VEGETATION DISTRIBUTION SHIFTS (NO UPDATE)

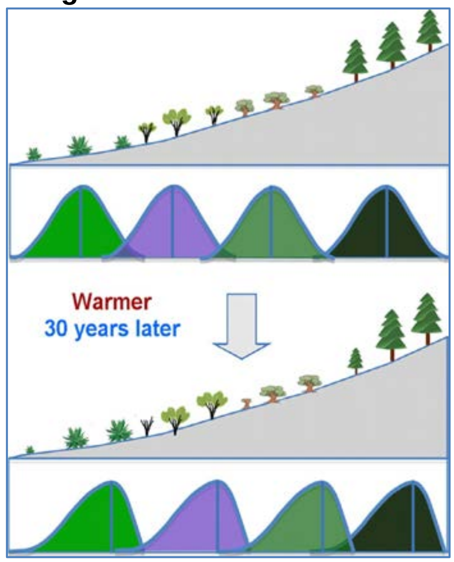
The distribution of vegetation across the north slope of Deep Canyon in the Santa Rosa Mountains has moved upward 213 feet in the past 30 years.

Figure 1. Change in mean elevation* of plant species in the Deep Canyon Transect

Common Name	Mean elevation, m: 1977	Mean elevation, m: 2006-2007	Change
White Fir	2,421	2,518	96
Jeffrey Pine	2,240	2,267	28
Canyon Live Oak	1,987	2,033	47
Sugar Bush	1,457	1,518	61
Desert Ceanothus	1,602	1,671	70
Muller's Scrub Oak	1,485	1,522	37
Creosote Bush	317	459	142
Burrobush	630	748	118
Brittlebush	574	674	100
Desert Agave	693	643	-50
Mean change in elevation			**65 m (213 ft)**
95% confidence interval			34 m (112 ft)

** Change in cover-weighted mean elevation of ten most widely distributed species in the Deep Canyon Transect*

Figure 2. A conceptual diagram: Vegetation distribution shifts



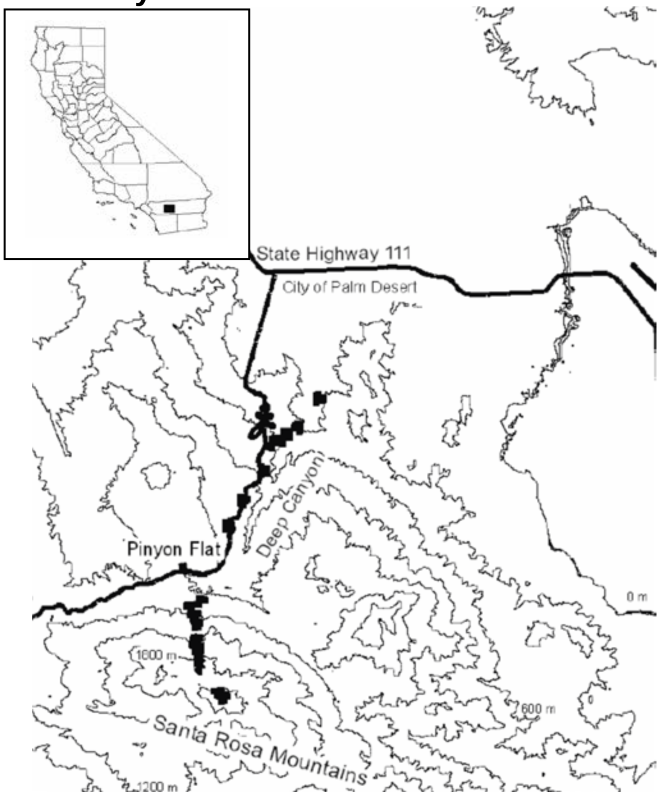
Source: Breshears et al., 2009

What does the indicator show?

The mean elevation of nine of the ten dominant plant species in the Deep Canyon Transect of Southern California's Santa Rosa Mountains (see map, Figure 3) have moved upslope in the past 30 years (Kelly and Goulden, 2008). A comparison of two vegetation surveys of plant cover — one in 1977 and the other in 2006-2007 — along an 8,400-foot elevation gradient found that the average elevation of the dominant species rose by 65 meters (213 feet) between the surveys. All vegetation types moved upward, including small desert shrubs, chaparral, Canyon oak, and large conifers.

Although the species distribution moved upslope, the upper and lower range limits of these species have not changed. At the lower half of the species' ranges, individual plants have pruned limbs or completely died, reducing their dominance. An increase in cover was observed at the upper half of the species' ranges, where mature plants have reproduced and grown in size, increasing their dominance.

Figure 3. The sites of the Deep Canyon surveys and their location in California



Source: Kelly and Goulden, 2008

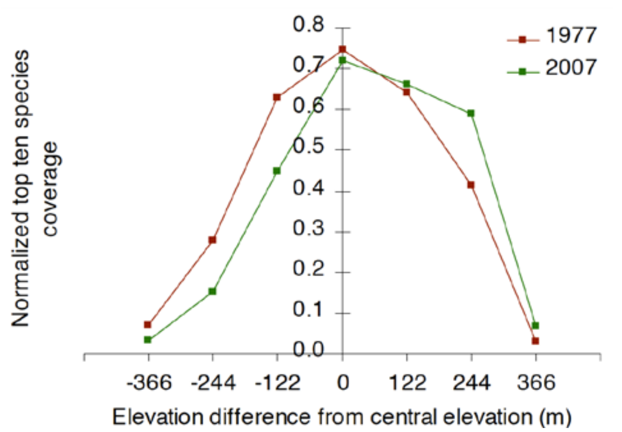
The conceptual diagram above illustrates these changes. Vegetation species along the mountain slope were distributed in a bell curve along the slope in 1977, with the highest abundances at the middle of each species' range. After 30 years of warming and drought, vegetation experienced die-off at the lower edges of each species' range, while plants at the cooler, wetter, upper elevations increased in dominance.

Vegetation distribution changes at Deep Canyon can be compared to the conceptual diagram using the graph in Figure 4. A detailed discussion of the derivation of the metrics presented is beyond the scope of this narrative (see Kelly and Goulden, 2008 for details).

In simple terms, Figure 4 shows plant coverage (which represents the percent of ground surface covered by vegetation) plotted against elevation, with “0” representing the “center elevation” (the midpoint of the lowest and highest elevations where each species was found.) (The y-axis of the graph shows “normalized” coverage, derived by dividing each species’ coverage at each elevation in 2007 by its maximum coverage at any elevation in 1977 and averaging across the ten dominant species.)

Figure 4 shows that the ten dominant species in the survey area had a symmetric normalized distribution in 1977. This changed to an upwardly skewed distribution in 2007. From 1977 to 2007, cover declined in the lower parts of the species’ original ranges (by a median of 46 percent) and increased in the upper parts of the original ranges (by 12 percent).

Figure 4. Vegetation distribution, ten dominant species at Deep Canyon



Source: Kelly and Goulden, 2008

Why is this indicator important?

Plant ranges are limited by environmental conditions. On a mountain slope, the climate of the lower extent of a species' range experiences warmer and drier conditions, while the upper extent of a species' range is cooler and wetter. Climate warming or drought is expected to increase stress on plants at lower elevations, pushing them upward into the cooler, wetter climates higher on the slope. Recent climate warming and drying has been found to be pushing conifers upslope across the Southwestern United States by killing the trees at the lower, warmer, drier edges of their ranges (Allen and Breshears, 1998; McDowell et al., 2010).

The climate and vegetation gradient of Deep Canyon's slopes is analogous to the south-to-north gradient of California. Deep Canyon's climate ranges from hot desert at the mountain base, stretching upward through warm chaparral, and finally into mild conifer forests at the mountain peak. This vegetation and climate gradient is similar to the transition along the state of California, from the southern deserts, northward through chaparral-covered foothills and mountains, and into the mild evergreen forests of northern California. Understanding the effects of local climate change on Deep Canyon's vegetation gradient will help to predict how California's vegetation will respond to a warmer or drier climate.

This indicator is consistent with biological range shifts seen around the globe (Chen et al., 2011). Plant, bird, mammal, and insect ranges are retreating away from the equator and up mountain slopes, generally tracking the temperature changes observed within each species' range. There is major uncertainty surrounding any individual species' ability to migrate in response to climate change. In Deep Canyon, no species were found outside their historic range. If species are not able to establish in new locations, this study might be revealing the beginning of a local extinction of each species and local ecosystem collapse.

What factors influence this indicator?

The climate of Deep Canyon has become warmer and drier in the past 30 years. Temperatures have increased 1.1 ^{0}F from 1977 to 2007, and droughts have intensified. The combination of warming and drying has effectively moved the climate zones of Deep Canyon upslope about 200 feet, similar to the amount the vegetation has shifted upslope.

The change in plant distribution observed in Deep Canyon may be attributed in part to a severe drought from 1999 to 2002. This drought caused marked vegetation mortality throughout Southern California, directly through drought stress and indirectly through insect attack, and many recently dead plants were observed during the survey. However, recent mortality alone cannot explain the elevation shifts. Many plants that had died before the 1999–2002 drought were also noted, as well as an increase in cover in the upper half of the species' ranges. These trends indicate that warming and/or drying of climate has been stressing the lower elevation plants and providing more favorable conditions for plants at higher elevations over the 30-year period. These changes are consistent with predictions of the effects of climate warming and drought on mountain ecosystems.

Four considerations provide evidence that the observed vegetation redistribution is attributable to climate:

- Vegetation shifts were uniform across elevation, implying that the ultimate causal factor was uniformly distributed. Recent climatic trends in Southern California do not appear to vary strongly with elevation.

- The vegetation shifts are consistent with the expected bioclimatic effects of most of the observed climatic shifts. Increased temperature, longer frost-free period, increased elevation of the snow line, and occurrence of severe drought should increase plant stress in some years. This increased stress would be expected to decrease a species' ability to survive in the drier, warmer, lower parts of its range and increase its ability to survive in the wetter, cooler, upper parts of its range.

- The change from a symmetrical vegetation distribution to an upwardly skewed distribution (see Figure 4), when averaged across species and elevation, can be interpreted as a sign of the impact of climate change on vegetation distribution.

- The vegetation shifts resulted in part from mortality during the 1987–1990 and 1999–2002 droughts. The connection between mortality and drought is consistent with a fingerprint of climate change.

Two alternative explanations for the vegetation redistribution, changes in fire frequency or air pollution, merit consideration. The wildfire regime in Southern California has changed over the last century, resulting in plant demographic shifts, especially in montane forest. However, the fire regime in Deep Canyon is similar to its historical norm, and fire effects would not produce uniform changes across the elevation gradient. Schwilk and Keeley (2012) claim that the upslope redistribution of one species in Deep Canyon, *Ceanothus greggii*, was due to elevational differences in historic fires and not by climate warming. However, observations of postfire recovery of *C. greggii* outlined in Zammit and Zedler (1993) support the conclusion that an influence stronger than fire history is redistributing Deep Canyon's dominant species upwards. Air pollution as an explanation is similarly problematic: ozone-related mortality is concentrated only at higher elevations, and would not produce the uniform changes that were observed across the elevation gradient.

The upward movement of the dominant species at Deep Canyon in just 30 years can also be attributed to recent changes in the local climate. The establishment of species at locations well above their previous ranges appears to have been minimal, and the observed upslope movement is a result of shifting dominance within existing communities, rather than the expansion of ranges to new elevations. The climate factor most influential on species redistribution could not be determined. In fact, the various observed climatic changes may interact and reinforce each other; climate warming coupled with increasing climate variability intensifies the effects of extreme yet unexceptional droughts.

The local changes could be caused by regional urban heat island effects or long-term climate fluctuations, such as the Pacific Decadal Oscillation. Nonetheless, the climate changes observed are similar to climate changes that have been predicted with or attributed to greenhouse gas-forced global climate change. The study results imply that surprisingly rapid shifts in the distribution of plants can be expected with climate change, at least in areas where seed dispersal is not a major constraint, and that global climate change may already be influencing the distribution of vegetation.

Additionally, the exact mechanisms of the plant mortality are unknown. How a tree dies in response to drought is a surprisingly difficult question that the scientific community continues to discuss (Waring, 1987; Breshears et al., 2009; van Mantgem et al., 2009). Drought and warming have caused forest mortality worldwide and no other plausible explanation for the vegetation shifts were observed.

Technical Considerations

Data Characteristics

This indicator is based on a re-survey of an initial vegetation study conducted in 1977 (Zabriskie, 1979). Zabriskie's survey consisted of 22 belt-transect surveys 400 yards long, at 400' elevation intervals, from 0' to 8400' elevation along the north face of the Santa Rosa Mountains. These surveys counted live perennial vegetation crossing the 400-yard transect and noted species and coverage amount.

The exact location of Zabriskie's original surveys is lost. The study investigators were able to relocate the surveys within 10-20 yards of the original location using the original selection criteria: north-facing slopes, with transects centered on north-facing ridgelines and following the 400' interval isocontour. Jan Zabriskie also toured the sites with the investigators to explain his original sampling strategy and point out original locations.

Strengths and Limitations of the Data

A common problem in revisiting historic studies is finding the exact location of the original sites. Discussion with Zabriskie, original maps, careful and consistent site location criteria, and a relatively small geographic area, provide confidence in the investigators' accuracy in relocating the original survey sites. Location inaccuracy is the largest source of uncertainty in the data. The vegetation coverage methodology was identical to Zabriskie's and could result in biases of less than a few percent per transect. Year-to-year fluctuations could be a problem in extrapolating one survey to a 30-year trend. A major strength of this survey is that the species evaluated in this survey are generally long-lived, thus the vegetation changes observed are the result of long-term trends and not short-term variability. Species in the survey such as yucca, white fir, creosote, and California lilac have lifespans of decades to centuries, and thus high mortality rates within 30 years are considered significant changes. Finally, weather station data do not come from within the survey site; the climate data come from nearby stations around the Southern California desert mountains.

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References:

Breshears DD (1998). Drought-induced shift of a forest–woodland ecotone: Rapid landscape response to climate variation. *Proceedings of the National Academy of Sciences* **95**(25): 14839-14842.

Breshears DD, Myers OB, Meyer CW, Barnes FJ, Zou CB, et al. (2009). Tree die-off in response to global-change-type drought: Mortality insights from a decade of plant water potential measurements. *Ecology and the Environment* **7**(4): 185-189.

Chen I-C, Hill JK, Ohlemüller R, Roy DB and Thomas CD (2011). Rapid range shifts of species associated with high levels of climate warming. *Science* **333**(6045): 1024-1026.

Kelly AE and Goulden ML (2008). Rapid shifts in plant distribution with recent climate change. *Proceedings of the National Academy of Sciences* **105**(33): 11823-11826.

McDowell NG, Allen CD and Marshall L (2010). Growth, carbon-isotope discrimination, and drought-associated mortality across a Pinus ponderosa elevational transect. *Global Change Biology* **16**(1): 399-415.

Schwilk, D.W. and J.E. Keeley (2012) A plant distribution shift: temperature, drought, or past disturbance? *PLoS ONE* **7**(2):e31173.

van Mantgem PJ, Stephenson NL, Byrne JC, Daniels LD, Franklin JF, Fulé PZ, et al. (2009). Widespread increase of tree mortality rates in the western United States. *Science* **323**(5913): 521-524.

Waring RH (1987). Characteristics of trees predisposed to die. *Bioscience* **37**(8): 569-574.

Zabriskie JG (1979). *Plants of Deep Canyon and the Central Coachella Valley, California.* (1st ed.). Riverside, CA: Philip L. Boyd Deep Canyon Desert Research Center, University of California.

Zammit CA and Zedler PH (1993). Size structure and seed production in even-aged populations of Ceanothus greggii in mixed chaparral. *Journal of Ecology* **81**(3): 499-511.