

Climate Change Trends and Vulnerabilities, Craters of the Moon National Monument and Preserve, Idaho

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Climate Trends for the Area within Park Boundaries

- **Historical temperature** Average annual temperature in the park increased at a rate of $1.1 \pm 0.6^{\circ}\text{C}$ ($2 \pm 1.1^{\circ}\text{F.}$) per century in the period 1950-2013, but the annual trend was not statistically significant (Table 1, Figure 1). Spring and summer temperatures did increase at statistically significant rates (Table 1).
- **Historical precipitation** Total annual precipitation varied in the period 1950-2013 and showed no statistically significant trend (Table 2, Figure 2).
- **Spatial patterns** Historical temperature increases (Figure 3) and precipitation decreases (Figure 4) were greater at higher elevations.
- **Projected temperature and precipitation** If the world does not reduce emissions from power plants, cars, and deforestation by 40-70%, models project future heating at up to five times the historical rate (Table 3, Figure 5) and increases in precipitation (Table 4, Figure 5). Projected changes are generally similar across the monument and preserve, showing low spatial variation.
- **Aridity** Even if precipitation increases, temperature increases may overcome any cooling effects of increased precipitation, leading to increased evapotranspiration and overall aridity.
- **Extreme heat** Under the highest emissions scenario, models project an increase of 9-15 more days per year with a maximum temperature $>35^{\circ}\text{C}$ (95°F.) (Kunkel et al. 2013).
- **Extreme storms** Projections under the highest emissions scenario project an increase in 20-year storms (a storm with more precipitation than any other storm in 20 years) to once every 4-6 years (Walsh et al. 2014).

Historical Impacts in the Region Attributed to Human-Caused Climate Change

- **Wildfire** Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor determining how much land burned, even during periods of active fire suppression (Littell et al. 2009).
- **Bark beetles and tree mortality** Climate change has caused bark beetle outbreaks, including in Eastern Idaho, leading to the most extensive tree mortality across western North America in the last 125 years (Raffa et al. 2008).
- **Bird range shifts** Analyses of Audubon Christmas Bird Count data across the United States, including counts southwest of the park in Pocatello, detected a northward shift of winter ranges of a set of 254 bird species at an average rate of 0.5 ± 0.3 km per year from 1975 to 2004, attributable to human climate change (La Sorte and Thompson 2007). Further analyses demonstrate poleward shifts in winter distributions of six raptor species listed by the NPS Inventory and Monitoring Program as breeding in the park (American Kestrel (*Falco sparverius*) and Red-tailed Hawk (*Buteo jamaicensis*)), or observed in the park (Golden Eagle (*Aquila chrysaetos*), Northern Harrier (*Circus cyaneus*), Prairie Falcon (*Falco mexicanus*), and (Rough-legged Hawk (*Buteo lagopus*)) (Paprocki et al. 2014).

Future Vulnerabilities

Plants

- **Wildfire** Under high emissions, potential fire frequencies could increase up to 25% by 2100 (Moritz et al. 2012). Targeted use of prescribed burning and wildland fire can reduce the future vulnerability of forests to catastrophic wildfire under climate change (Stephens et al. 2013).
- **Biome shifts** Under all emissions scenarios, the southern end of the park could serve as a refugium to biome shifts due to climate change (Gonzalez et al. 2010) and to the combined impacts of biome shifts and habitat loss (Eigenbrod et al. 2015).
- **Limber pine** In the Sierra Nevada, high temperatures and drought increased limber pine (*Pinus flexilis*) mortality from 1985 to 1995 (Millar et al. 2007), suggesting vulnerability to limber pine under climate change. The lack of additional mortality following a subsequent drought (1999-2004) suggests limber pine could be more resilient to moisture stress (Millar et al. 2007). In the southern Rocky Mountains, groups of planted limber pine (*Pinus flexilis*) with natural genetic resistance to the fungal pathogen white pine blister rust (*Cronartium ribicola*) exhibited reduced leaf gas exchange (Vogan and Schoettle 2015). Reduced gas exchange can reduce growth and competitive ability under drought conditions. Seedling plantation

experiments at Niwot Ridge, Colorado found that seasonal moisture stress, higher soil surface temperatures when snow melts, and earlier germination increase the vulnerability of limber pine seedlings to mortality (Moyes et al. 2013).

- **Kipukas** Survey of sagebrush steppe plant distribution in kipukas (patches of sagebrush steppe isolated by lava flows ca. 2000-15 000 years before present) in the monument and preserve found exotic plant distribution is influenced by the railway and agriculture, but the native plant community is more strongly influenced by aridity along an elevational gradient (Bangert and Huntly 2010). The highest abundance and diversity of exotic species was observed in the hottest, driest, lowest-elevation kipukas, and exotic species richness was higher in the southern regions that are also nearest the railroad corridor. Cheatgrass (*Bromus tectorum*) represented 95% exotic cover. Kipukas are inhabited by undisturbed plant communities, but those near the railway can no longer act as a refuge for native plants.
- **Invasive plant species** While two varieties of the invasive Palmer's penstemon (*Penstemon palmeri palmeri* and *P. palmeri eglandulosus*) are currently uncommon in the park, research in Zion National Park (Booth 2011) found that this perennial is more productive and flowers earlier under warmer temperatures. Although invasive spotted knapweed (*Centaurea biebersteinii*) and leafy spurge (*Euphorbia esula*) are also uncommon in the park, they may become more common under high emissions scenarios, along with yellow starthistle (*Centaurea solstitialis*), which is present in areas adjacent to the park (Bradley et al. 2009).

Wildlife

- **Pika (habitat shifts)** American pika (*Ochotona princeps*) currently occur in the park, but historical records (1898 to 2008) throughout the Great Basin south and east of the park reveal extirpation at 10 of 25 research sites and a mean upslope shift of 360 m (Beever et al. 2011, 2016). In protected areas of the western U.S., exposure to relatively high temperatures may limit pika dispersal (Castillo et al. 2016).

As warmer temperatures shift upslope, pika across the western US are vulnerable to upslope habitat shifts, losing habitat at lower elevations (Beever et al. 2011, Calkins et al. 2012, Galbreath et al. 2009). Under the low (RCP 4.5) and highest (RCP 8.5) emissions scenarios, species distribution models using field data of pika occurrences in the park project potential occupancy decreases of 11-44% by 2100 due to heat stress, changes in the growing season, and changes in habitat connectivity (Schwalm et al. 2016). Modelling across the Great Basin for 39 sites, including the park, indicate that pika body heat regulation behavior could

buffer some effects of climate change (Mathewson et al. 2016). These behaviors, which include sweating, panting, and retreating to cool interstices in rocky habitat, could reduce projected habitat loss by 8-19% relative to projections from models based only on increasing temperature (Mathewson et al. 2016). Smaller body sizes of pika in the park relative to pika in adjacent mountain regions could allow pika to maintain activity levels in warm temperatures (Mathewson et al. 2016, Varner et al. 2016).

- **Pika (lava habitat)** Pika surveys in the park (144 sites) indicate that lava habitat may provide refugia under climate change (Rodhouse et al. 2010). Surveys found pika only at sites above 1605 m elevation, while one area (250 km²) of pahoehoe lava in the northern region of the park accounted for 91% of pika occurrence. Pika occurrence was highest on structurally complex Pahoehoe lava, which has large broken surfaces with fissures, pits, and overhangs, that can provide thermal refugia.
- **Pika (vegetation)** Fine-scale analyses of pika habitat, including sites in the park (Castillo et al. 2014), indicate pika presence is not solely tied to climate (Castillo et al. 2014, Erb et al. 2011, 2014, Jeffress et al. 2013). Pika distributions correlated more closely with vegetation than climate, although vegetation composition is related to microclimate (Ray et al. 2016). Pika occurrence was also higher in structurally complex lava flow types with forb cover (including rock spirea (*Holodiscus dumosus*), mock orange (*Philadelphus lewisii*), and fernbush (*Chamaebatiaria millefolium*)) (Rodhouse et al. 2010). Any reduction of these forbs under climate change would increase the vulnerability of pika (Rodhouse et al. 2010). Pika dietary flexibility could provide adaptive capacity to changes in forage due to climate change (Varner et al. 2016).
- **Yellow-bellied marmot** Analyses in western Colorado of yellow-bellied marmot (*Marmota flaviventris*), which occurs in the park, found the date of emergence from hibernation advanced 38 days from 1976 to 1999 as temperatures increased (Inouye et al. 2000). Under future climate change, the species may be vulnerable to a mismatch of food availability and the timing of the end of hibernation.
- **Elk** Research on North American elk (*Cervus elaphus*) in the Idaho National Laboratory, north of the park, found that elk in arid environments selected foraging areas that would help keep their bodies cool (thermoregulation) over areas providing highest-quality forage (Long et al. 2014). Elk could be vulnerable to reduced reproductive success and survival from reduced forage quality if climate change increases temperatures (Long et al. 2014).
- **Loggerhead shrike** Field surveys of loggerhead Shrike (*Lanius ludovicianus*) in three

sagebrush-scrub (*Artemisia tridentata*) rangeland sites west of the park in the Snake River Plain found two-thirds of nests in sagebrush and one-fifth in bitterbrush (*Purshia tridentata*) (Woods and Cade 1996). Since the park may act a refugium for sagebrush (Gonzalez et al. 2010, Eigenbrod et al., 2015), it may also act as a refugium for loggerhead shrike.

- **Double-crested cormorant** Assessments of migration patterns (1978-2005) on Mustang Island, Texas, of double-crested cormorant (*Phalacrocorax auritus*), a native species of concern observed in the park, found significant correlations between higher temperatures and later arrival dates, thereby decreasing their stay on the island (Foster et al. 2010). Because this cormorant breeds on Mustang Island, decreased time on the island could shorten the breeding season and increase vulnerability under climate change (Foster et al. 2010).
- **MacGillivray's Warbler** Analyses south of the park in the central Great Basin, Nevada, found colonization rates of MacGillivray's Warbler (*Oporornis tolmiei*) were higher in areas of higher shrub cover, suggesting vulnerability to any changes in shrub cover under climate change (Dickson et al. 2009).
- **Bats (aridity)** Increasing aridity can reduce bat reproduction (Adams and Hayes 2008). Bats may be disproportionately affected by increased aridity relative to other mammals because small body size and a large surface area-to-volume ratio predisposes them to dehydration through evaporative loss (Adams 2010), which could be higher in species with large ears such as the Townsend's big-eared bats (*Corynorhinus townsendii*) that are in the park (Gillies et al. 2014). Research on bats in the park (Gillies et al. 2014) indicates future vulnerabilities to changes in humidity. Modeling based on surveys of Townsend's big-eared bat winter habitat at 13 lava tube caves in southeastern Idaho, inside and outside the park, related cave occupancy to three variables related to humidity: distance to ephemeral water (mean = 10.9 km), presence of structural features (collapse or constriction in 100% of occupied caves), and lower mean cave height (~10.5 m). Hibernating bats may better maintain water balance by avoiding hibernacula with extremely low humidity during the winter, when cold air holds little moisture, affecting the suitability of caves as overwintering sites for Townsend's big-eared bats in the park. High relative humidity is also important to successful hibernation for little brown bats (*Myotis lucifugus*) (Thomas et al. 1990).
- **Bats (White nose syndrome)** White nose syndrome is a disease caused by the invasive fungus *Pseudogymnoascus destructans*, which has infected and killed big brown bats (*Eptesicus fuscus*) and little brown bats (*Myotis lucifugus*) in parts of the U.S. Although white nose syndrome is currently not present in the park, some areas of the park currently have

suitable climate conditions for the disease and their extent may increase under projected future climate. White nose syndrome is associated with precipitation frequency (30% of days with any precipitation), annual temperature (38-40°C), mean temperature of the wettest quarter (2-17°C), and precipitation during the wettest month (<100 mm) (Flory et al. 2012). Analyses of white nose syndrome found it can develop in arid conditions (~82% relative humidity at 6.5°C) (Lorch et al. 2011) that occur in the park (Gillies et al. 2014). The speed and severity of the historic spread of white nose syndrome suggest, however, that factors other than climate dominate.

Table 1. Historical average temperatures and temperature trends of the area within the boundaries of Craters of the Moon National Monument and Preserve. SD = standard deviation, SE = standard error, sig. = statistical significance, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$.

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century ⁻¹			°C century ⁻¹		
Annual	6.9	0.9	0.4	0.2		1.1	0.6	
December-February	-5	2	0.5	0.5		0	1.1	
March-May	6.4	1.3	0.7	0.4		2.6	0.9	**
June-August	18.8	0.9	0.4	0.3		1.5	0.7	*
September-November	7.4	1.1	0.2	0.3		0.2	0.8	
January	-6.2	2.6	0.7	0.7		2	1.6	
February	-3.3	2.7	0.8	0.7		0	1.8	
March	1.5	2.1	1.3	0.6	*	5	1.5	**
April	6.4	1.9	0.2	0.5		1.9	1.3	
May	11.2	1.5	0.5	0.4		0.8	1	
June	16.1	1.6	0.4	0.5		1.2	1.2	
July	20.4	1.4	0.5	0.4		1.5	1.2	
August	19.9	1.3	0.4	0.3		1.7	0.8	*
September	14.3	1.6	0.8	0.5		1.5	1.3	
October	7.8	1.3	0.3	0.5		-0.4	1.2	
November	0	2.1	-0.5	0.5		-0.4	1.4	
December	-5.5	2.5	-0.1	0.7		-1.8	1.8	

Table 2. Historical average precipitation totals and precipitation trends of the area within the boundaries of Craters of the Moon National Monument and Preserve. No trends were statistically significant. SD = standard deviation, SE = standard error.

	1971-2000		1895-2010		1950-2010	
	mean	SD	trend	SE	trend	SE
	mm y ⁻¹		% century ⁻¹		% century ⁻¹	
Annual	295	70	6	8	11	23
December-February	92	38	9	9	-5	26
March-May	88	30	3	10	34	28
June-August	48	28	18	18	-22	43
September-November	68	26	-4	14	26	35
January	32	17	-2	17	-28	47
February	29	19	-16	16	-22	55
March	29	17	-10	20	26	42
April	25	13	13	13	64	33
May	34	19	6	16	18	46
June	23	18	34	27	-3	62
July	14	12	-6	26	1	61
August	11	9	9	26	-83	70
September	18	14	8	24	-3	55
October	20	13	-16	20	85	54
November	30	20	-1	18	-1	47
December	31	25	42	19	*	32

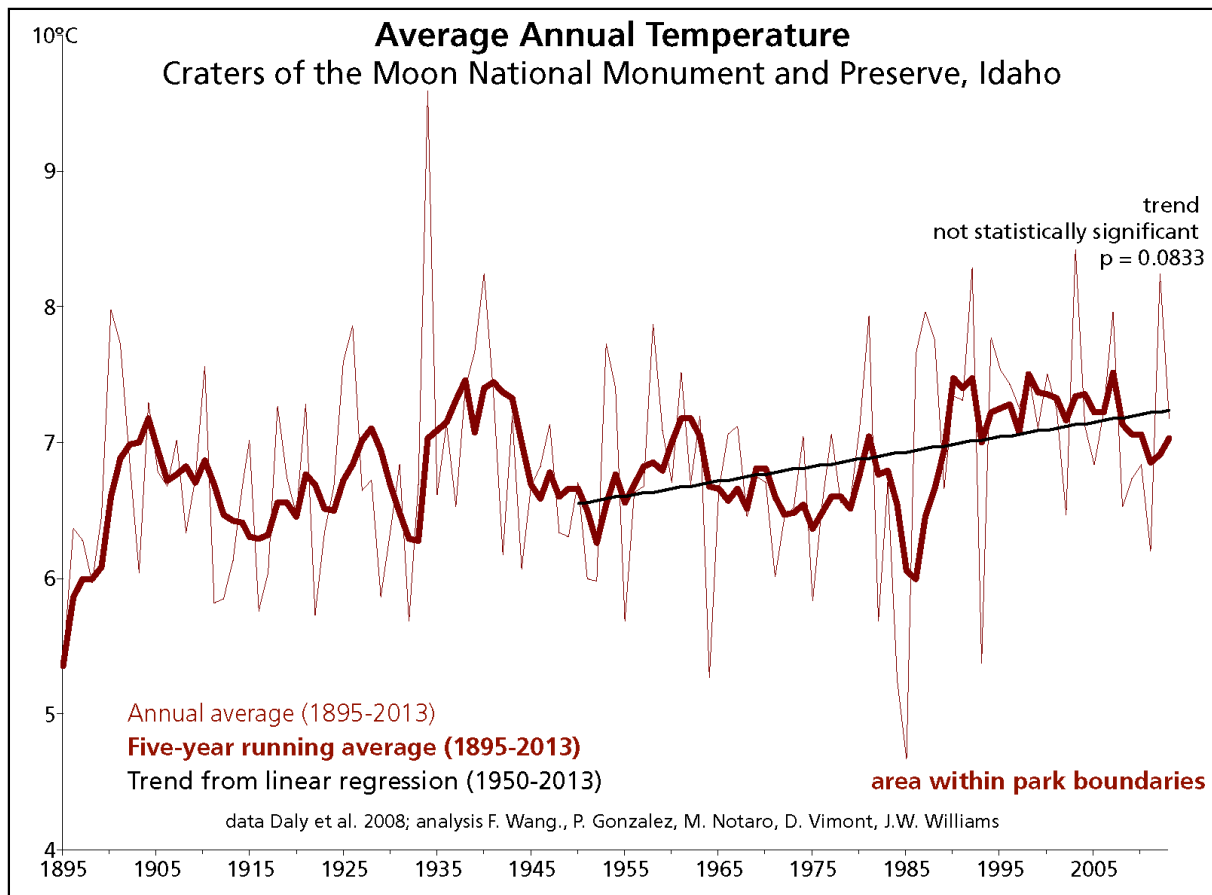
Table 3. Projected temperature increases (°C), 2000 to 2100, for the area within the boundaries of Craters of the Moon National Monument and Preserve, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	2	1	3.2	1.1	3.6	1.2	5.6	1.3
December-February	2	1.1	3.4	1.3	3.7	1.4	5.7	1.6
March-May	2.1	1.6	3	2	3.6	1.8	4.9	1.9
June-August	1.9	1.1	3.3	1.3	3.9	1.1	6.2	1.4
September-November	1.8	0.8	3.3	1.9	3.4	0.9	5.7	2.2
January	2.2	1.3	3.5	1.4	3.8	1.5	5.9	1.6
February	2	1.4	3.4	1.7	3.9	1.7	5.8	1.9
March	2.4	1.8	3.4	2.2	4.1	2.1	5.5	2.3
April	2.2	2	2.9	2.3	3.6	2.3	4.6	2.3
May	1.7	1.3	2.6	1.6	3.1	1.2	4.5	1.7
June	1.8	1	3	1.7	3.6	1.1	5.7	1.9
July	1.8	1.1	3.3	1.5	3.9	1.2	6.3	1.6
August	2	1.2	3.6	1.3	4.2	1.4	6.7	1.5
September	2	1	3.8	1.8	4	1.1	6.6	2.1
October	1.7	0.9	3.2	2.1	3.3	0.9	5.5	2.5
November	1.6	0.7	2.9	1.9	3	0.9	4.9	2.2
December	1.9	0.9	3.2	1.8	3.3	1.3	5.3	2

Table 4. Projected precipitation changes (%), 2000 to 2100, for the area within the boundaries of Craters of the Moon National Monument and Preserve, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation.

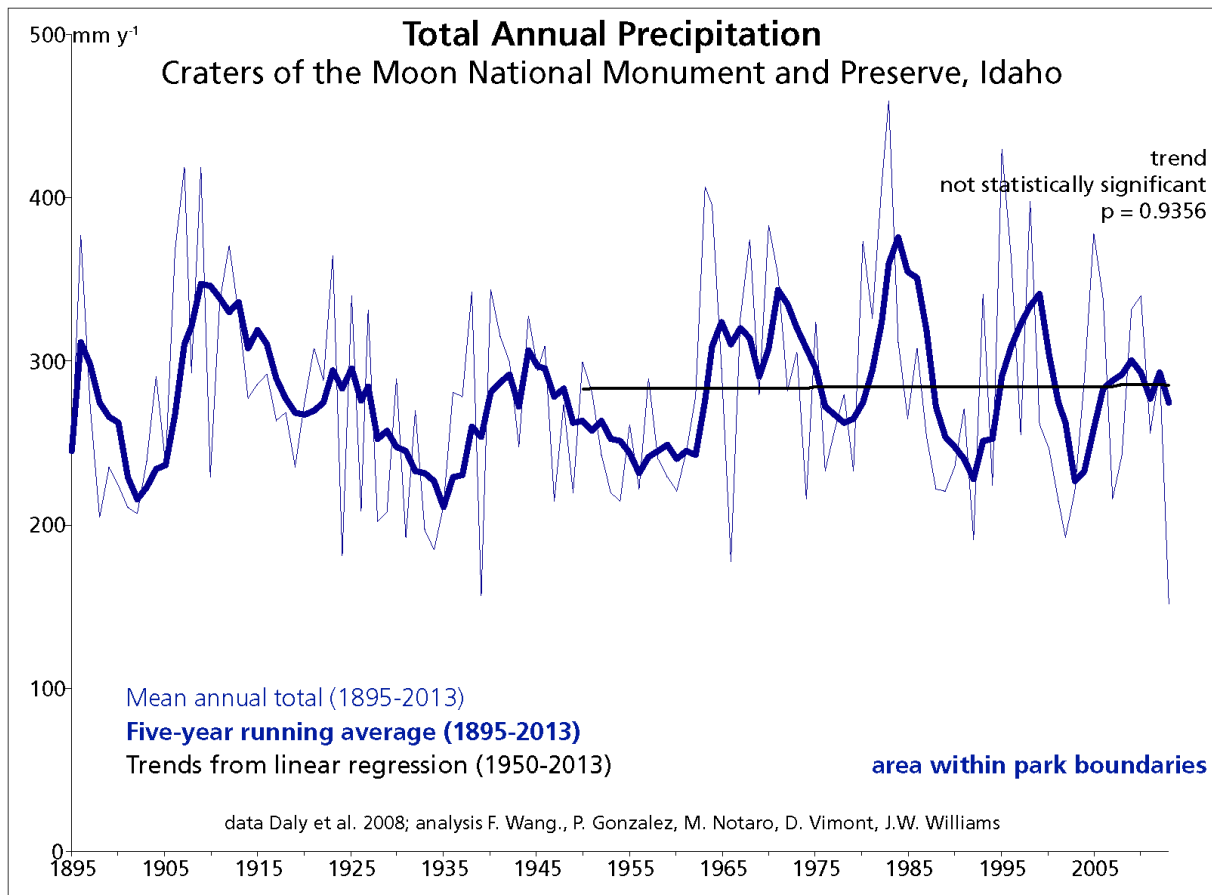
	Emissions Scenarios							
	Reductions		Low		High		Highest	
	RCP2.6		RCP4.5		RCP6.0		RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	8	6	8	7	11	8	13	9
December-February	7	11	13	12	16	13	23	16
March-May	14	19	11	17	19	20	17	17
June-August	8	18	2	22	-1	19	-2	29
September-November	2	9	1	13	4	10	6	15
January	6	15	12	14	13	16	21	20
February	4	19	17	24	16	22	29	28
March	9	19	16	17	22	21	27	23
April	26	28	19	28	30	33	29	28
May	9	23	0	21	9	22	0	23
June	7	16	-1	29	-3	16	-14	25
July	9	25	4	27	0	27	4	39
August	11	36	7	34	1	30	15	61
September	2	23	-1	25	0	20	6	29
October	6	17	-1	17	4	17	4	19
November	0	9	4	16	7	15	8	19
December	14	24	12	25	22	27	23	26

Figure 1.



Main conclusion: Temperature increased, but the rate was not statistically significant.

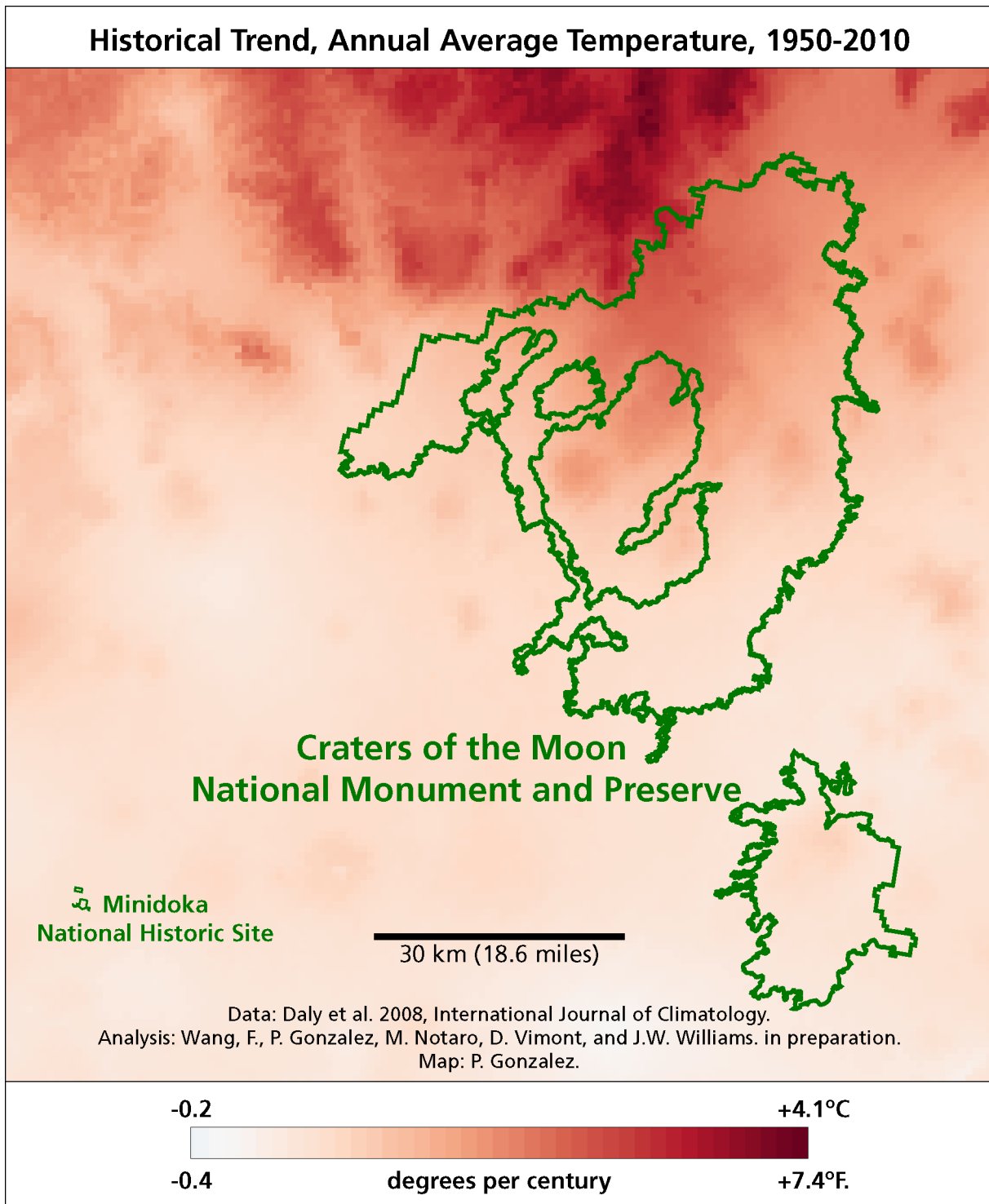
Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 2.

Main conclusion: Precipitation did not show a statistically significant trend.

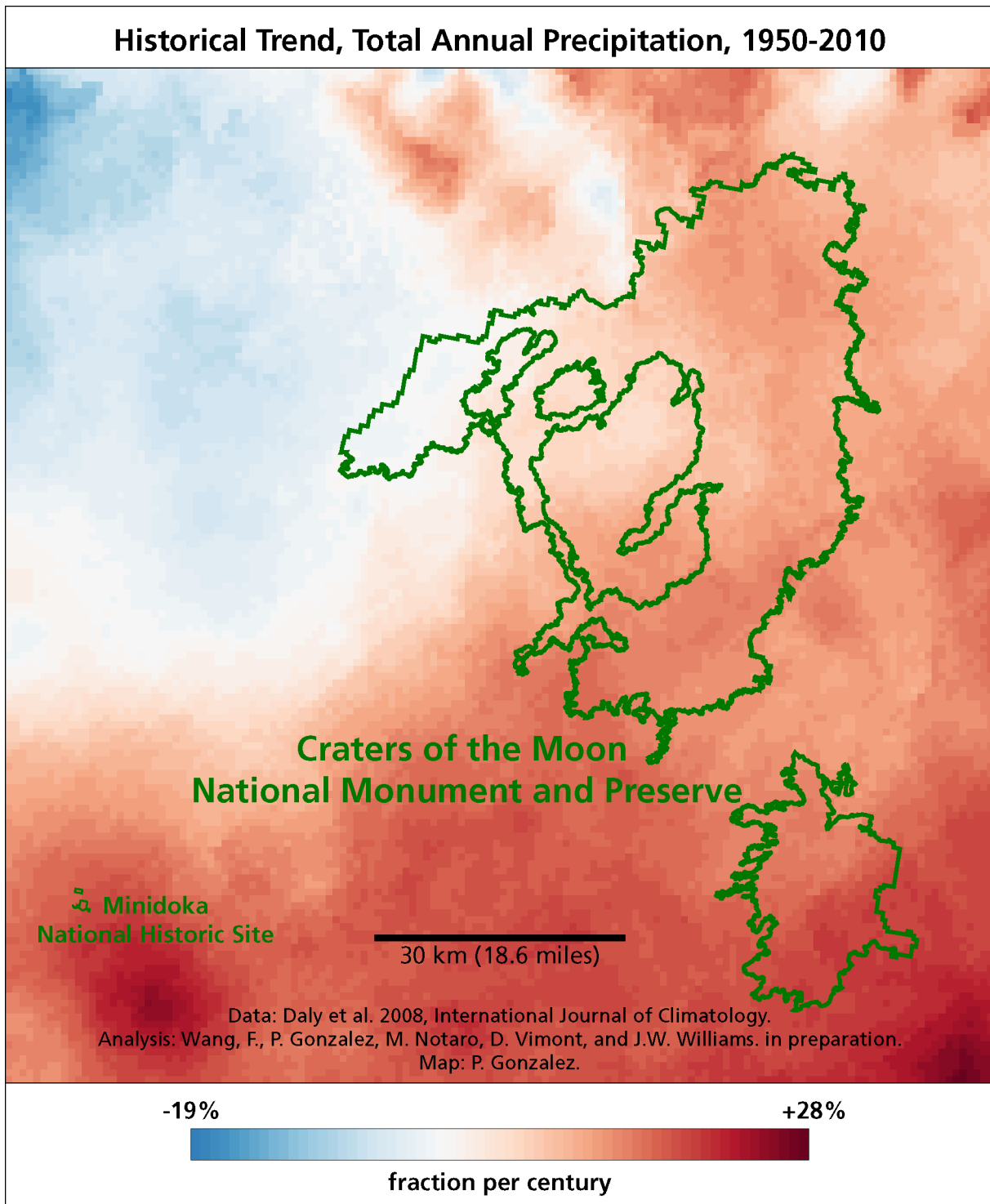
Note that the U.S. weather station network was more stable for the period starting 1950 than for the period starting 1895. (Data: National Oceanic and Atmospheric Administration, Daly et al. 2008. Analysis: Wang et al. in preparation, University of Wisconsin and U.S. National Park Service).

Figure 3.

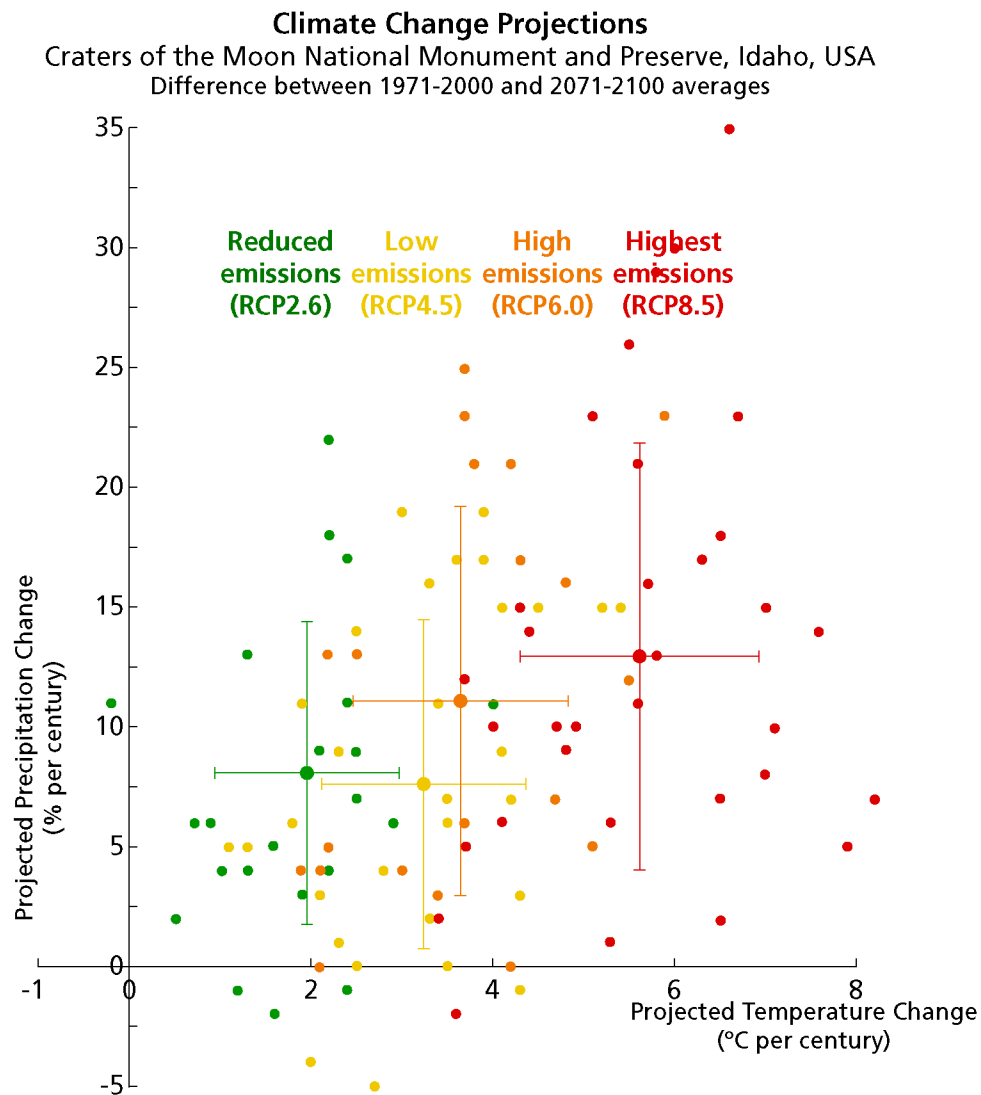


Main conclusion: Temperature increases are greater at higher elevations.

Figure 4.



Main conclusion: Precipitation decreases are greater at lower elevations.

Figure 5.

Data: Intergovernmental Panel on Climate Change 2013, Daly et al. 2008
Analysis: F. Wang, P. Gonzalez, M. Notaro, D. Vimont, J.W. Williams; Graph P. Gonzalez

Main conclusion: Models agree on projection of temperature increases and total precipitation increases in the park.

Each small dot is the output of a single climate model. The large color dots are the average values for the four IPCC emissions scenarios and the historical baseline. The lines are the standard deviations of each average value.

References

- Adams, R.A. 2010. Bat reproduction declines when conditions mimic climate change projections for western North America. *Ecology* 91: 2437-2445
- Adams, R.A. and M.A. Hayes. 2008. Water availability and successful lactation by bats as related to climate change in arid regions of western North America. *Journal of Animal Ecology* 77: 1115-121.
- Bangert, R. and N. Huntly. 2010. The distribution of native and exotic plants in kipukas in the park, representative of a naturally fragmented sagebrush-steppe landscape. *Biological Invasions* 12: 1627-40.
- Beever, E.A., C. Ray, J.L. Wilkening, P.F. Brussard, and P.W. Mote. 2011. Contemporary climate change alters the pace and drivers of extinction. *Global Change Biology* 17: 2054-2070.
- Beever, E.A., J.D. Perrine, T. Rickman, M. Flores, J.P. Clark, C. Waters, S.S. Weber, B. Yardley, D. Thoma, T.C.-Preston, K.E. Goehring, M. Magnuson, N. Nordensten, M. Nelson, G.H. Collins. 2016. Pika (*Ochotona princeps*) losses from two isolated regions reflect temperature and water balance, but reflect habitat area in a mainland region. *Journal of Mammalogy* 97: 1495-1511.
- Booth, EM. 2011. Potential effects of climate change on *Penstemon palmeri* (Plantaginaceae) in Zion National Park, Utah. M.S. Thesis, Northwestern University, Glencoe, IL.
- Bradley, B.A., M. Oppenheimer, and D.S. Wilcove. 2009. Climate change and plant invasions: restoration opportunities ahead? *Global Change Biology* 15: 1511-1521.
- Calkins, M.T., E.A. Beever, K.G. Boykin, J.K. Frey, and M.C. Andersen. 2012. Not-so-splendid isolation: Modeling climate-mediated range collapse of a montane mammal *Ochotona princeps* across numerous ecoregions. *Ecography* 35: 780-791.
- Castillo, J.A., C.W. Epps, A.R. Davis, and S.A. Cushman. 2014. Landscape effects on gene flow for a climate-sensitive montane species, the American pika. *Molecular Ecology* 23: 843-856.
- Castillo, J.A., C.W. Epps, M.R. Jeffress, C. Ray, T.J. Rodhouse, and D. Schwalm. 2016. Replicated landscape genetic and network analyses reveal wide variation in functional connectivity for American pikas. *Ecological Applications* 26: 1660-1676.
- Daly, C., M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis, and P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology*

28: 2031-2064.

- Dickson, B.G., E. Fleishman, D.S. Dobkin, and S.R. Hurteau. 2009. Relationship between avifaunal occupancy and riparian vegetation in the Central Great Basin (Nevada, USA). *Restoration Ecology* 17: 722-730.
- Eigenbrod, F., P. Gonzalez, J. Dash, and I. Steyl. 2015. Vulnerability of ecosystems to climate change moderated by habitat intactness. *Global Change Biology* 21: 275-286.
- Erb, L.P., C. Ray, and R. Guralnick. 2011. On the generality of a climate-mediated shift in the distribution of the American pika (*Ochotona princeps*). *Ecology* 92: 1730-1735.
- Erb, L.P., C. Ray, and R. Guralnick. 2014. Determinants of pika population density vs. occupancy in the Southern Rocky Mountains. *Ecological Applications* 24: 429-435.
- Flory, A.R., S. Kumar, T.J. Stohlgren, and P.M. Cryan. 2012. Environmental conditions associated with bat white-nose syndrome mortality in the north-eastern United States. *Journal of Applied Ecology* 49: 680-689.
- Foster, C.R., A.F. Amos, and L.A. Fuiman. 2010. Phenology of six migratory coastal birds in relation to climate change. *Wilson Journal of Ornithology* 122: 116-125.
- Galbreath, K.E., D.J. Hafner, and K.R. Zamudio. 2009. When cold is better: Climate-driven elevation shifts yield complex patterns of diversification and demography in an alpine specialist (American pika, *Ochotona princeps*). *Evolution* 63: 2848-2863.
- Gillies, K.E., P.J. Murphy, and M.D. Matocq. 2014. Hibernacula characteristics of Townsend's big-eared bats in Southeastern Idaho. *Natural Areas Journal* 34: 24-30.
- Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography* 19: 755-768.
- Inouye, D.W., B. Barr, K.B. Armitage, and B.D. Inouye. 2000. Climate change is affecting altitudinal migrants and hibernating species. *Proceedings of the National Academy of Sciences of the USA*. 97: 1630-1633.
- Intergovernmental Panel on Climate Change (IPCC). 2013. *Climate Change 2013: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Jeffress, M.R., T.J. Rodhouse, C. Ray, S. Wolff, and C.W. Epps. 2013. The idiosyncrasies of place: Geographic variation in the climate–distribution relationships of the American pika. *Ecological Applications* 23: 864-878.
- Kunkel, K.E., L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K.T. Redmond, and J.G. Dobson. 2013. *Regional Climate Trends and Scenarios for the U.S.* National Climate

- Assessment. Part 6. Climate of the Northwest. U.S. National Oceanic and Atmospheric Administration, Technical Report NESDIS 142-6, Washington, DC.
- La Sorte, F.A. and F.R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. *Ecology* 88: 1803-1812.
- Littell, J.S., D. McKenzie, D.L. Peterson, and A.L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. *Ecological Applications* 19: 1003-1021.
- Long, R.A., R.T. Bowyer, W.P. Porter, P. Mathewson, K.L. Monteith, and J.G. Kie. 2014. Behavior and nutritional condition buffer a large-bodied endotherm against direct and indirect effects of climate. *Ecological Monographs* 84: 513-32.
- Lorch, J.M., C.U. Meteyer, M.J. Behr, J.G. Boyles, P.M. Cryan, A.C. Hicks, A.E. Ballman, J.T.H. Coleman, D.N. Redell, D.M. Reeder, and D.S. Blehert. 2011. Experimental infection of bats with *Geomyces destructans* causes white-nose syndrome. *Nature* 480: 376-378.
- Mathewson, P., L. Moyer-Horner, E.A. Beever, N.J. Briscoe, M. Kearney, J.M. Yahn, and W.P. Porter. 2016. Mechanistic variables can enhance predictive models of endotherm distributions: The American pika under current, past, and future climates. *Global Change Biology*: 1354-1013.
- Millar, C.I., R.D. Westfall, and D.L. Delany. 2007. Response of high-elevation limber pine (*Pinus flexilis*) to multiyear droughts and 20th-century warming, Sierra Nevada, California, USA. *Canadian Journal of Forest Research* 37: 2508-20.
- Moritz, M.A., M.A. Parisien, E. Batllori, M.A. Krawchuk, J. Van Dorn, D.J. Ganz, and K. Hayhoe. 2012. Climate change and disruptions to global fire activity. *Ecosphere* 3: art49. doi:10.1890/ES11-00345.1.
- Moyes, A., C. Castanha, M. Germino, and L. Kueppers. 2013. Warming and the dependence of limber pine (*Pinus flexilis*) establishment on summer soil moisture within and above its current elevation range. *Oecologia* 171: 271-282.
- Paprocki, N. 2014. Regional distribution shifts help explain local changes in wintering raptor abundance: Implications for interpreting population trends. *PLOS One* 9: e86814.
- Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. *BioScience* 58: 501-517.
- Ray, C., E.A. Beever, and T.J. Rodhouse. 2016. Distribution of a climate-sensitive species at an interior range margin. *Ecosphere* 7: e01379. doi:10.1002/ecs2.1379.
- Rodhouse, T.J., E.A. Beever, L.K. Garrett, K.M. Irvine, M.R. Jeffress, M. Munts, and C. Ray.

2010. Distribution of American pikas in a low-elevation lava landscape: Conservation implications from the range periphery. *Journal of Mammalogy* 91: 1287-1299.
- Schwalm, D., C.W. Epps, T.J. Rodhouse, W.B. Monahan, J.A. Castillo, C. Ray, C. and M.R. Jeffress. 2016. Habitat availability and gene flow influence diverging local population trajectories under scenarios of climate change: a place-based approach. *Global Change Biology* 22: 1572-1584.
- Stephens, S.L., J.K. Agee, P.Z. Fulé, M.P. North, W.H. Romme, T.W. Swetnam, and M.G. Turner. 2013. Managing forests and fire in changing climates. *Science* 342: 41-42.
- Thomas, D.W., M. Dorais, and J.M. Bergeron. 1990. Winter energy budgets and cost of arousals for hibernating little brown bats (*Myotis lucifugus*). *Journal of Mammalogy* 71: 475-479.
- Varner, J., J.J. Horns, M.S. Lambert, E. Westberg, J.S. Ruff, K. Wolfenberger, E.A. Beever, and M.D. Dearing. 2016. Plastic pikas: Behavioural flexibility in low-elevation pikas (*Ochotona princeps*). *Behavioural Processes* 125: 63-71.
- Vogan, P.J. and A.W. Schoettle. 2015. Selection for resistance to white pine blister rust affects the abiotic stress tolerances of limber pine. *Forest Ecology and Management* 344: 110-119.
- Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, and J. Willis. 2014. Our changing climate. In Melillo, J.M., T.C. Richmond, and G. W. Yohe (Eds.) *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program, Washington, DC.
- Wang, F., P. Gonzalez, M. Notaro, D. Vimont, and J.W. Williams. in preparation. Significant historical and projected climate change in U.S. national parks.
- Woods, C.P. and T.J. Cade. 1996. Nesting habits of the loggerhead shrike in sagebrush. *Condor* 98: 75-81.