistRd	RngHab
	GrzPre99	GrzPost99
	AugMaxT	DistRd
Sites correctly classified*	22/25	18/19
Average of |(weighted P[occ] – occupancy status)|†	0.185	0.169

Beever et al. 2011, *GCBiol.*

Different drivers of extirpation? (c)

- **Use model-averaging of 20th-Century results to predict probability of extirpation *after* 1990s surveys for each site;**

- **test whether probabilities accurately predicted extirpations**

RESULT:

Logistic regression: $\chi^2_{1,17} = 0.03$, $P = 0.86$

Beever et al. 2011, *GCBiol.*

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Different drivers of extirpation? (d)

- Compare model-averaged coefficients between 20th Century and Overall periods

RESULTS:

Beever et al. 2011, *GCBiol.*

MaxElevR	~2x higher for Overall
Presence of grazing	>5x higher for Overall
Amt of talus habitat in mtn range	>9x lower for Overall
Distance to nearest rd	*no longer in top models*

So WHAT ???

- **Mammals worldwide typically have been endangered primarily by habitat loss, over-exploitation, lg. body size**

  Schipper et al. 2008

- **Climate is the single-strongest factor effecting distributional change (increasingly so), yet interacts with other factors to affect population dynamics**

- **When microclimate data are lacking, the residual measure can provide a first estimate of site vulnerability**

- **Early-warning signs of change are valuable**

- **Knowing past dynamics may not help forecast future**

So WHAT ???

- If talus areas are no longer habitable, relocation efforts in vain

- Species will likely respond individualistically to climatic influence; thus, extrapolation to other species may be risky

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Resiliency: assisted re-introductions(?)

- **In instances where re-introductions are considered, recipient locations should have meso- and micro-climates that are conducive to the focal species' persistence**

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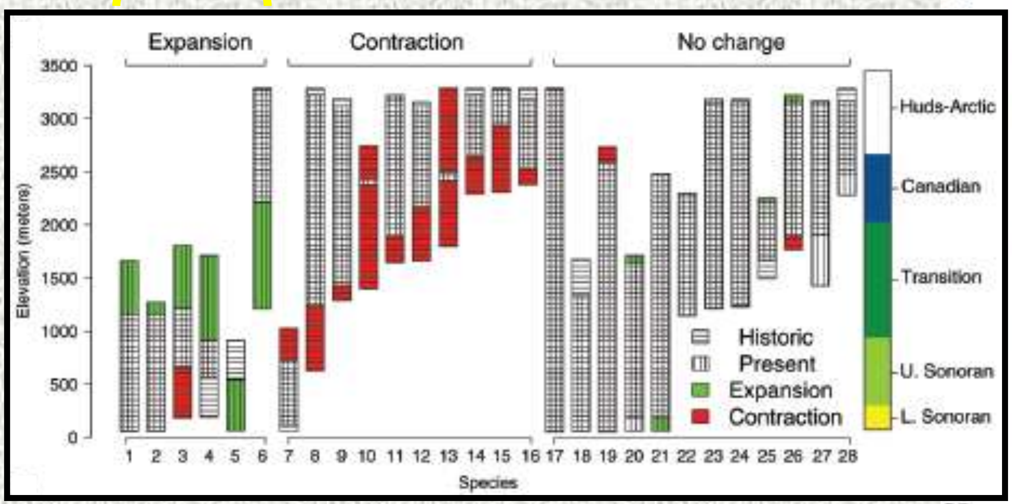
On extrapolation …

- Grinnell re-survey, YOSE

No.	Species	P(G)	P(C)	Original elevation range (m)	Range limit change (m)	
					Range expansions	
1	*Microtus californicus*	0.81	0.58	57–1160	+505 U	Elev
2	*Reithrodontomys megalotis*	0.99	0.87	57–1160	+112 U	Elev
3	*Peromyscus truei**	0.99	0.93	183–1220	**+589 U, +468 L**	Era*
4	*Chaetodippus californicus*	0.28	0.19	193–914	**+800 U**	Era*
5	*Sorex ornatus*	0.32	0.93	549–914	**−485 L**	Era
6	*Sorex monticolus*	0.99	0.97	2212–3287	**−1003 L**	Era
					Range contractions	
7	*Dipodomys heermanni*	0.16	0.98	57–1025	+63 L, **−293 U**	Era*
8	*Microtus longicaudus*	0.99	0.98	623–3287	**+614 L**	Era
9	*Zapus princeps*	0.98	0.90	1291–3185	+159 L, −64 U	Era
10	*Tamias senex*	0.95	0.71	1402–2743	+1007 L, −334 U	Elev
11	*Spermophilus lateralis*	0.70	0.89	1646–3200	**+244 L**	Era*
12	*Sorex palustris*	0.39	0.23	1658–3155	**+512 L**	Era
	*Neotoma cinerea**	0.90	0.71	1798–3287	**+609 L, −719 U**	Era*
	*Spermophilus beldingi**	0.98	0.98	2286–3287	+355 L	Elev
	Tamias alpinus	0.92	0.95	2307–3353	**+629 L**	Era
	Ochotona princeps†	NA	NA	2377–3871	+153 L	NA
					No change	
	*Peromyscus maniculatus**	0.99	0.99	57–3287	No change	Era*
	Thomomys bottae†	NA	NA	57–1676	No change	NA
	Spermophilus beecheyi	0.50	0.82	61–2734	−250 U	Era*
	Neotoma macrotis	0.90	0.91	183–1646	+67 U	Elev
	Peromyscus boylii	0.98	0.97	183–2469	−122 L	Elev
	Sorex trowbridgii	0.71	0.88	1160–2286	No change	Elev
	*Microtus montanus**	0.81	0.98	1217–3155	No change	Elev
	*Tamiasciurus douglasi**†	NA	NA	1229–3185	No change	NA
25	*Tamias quadrimaculatus*	0.95	0.85	1494–2210	+50 U	Era*
26	*Tamias speciosus**	1.00	1.00	1768–3155	+128 L, +65 U	Era*
27	*Thomomys monticola*†	NA	NA	1905–3155	No change	NA
28	*Marmota flaviventris*†	NA	NA	2469–3353	No change	NA



- Responses differed across taxa

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Species have shifted differently …

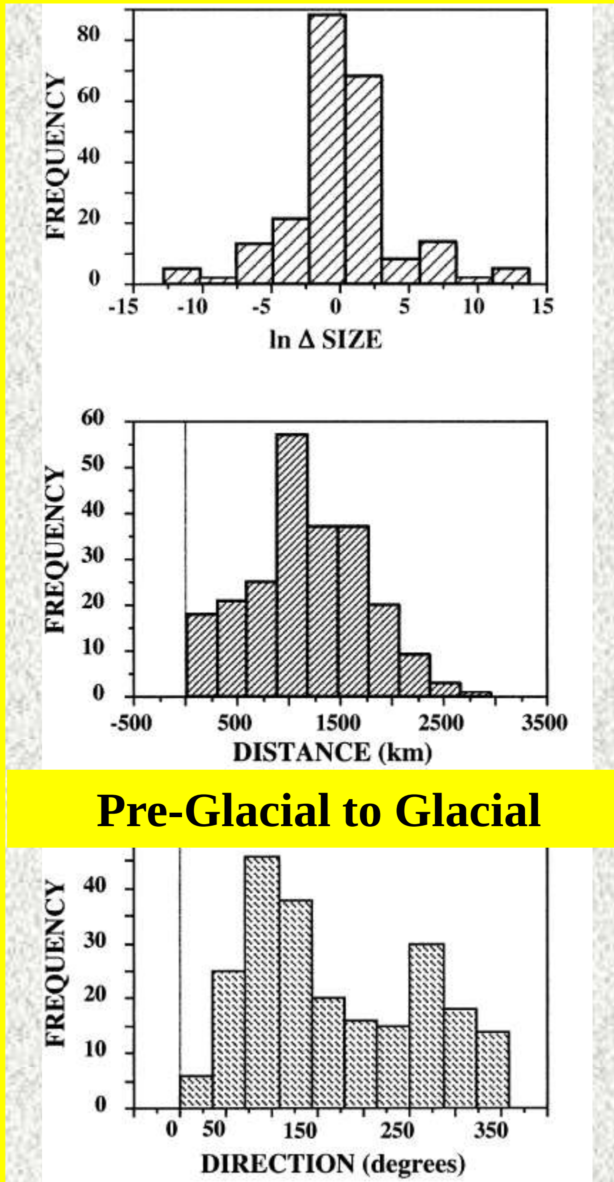
Lyons 2003, *J. Mammal.*

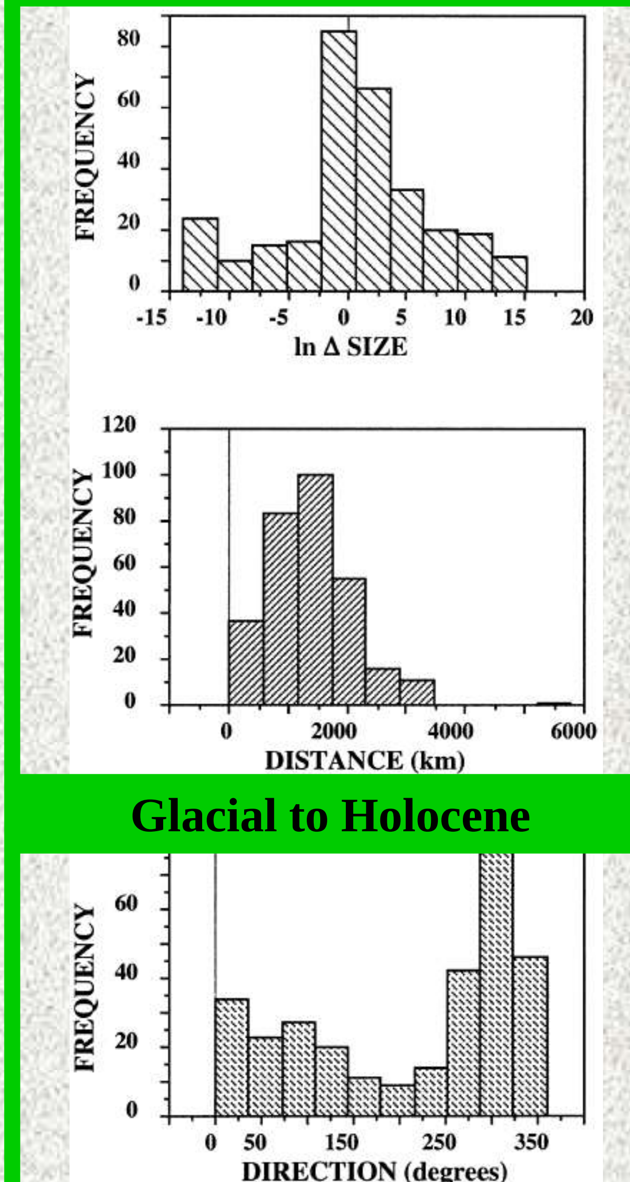
- **During paleo times, too … wildlife also shifted, diversely**

Δ in size of geographic range

Distance of range shift of centroid

Azimuth of range shift of centroid



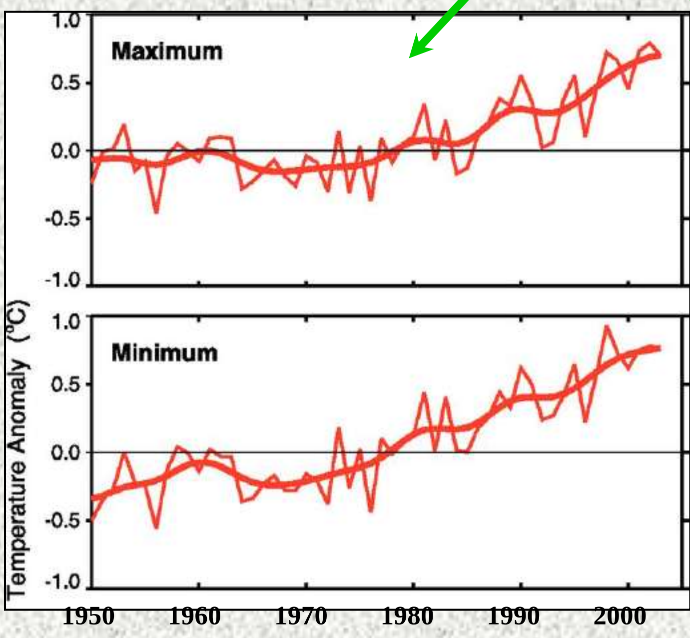


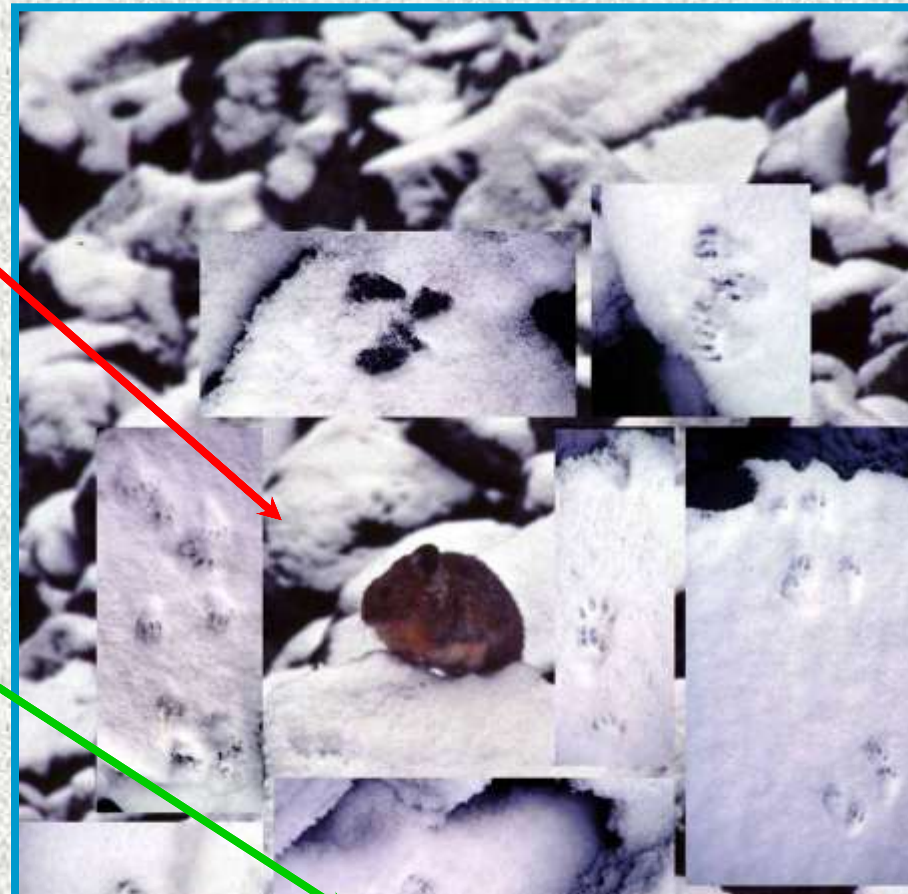
Interpretation

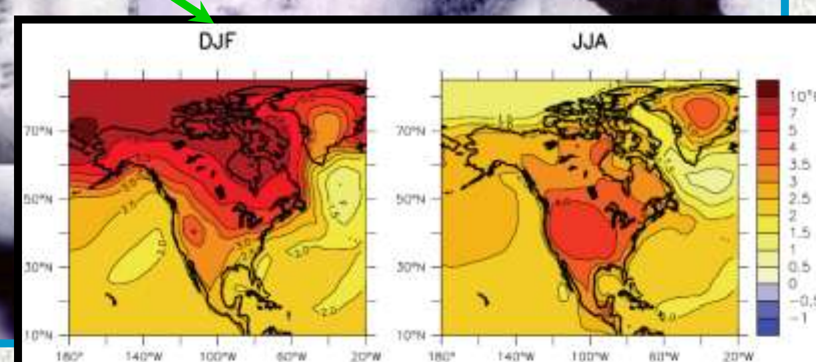
- **Importance of winter cold stress agrees with facts that:**

a) pikas are active yr-round (consequent E concerns), &

b) T minima have risen > T maxima







Benefits of broad-scale approaches

- **Provide greater collective sample size, power**
- **Broader domain of inference where results apply**
- **Allow discrimination of broad-scale patterns from local anomalies**
- **Allow detection and identification of cross-scale dynamics, synergistic interactions, and ecological thresholds**
- **Allow for assessment of greater diversity of potential system drivers**

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Methodological frontiers

- Airborne, geo-rectified IR and veg. sensors
- Derived ecohydrologic variables
- Physiological & genetic studies; facets; ENM modeling => sufficiency of areas, connectivity
- Bayesian approaches



Final take-home messages

- **Must proceed from solid understanding of life- and natural history**

Wolverine

Whitebark pine

- Behavioral plasticity to accommodate climate stress needs to be understood and incorporated

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- **Empirical verification of trend necessary for some wildlife spp.**

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- Empirical verification of trend necessary for some wildlife spp.

- **Multi-pronged approaches will provide best insights into specific mechanisms by which GCC acts upon species**

understood and incorporated

Final take-home messages

- **Distributional determinants may vary across species' ranges**
  - **context-dependencies likely to profoundly affect wildlife responses**
    - **Distributional changes in pikas have been observed in ne CA, NV, se OR, the Cascades, UT, CO, s. ID, YOSE, BC, & other locations; *variable magnitudes*.**
  - **decoupling of climate envelopes and static habitats**

Final take-home messages

- Must proceed from solid understanding of life- and natural history

- Empirical verification of trend necessary for some wildlife spp.

- Multi-pronged approaches will provide best insights into specific mechanisms by which GCC acts upon species

- Distributional determinants can vary across species' ranges
  - hypothesize that winter cold stress more important, here
  - disjunction between climate envelopes and static habitats

- **Behavioral plasticity to accommodate climate stress needs to be understood and incorporated**

Thanks !

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