Distribution Shifts of Yellow-Bellied Marmot, *Marmota flaviventris* (Audubon and Bachman, 1841) (Rodentia: Sciuridae), Populations to Higher Elevations: A Foreboding Phenomenon as Anthropogenic Climate Change Impacts Higher Elevation Ecosystems[1]

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Abstract: Several mammalian species populations in the Colorado Rocky Mountain Region have been observed redistributing upslope to cooler environments due to temperature increases caused by anthropogenic climate change. This study sought to understand the extent of future population redistributions and quantify the estimated elevation range contractions that may occur in this region over the coming decades. By observing historical data regarding *Marmota flaviventris*, or the yellow-bellied marmot, in this region, along with three-dimensional analysis over time, applicable projections of future redistributions and contracting habitat areas were identified. I found that there is a high probability that the habitat elevation range of the yellow-bellied marmot populations will significantly contract as populations disperse upslope. The projected redistributions to higher elevations are further supported by other compounding climate change factors, such as drought, soil deterioration, and other species distribution changes. This will likely result in dispersed redistributions to the cooler climate envelope of higher elevations over time. The situation facing *M. flaviventris* represents a scenario that may apply to numerous species as anthropogenic climate change continues to increase global temperatures and alter ecosystems.

Key Words: Redistribution, Yellow-Bellied Marmot, *Marmota flaviventris*, higher elevation ecosystems, anthropogenic climate change, impacts on higher elevation ecosystems

Introduction

Redistribution of small mammalian species populations in the high-elevation Colorado upslopes has been observed and is highly correlated to increasing temperatures (McCain et al. 2021). One such species is *Marmota flaviventris* (Audubon and Bachman, 1841) (Rodentia: Sciuridae), more commonly known as the yellow-bellied marmot. Over about three decades, the yellow-bellied marmot's elevation range has changed from 1,600-3,799 m to 1,850-3,799 m (McCain et al. 2021). High-elevation *M. flaviventris* population distribution areas are decreasing as the lower elevation limit shifts upslope (McCain et al. 2021).

Figure 1. The yellow-bellied marmot, *Marmota flaviventris*. Photo by David Iliff. License: CC BY-SA 3.0. https://upload.wikimedia.org/wikipedia/commons/4/43/Marmota_flaviventris_%28Yellow_Bellied_Marmot%29%2C_Yosemite_NP_-_Diliff.jpg

My analysis seeks to understand long-term spatial and elevation range estimations for the species based on future temperature projections. Projected distribution estimations were produced for several potential climate scenarios. Current temperatures and temperature projections were compiled along elevation and topography to further define the contracting redistribution of *M. flaviventris* populations in this region. These distribution changes result in the contraction of livable habitat of local *M. flaviventris* populations. The extent of contracting habitat space is quantified using elevation contraction rates, examining topography in the region, gathering temperature increase projections, and three-dimensional quantification over time that shows projected elevation ranges of *M. flaviventris* populations in the study area.

Methods

Data regarding past population movements to higher elevations were used to project *M. flaviventris* population redistributions. The estimated rate at which *M. flaviventris*' habitat area is contracting upslope was produced by analyzing recent data regarding the population's past redistribution patterns. Utilizing the species' historical elevation range in this region, current elevation range, and the change in temperature over those time periods, the estimated rate of elevation contraction (m/decade) was calculated (Table 1).

Table 1. Temperature increases and estimated *M. flaviventris* elevation range contractions from 1980 to 2010. A tabulation of estimated elevation contraction and temperature increase from 1980 to 2010 and per decade over the same period (McCain et al. 2021, Rasmussen et al. 2016) in the high elevation Colorado Rocky Mountain Region.

Estimated Elevation Contraction, 1980-2010	Estimated Temperature Increase, 1980-2010	Estimated Elevation Contraction/Decade, 1980-2010	Estimated Temperature Increase/Decade, 1980-2010
250 m	0.72°C	76.8 m	0.24°C

The lower limit of *M. flaviventris'* elevation range shifted upslope by 250 m overall, or about 76.8 m per decade, while the upper limit did not change (McCain et al. 2021). For this region, the temperatures have increased by an average of about 0.24°C per decade (McCain et al. 2021; Rasmussen et al. 2016). Meaning, from recent time periods*,* the typical habitat of *M. flaviventris* populations in the Colorado Rocky Mountain Region has contracted by an average of 76.8m per decade as temperatures increased an average of 0.24°C per decade. This decadal ratio, the historic *M. flaviventris* Elevation Contraction based on Temperature Changes (MECTC) is used to estimate elevation redistribution projections given different future temperatures.

It is predicted that Earth's average temperature will increase between 1.1 to 5.4°C by 2100 (Brunner et al. 2020, Herring 2021, Oo et al. 2019). While this describes the macro-global outlook, temperature projections in microclimates, like that of the Colorado Rocky Mountain Region, may vary from this global average. Elevation-dependent warming has been seen across the globe, with high-elevation regions warming at a faster rate (Cordes et al. 2020, Pepin et al. 2015, Rangwala and Miller 2012, Zhi 2020). According to climate projections, the Rocky Mountain area is predicted to increase an average of 0.5-1.0°C per decade (Rangwala et al. 2012, Rasmussen 2016). Multiple temperature projections are incorporated in calculations (increases of 0.5°C, 0.7°C, 0.9°C, 1.1°C, and 1.3°C per decade) to account for numerous possible temperature outcomes. The MECTC ratio estimates *M. flaviventris'* distribution based on elevation range at these projected temperature increases.

While the assumption of a linear relationship between temperature changes and the lower limit of *M. flaviventris'* range represents a valid relationship to observe, the two-dimensional model does not adequately relate the three-dimensional nature of mountainous regions. Common knowledge shows that, as elevation increases, the cross-sectional perimeter of the mountainous terrain decreases. Therefore, as *M. flaviventris* populations contract or redistribute upslope, there is less livable habitat in more than one direction. A topographic map (Figure 2) of a widely surveyed and researched peak in Colorado, Mount Evans, was used to estimate the change in cross-sectional perimeter as elevation increases.

Figure 2. Topographic map used to gather perimeter data at various elevations (United States Geological Survey 2021).

The MECTC ratio and the relationship between elevation and cross-sectional perimeter provide a three-dimensional look into *M. flaviventris*' contracting habitat. This data was used to develop decadal livable habitat projections for *M. flaviventris* and quantify the populations' potential redistributions.

Results

The historical MECTC ratio was utilized to calculate the upshift in elevation based on the projected temperature increases of 0.5ºC, 0.7ºC, 0.9ºC, 1.1ºC, and 1.3ºC per decade. The MECTC ratio, along with projected temperature increases, estimated the decadal change in the lower limit of *M. flaviventris*' livable elevation range, or the Elevation Change of the Lower Limit, ECLL.

$$\frac{76.8 \text{ m ECLL}}{0.24 \text{ ºC Inc. Temp}} \text{per decade} = \frac{\text{x (m) ECLL}}{\text{y ºC Inc. Temp}} \text{per decade}$$

Using the additive ECLL, the projected lower limit elevation (LLE) was calculated for future decades, which in turn predicted the elevation range projection (ERP), or the projected elevation range to which *M. flaviventris* will redistribute (Table 2 and Figure 3).

Table 2. Projected lower limit elevations for several decadal temperature increases.

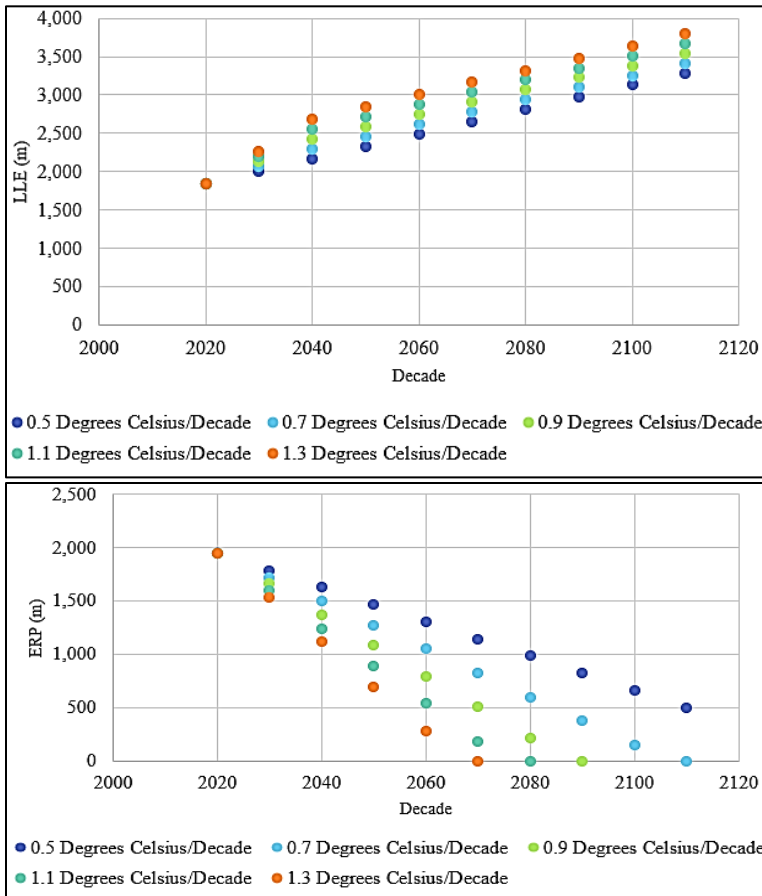| Degree Celsius Change/Decade	ECLL/Decade Calculated Using the MECTC
0.5°C	160 m
0.7°C	224 m
0.9°C	288 m
1.1°C	352 m
1.3°C	416 m

Figure 3. Projections of elevation range distribution for *M. flaviventris* populations based on different temperature increases per decade predictions. The upper panel represents the increasing Lower Limit Elevation (LLE) of *M. flaviventris*' elevation range over time based on the decadal increase in temperature. The lower panel represents the Elevation Range Projection (ERP) over time based on the decadal increase in temperature. The starting lower limit was 1,850 m and the starting elevation range was 1,949 m based on known data regarding the species (McCain et al. 2021).

While useful, Figure 3 is incomplete without further consideration for the three-dimensional nature of the mountainous region. The effects of elevation loss for high elevation species populations directly relate to the decrease in surface area as elevation increases. Examining cross-sectional perimeter shows how a contracting elevation range upslope decreases *M. flaviventris*' projected distribution space in multiple directions.

The relationship between elevation and cross-sectional area was calculated (Figure 4) to include a three-dimensional component in the spatial analysis of *M. flaviventris*' changing distribution area. Specifically, cross-sectional perimeter was utilized, since, relative to the volume of mountain ranges, *M. flaviventris* predominantly stays on the surface; their burrowing behaviors do not have geological significance compared to the volume of mountains. The perimeter was gathered from a topographic map (Figure 2).
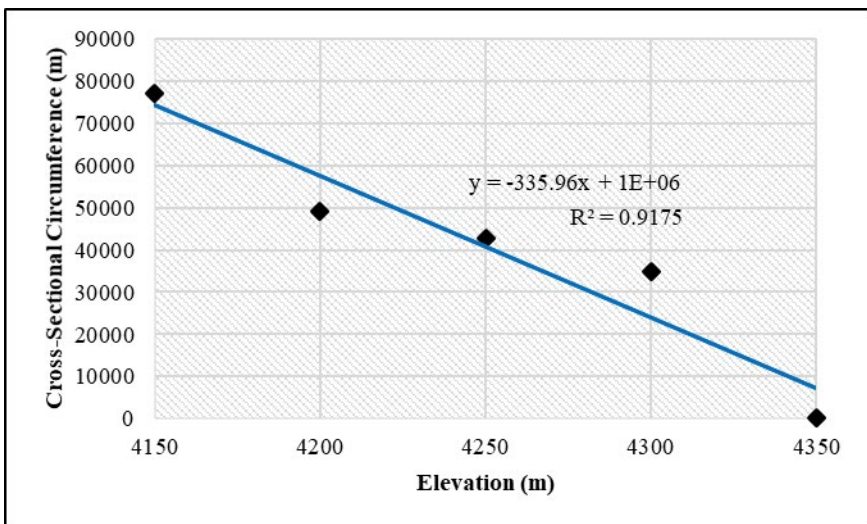

Figure 4. Estimated cross-sectional perimeter by elevation based on Mt. Evans. This figure shows the relationship between increasing elevation and decreasing cross-sectional perimeter.

Utilizing data of changing distribution area, temperature increase projections, and time, a three-dimensional analysis was conducted for temperature increases of 0.5°C, 0.7°C, 0.9°C, 1.1°C, and 1.3°C per decade (Figure 5). Figure 5 provides a three-dimensional estimation and visualization tool for comprehending the diminishing habitat or space *M. flaviventris* populations in the Colorado Rocky Mountain Region will likely occupy.
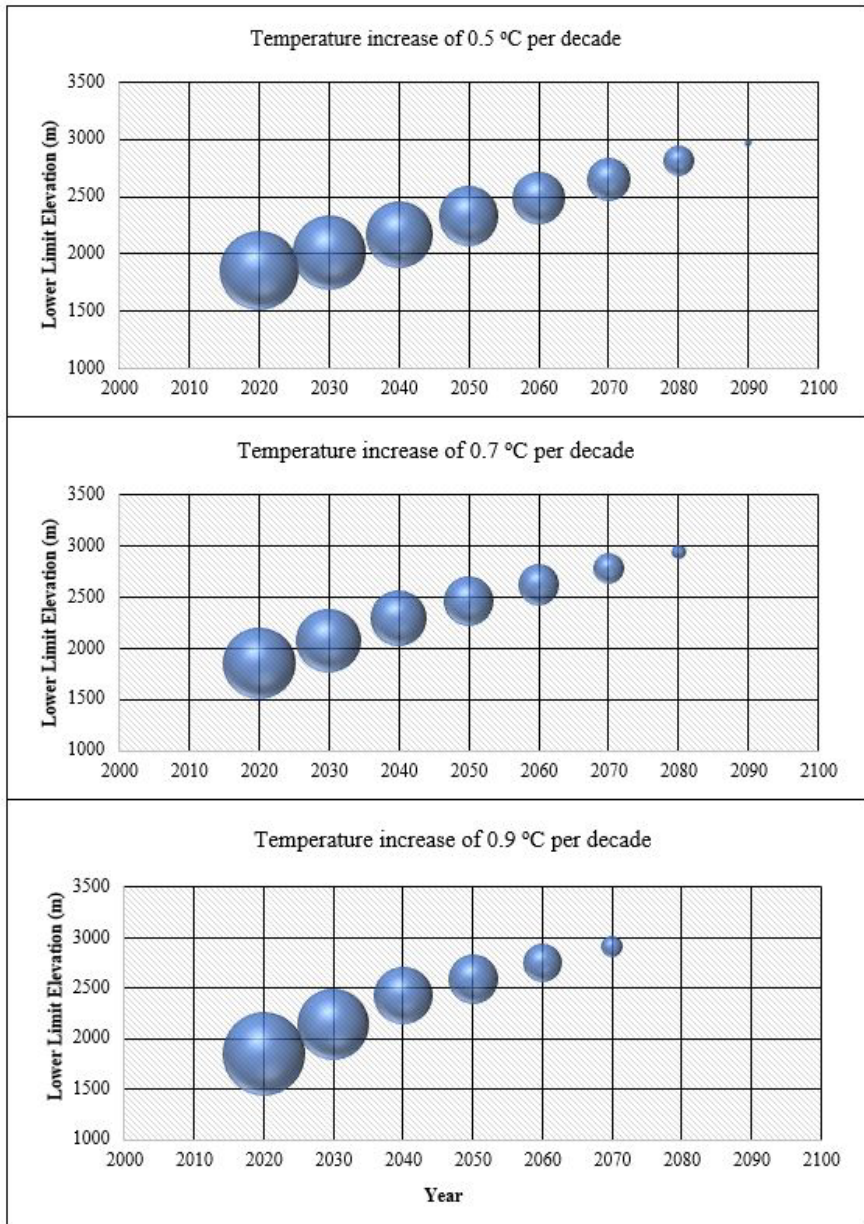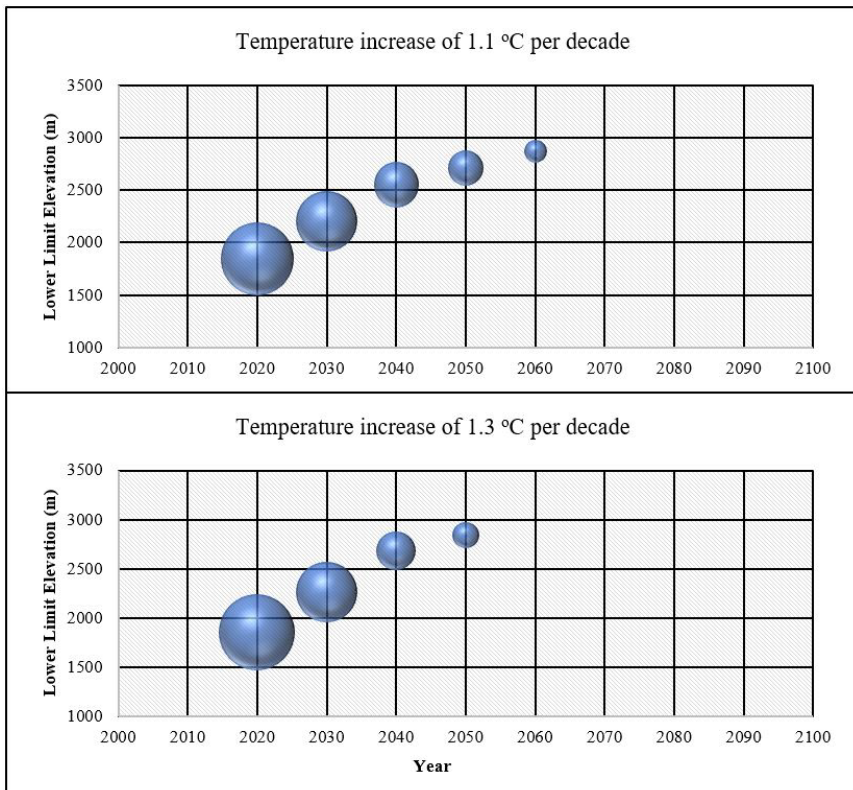
Figure 5. Estimated future distributions for *M. flaviventris* populations in the Colorado Rocky Mountain Region. Each panel shows the estimated distribution elevation range for *M. flaviventris* over time based on the decadal temperature increase labeled above each graph, ranging from 0.5 to 1.3 °C per decade. The relative size of the spheres indicates the estimated cross-sectional perimeter at that lower limit value (m).

Discussion and Conclusions

Based on several pieces of evidence, anthropogenic climate change greatens the likelihood that *M. flaviventris* populations in the Colorado Rocky Mountain Region will redistribute upslope in response to increasing temperatures. The populations' habitat area will contract since the lower limit elevation is shifting upslope, while the upper limit remains consistent (McCain et al. 2021). This pattern represents an application of temperature dependent species redistributions occurring in high elevation ecosystems in response to climate change.

Furthermore, as data were collected, it became increasingly relevant to discuss other environmental influences that will potentially contribute to population redistributions. The Colorado Rocky Mountain Region will experience less surface water, more droughts, lower water quality, deteriorated soil health,

and a decrease in snow cover (Fassnacht et al. 2018, Higuera et al. 2021, Inglis and Vukomanovic 2020, Overpeck and Udall 2020). These effects impact broad ecological systems. For example, sandy loam soils, a soil type *M. flaviventris* commonly burrows in, have a relatively high tendency for erosion as climate change issues become more prevalent. This deterioration becomes greater on sloped areas (Mondal et al. 2015), which are frequently home to yellow-bellied marmot burrows (Burdette et al. 2021, Svendsen 1976), suggesting that some of the soil *M. flaviventris* utilizes for burrow development may become more difficult and/or too unstable for them to use. Another aspect to consider is that temperature and precipitation changes, land-use change, rain and snowmelt alterations, and weather pattern intensification (i.e., storms, flooding, etc.) all contribute to potential worsening of water quality (Crawford et al. 2019, Milly and Dunne 2020, Murdoch et al. 2007, Rue and McKnight 2021, Slama et al. 2020, Todd et al. 2012). Colorado's already acidic and metal-rich watersheds due to mining practices throughout the state show increasing acidity and metal concentrations as temperatures rise (Rue and McKnight 2021). This decrease in water quality is caused by increasing dissolving capabilities of warmer water and expanding weathering fronts due to lower water levels (Rue and McKnight 2021, Todd et al. 2012). Water scarcity or other issues may greaten *M. flaviventris* population redistributions.

Not only will worsening soil health and water qualities and quantities impact *M. flaviventris*, but it will also affect the species' food sources. *M. flaviventris*' diet predominantly consists of grasses and forbs (Stallman and Holmes 2002). Plant species at high altitudes, including forbs, are experiencing redistributions, and are decreasing in prevalence (Bueno de Mesquita et al. 2018, Huxley and Spasojevis 2021, Inouye 2019, Niu et al. 2019, Pauchard et al. 2015, Winkler et al. 2016, Winkler et al. 2018). Additionally, biodiversity is broadly deceasing in this area (Seastedt and Oldfather 2021), which could impact *M. flaviventris*' different consumptive, predatory, and connected inter-species interactions in the ecosystem. Overall, these changing climatic and environmental variables within the Colorado Rocky Mountain region contribute to the likelihood of *M. flaviventris* population redistributing upslope over time. Paleorecords support these findings as well. *M. flaviventris'* high sensitivity to environmental variations and high probability of redistribution in response to those variations was observed utilizing isotopic data (Reynard et al. 2015). And genetic diversity within *M. flaventris* populations has been correlated with historical habitat availability (Rankin et al. 2019). Meaning, the less habitat available to *M. flaviventris*, the less genetic diversity its populations exhibit. This could become an issue as *M. flaviventris* habitats in the Colorado Rocky Mountain Region contract.

The repercussions of *M. flaviventris* population redistributions via habitat contraction are not quite clear. Smaller, more isolated populations of the species have been observed to be more prone to extinction (Frey et al. 2019), so redistributions to smaller habitat areas have the potential to negatively impact

biodiversity within and survival of *M. flaviventris* populations in the study region. Female yellow-bellied marmots at higher elevations have been shown to produce less offspring (Woods et al. 2010), potentially stressing the populations that disperse upslope. However, *M. flaviventris* has been shown to have significant climate resiliency, perhaps due to its hibernating behaviors that allow the species to avoid changing climates during hibernation periods (Rinnan and Lawler, 2019), even though divergent seasonal and inter-annual behaviors have been observed in the species in response to climate alterations (Cordes et al. 2020). The effects of climate change on yellow-bellied marmot hibernation behaviors and fitness are complex. For instance, populations have been observed to increase in number due to changes in snowpack since lower snow levels typically means heightened foraging capabilities (Ozgul et al. 2010, Vuren and Armitage 2019). Furthermore, *M. flaviventris* populations have been found in diverse climates. *M. flaviventris* populations were recently seen in the Jemez Mountains of New Mexico because wildfires are potentially changing their behavior/habitat distribution patterns (Frey et al. 2019). Therefore, the species has shown positive responses to redistribution, especially when considering redistributions in this species have been observed in the paleorecord (Reynard et al. 2015).

Based on the data from this study, it is likely that *M. flaviventris* populations in the high-elevation Colorado Rocky Mountain region will redistribute upslope to a cooler climate envelope. Increasing temperatures will cause the species populations in this area to disperse upslope over time. Furthermore, other climate change side effects will likely exacerbate negative impacts in the Colorado Rocky Mountain Region. These impacts increase the likelihood of *M. flaviventris* populations redistributing. While these populations may prove resilient and plastic in response to these changes, that is not guaranteed, and other species may not fare as well. Overall, *M. flaviventris* exemplifies a model organism for a concerning situation already occurring anthropogenic climate change causing large-scale redistributions of populations in Colorado Rocky Mountain Region ecosystems.

Literature Cited

Brunner, L., A. G. Pendergrass, F. Lehner, A. L Merrifield, R. Lorenz, and R. Knutti. 2020. Reduced global warming from CMIP6 projections when weighting models by performance and Independence. *Earth Systems Dynamics* 11(4):995-1012. https://doi.org/10.5194/esd-11-995-2020

Bueno de Mesquita, C. P., L. S. Tillmann, C. D. Bernard, K. C. Rosemond, N. P. Molotch, and K. N. Suding. 2018. Topographic heterogeneity explains patterns of vegetation response to climate change (1972–2008) across a mountain landscape, Niwot Ridge, Colorado. *Arctic, Antarctic, and Alpine Research* 50(1). 16 pp. https://doi.org/10.1080/15230430.2018.1504492

Burdette, A., A. C. Klassen, M. Rodriguez, and A. Z. Verhey. 2021. Microhabitat selection of rock outcrops in yellow-bellied marmots (*Marmota flaviventris*). *California Ecology and Conservation Research* 5(5). 8 pp. https://doi.org/10.21973/N3KT0V

Cordes, L. S., D. T. Blumstein, K. B. Armitage, P. J. CaraDonna, D. Z. Childs, B. D. Gerber, J. G. Martin, M. K. Oli, and A. Ozgul. 2020. Contrasting effects of climate change on seasonal survival of a hibernating mammal. *Proceedings of the National Academy of Sciences* 117(30): 18119–18126. https://doi.org/10.1073/pnas.1918584117

Crawford, J. T., E.-L. S. Hinckley, M. I. Litaor, J. Brahney, and J. C. Neff. 2019. Evidence for accelerated weathering and sulfate export in high alpine environments. *Environmental Research Letters* 14(12). 10 pp. https://doi.org/10.1088/1748-9326/ab5d9c

Fassnacht, S., N. Venable, D. McGrath, and G. Patterson. 2018. Sub-seasonal snowpack trends in the Rocky Mountain National Park area, Colorado, USA. *Water* 10(5):562. 19 pp. https://doi.org/10.3390/w10050562

Frey, J. K., E. A. Beever, C. D. Hathcock, R. R. Parmenter, and M. L. Westover. 2019. Discovery of the yellow-bellied marmot (*Marmota flaviventris*) in the Jemez Mountains, New Mexico: Examining competing hypotheses for range extension. *Western North American Naturalist* 79(3):285-294. https://doi.org/10.3398/064.079.0301

Herring, D. 2021. Climate Change: Global Temperature Projections. *Climate.gov: Science and Information for a Climate-Smart Nation.* https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature-projections

Higuera, P. E., B. N. Shuman, and K. D. Wolf. 2021. Rocky Mountain subalpine forests now burning more than any time in recent millennia. *Proceedings of the National Academy of Sciences* 118(25). 5 pp. https://doi.org/10.1073/pnas.2103135118

Huxley, J. D. and M. J. Spasojevic. 2021. Area not geographic isolation mediates biodiversity responses of alpine refugia to climate change. *Frontiers in Ecology and Evolution* 9(Article 633697):11 pp. https://doi.org/10.3389/fevo.2021.633697

Inglis, N. C. and J. Vukomanovic. 2020. Climate change disproportionately affects visual quality of cultural ecosystem services in a mountain region. *Ecosystem Services* 45(Article 101190):10 pp. https://doi.org/10.1016/j.ecoser.2020.101190

Inouye, D. W. 2019. Effects of climate change on alpine plants and their pollinators. *The New York Academy of Sciences* 1469(1):26–37. https://doi.org/10.1111/nyas.14104

Mondal, A., D. Khare, S. Kundu, P. K. Meena, P. K. Mishra, and R. Shukla. 2015. Impact of climate change on future soil erosion in different slope, land use, and soil-type conditions in a part of the Narmada River Basin, India. *Journal of Hydrologic Engineering* 20(6):12 pp. https://doi.org/10.1061/(asce)he.1943-5584.0001065

McCain, C. M., S. R. King, and T. M. Szewczyk. 2021. Unusually large upward shifts in cold-adapted, montane mammals as temperature warms. *Ecology* 102(4): 12 pp. https://doi.org/10.1002/ecy.3300

Milly, P. C. D. and K. A. Dunne. 2020. Colorado River flow dwindles as warming-driven loss of reflective snow energizes evaporation. *Science* 367(6483):1252–1255. https://doi.org/10.1126/science.aay9187

Murdoch, P. S., J. S. Baron, and T. L. Miller. 2007. Potential effects of climate change on surface-water quality in North America. *Journal of the American Water Resources Association* 36(2): 347–366. https://doi.org/10.1111/j.1752-1688.2000.tb04273.x

Niu, Y., S. Yang, J. Zhou, B. Chu, S. Ma, H. Zhu, and L. Hua. 2019. Vegetation distribution along mountain environmental gradient predicts shifts in plant community response to climate change in alpine meadow on the Tibetan Plateau. *Science of the Total Environment* 650:505–514. https://doi.org/10.1016/j.scitoten v.2018.08.390

Oo, H. T., W. W. Zin, and C. C. Thin Kyi. 2019. Assessment of future climate change projections using multiple global climate models. *Civil Engineering Journal* 5(10):2152–2166. https://doi.org/10.28991/cej-2019-03091401

Overpeck, J. T., and B. Udall. 2020. Climate change and the aridification of North America. *Proceedings of the National Academy of Sciences* 117(22):11856–11858. https://doi.org/10.1073/pnas.2006323117

Ozgul, A., D. Z. Childs, M. K. Oli, K. B. Armitage, D. T. Blumstein, L. E. Olson, S. Tuljapurkar, and T. Coulson. 2010. Coupled dynamics of body mass and population growth in response to environmental change. *Nature* 466(7305):482–485. https://doi.org/10.1038/nature09210

Pauchard, A., A. Milbau, A. Albihn, J. Alexander, T. Burgess, C. Daehler, G. Englund, F. Essl, B. Evengård, G. B. Greenwood, S. Haider, J. Lenoir, K. McDougall, E. Muths, M. A. Nuñez, J. Olofsson, L. Pellissier, W. Rabitsch, L. J. Rew, M. Robertson, N. Sanders, and C. Kueffer. 2015. Non-native and native organisms moving into high elevation and high latitude ecosystems in an era of climate change: New challenges for ecology and conservation. *Biological Invasions* 18(2):345–353. https://doi.org/10.1007/s10530-0151025-x

Pepin, N., R. S. Bradley , H. F. Diaz, M. Baraer, E. B. Caceres, N. Forsythe, H. Fowler, G. Greenwood, M. Z. Hashmi, X. D. Liu, J. R. Miller, L. Ning, A. Ohmura, E. Palazzi, I. Rangwala, W. Schoner, I. Severskiy, M. Shahgedenova, and M. B. Wang. 2015. Elevation-dependent warming in mountain regions of the world. *Nature Climate Change* 5(5): 424–430. https://doi.org/10.1038/nclimate2563

Rangwala, I., J. Barsugli, K. Cozzetto, J. Neff, and J. Prairie. 2012. Mid-21st century projections in temperature extremes in the southern Colorado Rocky Mountains from regional climate models. Climate Dynamics, 39(7-8): 1823–1840. https://doi.org/10.1007/s00382-011-1282-z

Rangwala, I. and J. R. Miller. 2012. Climate change in mountains: A review of elevation-dependent warming and its possible causes. *Climatic Change* 114(3-4):527–547. https://doi.org/10.1007/s10584-012-0419-3

Rankin, A. M., R. S. Schwartz, C. H. Floyd, and K. E. Galbreath. 2019. Contrasting consequences of historical climate change for marmots at Northern and temperate latitudes. *Journal of Mammalogy* 100(2):328–344. https://doi.org/10.1093/jmammal/gyz025

Rasmussen, D. J., M. Meinshausen, and R. E. Kopp. 2016. Probability-weighted ensembles of U.S. county-level climate projections for climate risk analysis. *Journal of Applied Meteorology and Climatology* 55(10):2301–2322. https://doi.org/10.1175/jamc-d-15-0302.1

Reynard, L. M., D. J. Meltzer, S. D. Emslie, and N. Tuross. 2015. Stable Isotopes in Yellow-Bellied Marmot (Marmota Flaviventris) Fossils Reveal Environmental Stability in the Late Quaternary of the Colorado Rocky Mountains. *Quaternary Research* 83(2): 345–354. https://doi.org/10.1016/j.yqres.2014.12.006

Rinnan, D. S., and J. Lawler. 2019. Climate-Niche Factor Analysis: A spatial approach to quantifying species vulnerability to climate change. *Ecography* 42(9): 1494–1503. https://doi.org/10.1111/ecog.03937

Rue, G. P. and D. M. McKnight. 2021. Enhanced Rare Earth Element Mobilization in a mountain watershed of the Colorado mineral belt with concomitant detection in aquatic biota: Increasing climate change-driven degradation to water quality. *Environmental Science & Technology* 55(21): 14378–14388. https://doi.org/10.1021/acs.est.1c02958

Seastedt, T. R. and M. Oldfather. 2021. Climate change, ecosystem processes and biological diversity responses in high elevation communities. *Climate* 9(5). 16 pp. https://doi.org/10.3390/cli9050087

Slama, F., E. Gargouri-Ellouze, and R. Bouhlila. 2020. Impact of rainfall structure and climate change on soil and groundwater salinization. *Climatic Change* 163(1): 395-413. https://doi.org/10.1007/s10584-020-02789-0

Stallman, E. L., and W. G. Holmes. 2002. Selective foraging and food distribution of high-elevation yellow-bellied marmots (*Marmota flaviventris*). *Journal of Mammalogy* 83(2):576–584. https://doi.org/10.1644/1545-1542(2002)083<0576:sfafdo>2.0.co;2

Svendsen, G. E. 1976. Structure and location of burrows of yellow-bellied marmot. *The Southwestern Naturalist* 20(4):487–494. https://doi.org/10.2307/3669865

Todd, A. S., A. H. Manning, P. L. Verplanck, C. Crouch, D. M. McKnight, and R. Dunham. 2012. Climate-change-driven deterioration of water quality in a mineralized watershed. *Environmental Science & Technology* 46(17):9324–9332. https://doi.org/10.1021/es3020056

U.S. Geological Survey. 2021. U.S. Topo Map: Mount Evans Quadrangle. *U.S. Department of the Interior*. https://apps.nationalmap.gov/viewer/

Vuren, D. V. and K. B. Armitage. 1991. Duration of snow cover and its influence on life-history variation in yellow-bellied marmots. *Canadian Journal of Zoology* 69(7):1755–1758. https://doi.org/10.1139/z91-244

Winkler, D. E., R. J. Butz, M. J. Germino, K. Reinhardt, and L. M. Kueppers. 2018. Snowmelt timing regulates community composition, phenology, and physiological performance of Alpine Plants. *Frontiers in Plant Science* 9. 13 pp. https://doi.org/10.3389/fpls.2018.01140

Winkler, D. E., K. J. Chapin, and L. M. Kueppers. 2016. Soil moisture mediates alpine life form and community productivity responses to warming. *Ecology* 97(6): 1553–1563. https://doi.org/10.1890/15-1197.1

Woods, B. C., C. L. Brown, and M.A. Cobb. 2010. Elevation variation in life-history characteristics of populations of yellow-bellied marmots (*Marmota flaviventris*). *Ethology Ecology & Evolution* 21(3-4):381–392. https://doi.org/10.1080/08927014.2009.9522493

Zhi, W., K. H. Williams, R. W. H. Carroll, W. Brown, W. Dong, D. Kerins, and L. Li. 2020. Significant stream chemistry response to temperature variations in a high-elevation mountain watershed. *Communications Earth & Environment 1(1).* 10 pp. https://doi.org/10.1038/s4324702-0-00039-w