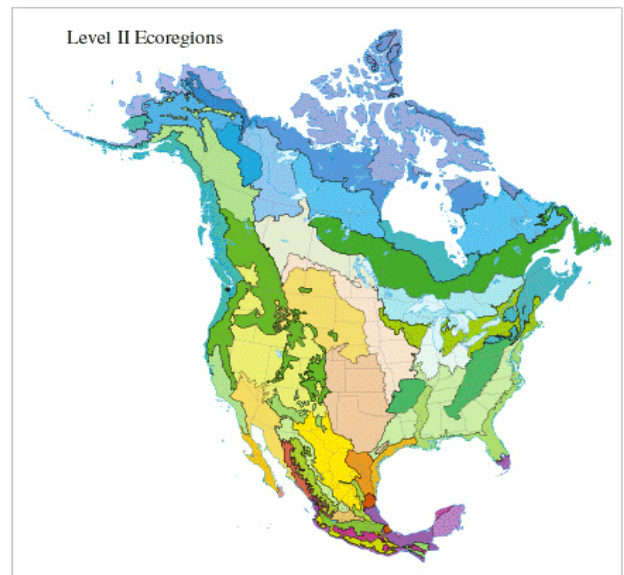




You won't find palm trees in the Arctic or polar bears in the Amazon rainforest. Earth's species are adapted to live under specific light, temperature, moisture and soil chemistry conditions. Areas with similar climate and vegetation, such as tropical rainforests, are known as *biomes*. Desert and xeric (low moisture) shrublands are other types of biome; boreal forests are yet another. Where on Earth these biomes lie is primarily determined by proximity to the equator and to the nearest ocean. Temperatures are warmer near the equator and the climate is generally wetter with less seasonal extremes the closer a location is to the ocean. As Earth's climate warms, the locations these biomes cover will generally move closer to the poles. As Earth's climate cools, biomes generally contract closer to the Equator.

Mountains also create climate variability. On a global scale, mountains can "block" the movement of moisture from the oceans to the land masses. Dry regions such as the deserts of the intermountain West, America's Great Plains and the Atacama Desert in South America are particularly dry because they sit in mountain *rain shadows*. On a more local scale, different elevations correspond to different *life zones*, or areas of similar climate and vegetation – something evident to anyone who has driven across the western U.S. Around the San Francisco Mountains in Arizona, for example, lowland deserts where cactus and mesquite grow transition into higher elevation sagebrush and juniper zones. Climbing higher, Ponderosa Pines gradually replace junipers, and at yet higher elevations aspens replace Ponderosa Pines. Near the summits, Douglas firs and alpine spruces dominate. A 19th century American naturalist, C.H. Merriam, noticed the transition from different life zones as one moved to higher elevations corresponded to similar transitions as one moved to higher latitudes. His general rule of thumb, which is still accepted today, holds that every mile in elevation gained is roughly equivalent to 800 miles of latitude gained, all other things (distance to the ocean, soil type, etc.) being equal. Why do such elevational transitions occur? There are three primary reasons:



The lower 48 states divided into Ecoregions, geographic zones with similar climate and species that have evolved together into a community. In the West, for example, green indicates forested mountain regions; pale yellow indicates lowland xeric desert landscapes. Image Courtesy of EPA.

- **Temperature:** Average temperatures drop by about 3.8 degrees Fahrenheit for every 1,000 feet gained in elevation. Lower average temperatures mean there is less moisture drawn out of the soil and plants through evaporation, but it also means more extreme cold during winter.
- **Precipitation:** Mountains force air masses passing through to rise. As this happens, the air cools causing condensation, cloud formation and eventually precipitation – a phenomenon known as *orographic precipitation*. Precipitation tends to increase as elevation increases. Because orographic precipitation drains the moisture from the air, it is responsible for the rain shadow effect described above.
- **Winds:** Wind speed increases at higher elevations at a rate of about 7.5 miles per hour for every mile in elevation gained. Because stronger winds cause physical damage, they discourage tree growth above certain elevations. Only specifically adapted ground hugging plants, such as grasses, sedges, mosses, shrubs and lichens can survive the extreme cold and winds of alpine zones.

Additionally, higher elevation areas have highly variable topography with steep cliffs, frequently disturbed landscapes, lots of ice and snow, and different slope aspects (slopes facing north tend to host different life zones than those found on south facing slopes) that create many microclimates in relatively small geographic areas.

Mountain Ecosystems in a Changing Climate

As Earth warms, just as biomes move closer to the poles, mountain life-zones move to higher elevations. In Vermont's Green Mountains, for example, broadleaf forests at lower elevations have been moving upslope and encroaching on the traditional habitat of conifer species that are better adapted to the extreme cold of the far north and higher elevations. Over the past 40 years, the mountain area dominated by broadleaf forests increased by 19 percent as the region warmed by two degrees Fahrenheit and precipitation increased by 40 percent. It is important to note that the movement of life zones is a theoretical concept; in reality, every species responds differently to climate change, meaning that ecosystems and relationships between species change along with climate.

Climate change also changes plant growth forms. Conifers grow more like bushes once they reach certain elevations, inhabiting *krummholz zones*, or treeline zones where cold temperatures, strong winds and long durations of snow cover limit tree growth. Over the course of the last century, the *krummholz* zones of the Sierra Nevada Mountains experienced an average minimum temperature increase of 6.7 degrees Fahrenheit. These warmer temperatures allowed the *krummholz* trees to "stand up" and mean annual branch growth in these zones increased by between 130 and 400 percent. This phenomenon has also been observed in the Cascade Mountains of Oregon and Washington, as well as in Glacier National Park in Montana. In all these ranges, trees have begun to grow more and expand into areas that were previously meadows or snowfields inhabited only by low lying plants that can better tolerate long periods of snow cover and high winds.



One of the Three Sisters mountains in Oregon. This area has witnessed increased growth in the *krummholz* zone as well as movement of the treeline to higher elevations. Image Courtesy of USGS.

Snowpack Changes Affect Mountain Plants

Snowpack, the amount of snow that accumulates annually in a mountain area, and *snow cover*, the area covered by snow, are important regulators of the types of species that inhabit mountain ecosystems. In the sub-alpine transition zones in Oregon's Cascade Mountains, for example, tree growth and establishment are limited on north facing slopes by the long duration of seasonal snow cover. On south facing slopes, however, more snow pack means a longer period of the year when the soil is moist, which promotes tree growth and establishment. In the Pacific Northwest today, temperatures are warmer than they were in the 1950s and more annual precipitation falls as rain instead of snow. Some Cascade stations are reporting less than half the snow accumulation they did in the 1930s. Not surprisingly, during warming periods of the 20th century, tree establishment on north-facing slopes increased while on south facing slopes, as well as the southern parts of the region, tree establishment was limited.



Showy Milkweed is pollinated by a swallowtail butterfly at a high-altitude location in Yosemite National Park, California. Image courtesy of NPS.

Snow cover and timing of snow melt also affect the lives of flowering plants and pollinators, such as bees, beetles and butterflies. Flower buds are particularly vulnerable to frost damage – a plant takes a risk when it buds in the spring, as spring frost may wipe out its reproductive efforts. While one might think that warmer temperatures would lead to less frost mortality, earlier loss of snow cover due to warmer temperatures actually encourages plants to flower earlier. But, overall warming has not eliminated spring frosts and buds now appear to be at greater risk of frost damage. In the Rocky Mountains, two plots separated by a 40 foot difference in elevation had a 3.7 degree average temperature difference and a corresponding difference in snow cover duration and melt timing. The colder plot had 37 percent less frost damage than the other plot. Higher atmospheric carbon dioxide (CO₂) levels also appear to make many species more sensitive to frost damage – atmospheric CO₂ levels are 40 percent higher today than in the 18th century.

Every species responds differently to climate changes. Some plant species will not show an earlier flowering response to a warming trend, while others will. Mistiming between plants flowering and the hatching of their pollinators, for example, means ecosystem dysfunction. Species that share pollinators often flower together and if one species flowers earlier, this species can gain a competitive advantage or disadvantage over the others. Or, if species that flowered at different times (a form of *niche partitioning* or a division of available resources to lessen competition) begin flowering at the same time, additional competition for pollinators can ensue.

Special thanks to Dr. Daniel B. Fagre at the United States Geological Survey for his contribution to this paper.

Sources:

Beckage, B. et al. "A rapid upward shift of a forest ecotone during 40 years of warming in the Green Mountains of Vermont." *PNAS* 105 (2008): 4197-4202.

Forrest, J et al. "Flowering phenology in subalpine meadows: Does climate variation influence community co-flowering patterns?" *Ecology* 91 (2010): 431-440.

Inouye, DW. "Effects of Climate Change on Phenology, Frost Damage, and Floral Abundance of Montane Wildflowers." *Ecology* 89 (2008): 353-362.

Lambrecht, SC et al. "Reproductive and physiological responses to simulated climate warming for four subalpine species." *New Phytologist* 173 (2007): 121-134.

MacDonald, GM. *Biogeography: Space, Time and Life*. Danvers, MA: John Wiley & Sons, Inc, 2003.

Martin, M et al. "Reduced early growing season freezing resistance in alpine treeline plants under elevated atmospheric CO₂." *Global Change Biology* 16 (2009): 1057-1070.

McVicar, TR. "Observational evidence from two mountainous regions that near-surface wind speeds are declining more rapidly at higher elevations than lower elevations: 1960-2006." *Geophysical Research Letters* 37 (2010): L06402.

Millar, CI et al. "Response of Subalpine Conifers in the Sierra Nevada, California, U.S.A., to 20th-Century Warming and Decadal Climate Variability." *Arctic, Antarctic, and Alpine Research* 36 (2004): 181-200.

Miller, Eric and Halpern, Charles. "Effects of environment and grazing disturbance on tree establishment in meadows of the central Cascade Range, Oregon, USA." *Journal of Vegetation Science* 9: 265-282, 1998.

Peterson, DW and Peterson, DL. "Mountain Hemlock Growth Responds to Climatic Variability at Annual and Decadal Time Scales." *Ecology* 82 (2001): 3330-3345.

Powell, S and Hansen, A. "Conifer Cover Increase in the Greater Yellowstone Ecosystem: Frequency, Rates, and Spatial Variation." *Ecosystems* 10 (2007): 204-216.

Wipf, S et al. "Winter climate change in alpine tundra: plant responses to change in snow depth and snowmelt timing." *Climatic Change* 94 (2010): 105-121.