Science Perspectives

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Pacific Southwest Research Station
Forest Service, U.S. Department of Agriculture

Climate Change

Detecting Climate's Imprint on California Forests

Hiking the nearly treeless slopes of western Nevada's Wassuk Range, researcher Connie Millar found dead limber pine throughout the watersheds. Where scanty forests were present, the dead wood occurred above treeline. Investigation of these wood remnants, sculpted by the elements over hundreds of years, revealed a cyclical pattern of limber pine colonization and retreat tied to climate change.

Climate Cycles

Over the past two decades, scientists have made great strides in deciphering the story of climate that is recorded in tree rings, lake and ocean bottom sediments, coral reefs, and ice packs. Taken together, the studies paint a dramatic and unexpected picture of climate change—nested oscillating cycles whose additive effects may drive average temperatures up and down by as much as 20 °C. These changes far exceed the 0.7 °C average global temperature increase that occurred during the 20th century.

Moreover, rather than always being gradual, climatic shifts have often been abrupt, with marked changes in temperature and precipitation taking place over periods as short as a few years or decades.

Climatic peaks and valleys often resculpt landscapes and rapidly change the nature of the habitats they contain. In turn, these physical changes evoke sharp adjustments in animal and plant populations and the ranges they occupy. Natural climate change, explains researcher Dr. Connie Millar, is a significant force that may affect many small areas or large swaths of continents and adjacent oceanic waters. Such change may affect only individual populations or species; in contrast, it may displace entire plant and animal communities.

Climate change continually resets the stage on which successional dynamics such as fire, flood, insect infestations, and disease play out, notes Millar. Scientists and managers may assume that these secondary effects—in conjunction with overgrazing, fire suppression, and other human-related causes—have actually initiated ecological change. "Consequently, viewing climate change as the key player is a paradigm shift for scientists and managers alike," Millar says.

Occurring on several different scales, climate change is driven by factors as varied as ocean currents, solar flares, and earth's orbit around the sun.

Decade Scale: The shortest oscillations occur on a scale of a few years, like the often mentioned El Niño/La Niña cycle, to several decades. "The less familiar Pacific Decadal Oscillation catalyzes abrupt changes every 25 to 40 years in streamflow, snowpacks, forest productivity, and salmon abundance, among others," says Millar.

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From Science...

Major Themes

Climate Changes Cyclically: Historical oscillations of climate have occurred on scales of decades, centuries, and millennia.

Climate Changes Swiftly: Major shifts can occur over periods as brief as a few years or decades.

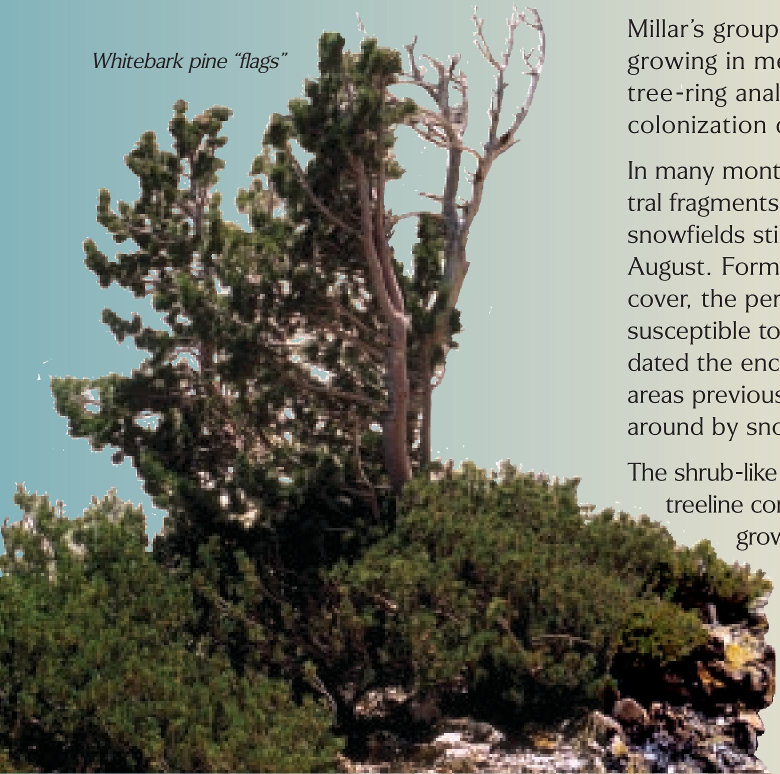
Ecosystems Respond: Climate change drives ecosystem change at both small and large scales.

Research Results

Decade Response: Trees of the high Sierra Nevada responded episodically and reversibly to 20th century decadal oscillations.

Century Response: Patterns of limber pine colonization and extirpation followed century-scale oscillations throughout large watersheds in the Sierra Nevada and Western Great Basin.

Millennium Response: Along the California coast, cyclical range changes in Monterey pine tracked climatic oscillations on thousand-year scales.



Whitebark pine "flags"

High Sierra Forests: Decadal Response

Encroachment into former snowfields

Enduring, unchanging—these words tend to characterize our perception of natural landscapes over a human lifetime. When landscapes do change, anthropogenic factors like overgrazing and fire suppression often get the blame.

In the high Sierra Nevada, montane forests lie interspersed with open meadows. But over the past century, forest boundaries have not remained static.

Based on her familiarity with paleo-landscapes, Millar had a hunch that an underlying cause driving high-altitude forest expansions was climate change. Perhaps so-called invasions of mountain meadows by alpine conifers were simply a natural response to smaller climatic rhythms.

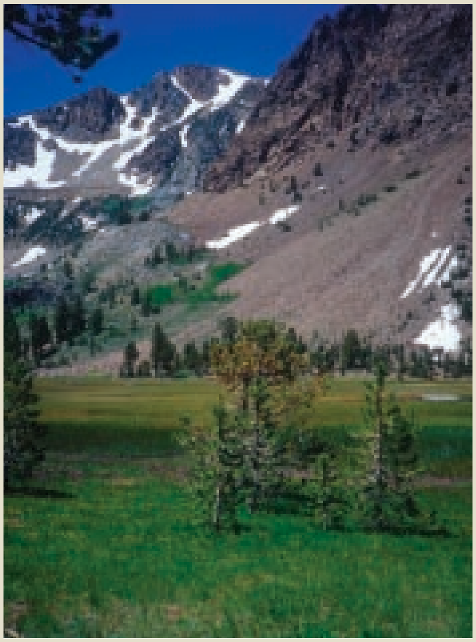
To test this theory, Millar and her colleagues looked at four aspects of conifer growth high in the Sierra Nevada. Two of the studies were related to colonization and two to growth patterns of individual trees. The research revealed striking correlations between colonization, growth, and multidecadal climatic cycles.

Millar's group examined young trees growing in meadows and through tree-ring analysis determined their colonization dates.

In many montane areas, only the central fragments of formerly persistent snowfields still linger through late August. Formerly shielded by snowy cover, the peripheral areas are now susceptible to colonizers. Millar's group dated the encroachment of trees into areas previously covered nearly year around by snowfields.

The shrub-like character of stunted treeline conifers is termed "krummholz growth." Enforced by severe wind, cold, and ice, the dwarf height is deceptive: some trees are as old as 1700 years. The horizontal expansion of krummholz tree crowns each year is related to the length and temperature of the growing season. Millar and her colleagues reconstructed each year's crown growth throughout the 20th century by taking stem samples from krummholz branches.

The group also examined natural "flags" at treeline sites—vertical branches that escape krummholz growth under favorable conditions. Millar's group measured the so-called release dates—that is, the year the vertical branches sprouted upwards.



Pine invading Sierran meadows

Analysis of the data showed that from 1920 to 1944, warm, wet, El Niño-like conditions encouraged snowfield colonization and horizontal growth in krummholz crowns. At the same time, meadow areas remained open and few krummholz flags released.

When ocean circulation and increased atmospheric aerosols brought cool, dry weather from 1945 to 1975, snowfields stabilized and horizontal krummholz growth slowed down. At the same time, pines began growing in the drier meadow areas, and a decrease in storm severity triggered krummholz flags.

The period 1976 to 1996 brought accelerated warming conditions, mostly attributable to the greenhouse effects of increased CO_2 in the atmosphere. Landscape response was similar to that seen between 1920 and 1944.

Across approximately 30 sites in this study, colonization and growth appeared to be independent of land-use factors such as fire suppression and grazing.

Limber Pine: Century-Level Change

In the arid Wassuk Range of western Nevada, limber pine survives only in remnant groves, primarily on north-facing slopes of Mt. Grant. Yet dead limber pine wood occurs throughout all major Mt. Grant drainages. It also occurs above the current treeline, often as standing trunks—sentries guarding an otherwise treeless landscape. The dead limber pines are repositories holding millennia of climatic and ecological data and bear testimony to continuous waves of colonization and retreat.

By extracting pencil-thin wood cores, Millar and her colleagues studied the tree rings from both live and dead limber pine trees throughout the slopes of Mt. Grant. The researchers used their data to develop a master chronology of seasonal growth and climate reaching back 3300 years. The trees had extended their range throughout entire drainages and subsequently died off, in synchrony with other limber pine populations across the western Great Basin and Sierra Nevada. While these multi-century cycles correlated closely to wet and dry periods of regional climate, as determined from a number of scientific studies by other researchers, Millar found no evidence that fire had played a major role in stand extirpations.

Monterey Pine: Millennial Cycles

The native range of Monterey pine is currently confined to three coastal locations in California—Point Año Nuevo, the Monterey Peninsula, and Cambria—and two Mexican islands. An integral and dramatic part of the California landscape, cone-studded Monterey pines silhouetted against coastal sunsets are a trademark central coast image.

Yet these signature pine forests, already disjunct and rare, face a variety of potent threats in their native location, including urbanization, genetic contamination, and virulent pathogens.

The question is how best to steward the remaining native trees. Traditionally, the three remaining California populations have been regarded as vestiges of larger, contiguous forests. Scientists thought that the majority of these pine forests succumbed to a warm, dry period occurring 4,000 to 8,000 years ago.

Conservation efforts focused on protecting the remaining native forests. At the same time, however, Monterey pines were escaping from ornamental plantings in various California habitats conducive to their growth. Not for long, though—forest managers generally dubbed the escapees as "exotics" and removed them.

A new viewpoint on the conservation effort emerges from Millar's research. Monterey pine pollen, needles, and cones lace sediment cores taken from bays and lakes of coastal California. Millar sifted through recent data and melded clues to former populations of Monterey pine with newly available information about past climates. Her work reveals a different picture of Monterey pine forests over the eons and suggests a more comprehensive and likely more successful conservation strategy.

Millar's work shows that during the last 2 million years, California Monterey pine populations have been small and fragmented. The populations repeatedly expanded and contracted, colonizing new areas while dying off in others.

During the cold that accompanied expanding glaciers, junipers dominated the landscape. In the warmest times between glacial periods, oaks outcompeted pines in coastal habitats. The intervals between these two extremes proved favorable to the pines. Abundant Monterey pine coincides with charcoal in sediment cores, evidence that ancient fires, common during periods of intermediate climate, played a role by opening cones and preparing seed beds.

Over the long term, Monterey pine survives contraction to remnant populations by recolonizing. Therefore, it may make as much sense to preserve Monterey pine now growing where it once occurred under similar climatic and ecological conditions as it does to conserve current "native" populations. Fire, which opens the door for Monterey pine reproduction, is sharply curtailed; initiating colonization through planting, or at least by preserving of escapees, could be the best way to ensure its long-term survival.

Monterey pine in its current native location

...To Management

A Conversation with Connie Millar

Q ***Forest managers no longer see fire as a scourge to be prevented. Instead, they view fire as an inevitable, natural process integral to forest management. Do you anticipate a paradigm shift of similar magnitude for climate change?***

Yes—in fact, the shift both in viewpoint and management approaches could be even greater. Traditionally, forest managers have attributed changing conditions in forests to readily apparent natural processes like fire, insects, disease, and floods. But often, climate change is the underlying reason for landscape alterations. Sometimes what is blamed on overgrazing, fire suppression, invasive species, or other human-related factors is also a result of climate change.

Today, managers are beginning to consider climate—both natural and modified by humans—as the major cause of forest changes. This realization, or paradigm shift, will markedly change how forests are monitored and managed.

Q ***With the importance of climate change coming to light, what should managers be thinking about?***

Managers could consider whether treating secondary factors will be successful. If the goal is short-term mitigation, for example to preserve trees for timber harvest, then fighting fire, insects, or disease is reasonable. Populations and places least sensitive to climate change may often be successfully managed for resilience in the short run.

Sometimes the stated objective is to stop change—that is, to preserve in perpetuity a species, population, or landscape the way it currently exists or to restore it to a former condition. However, attempting to preserve the past is futile if the landscape is highly sensitive to climate change. In these cases, change may be inevitable, and resisting it could lead to abrupt and undesired consequences in the future.

Forests established during pre-settlement times (the 1800s) are poor models for restoration today; they are even worse models for forests adapted to future warming conditions. Pre-settlement forests developed in response to the harshest period of the Little Ice Age, which ended during the late 19th century, and are generally not best adapted to the changing climates of the present and future.

Forest transformations as a result of climate change may occur within a human lifetime. To gain insight into what lies ahead, managers could look at how comparable landscapes responded historically and combine this knowledge with information on predicted climate change.

Q ***How does this new outlook affect conservation of rare and endangered species?***

Over time plants and animals may cycle, as a result of climate change, between being rare and widespread. If populations are shrinking because climatic conditions are changing, a species may no longer survive well within its former range. Alternately, if climate is favorable in other parts of a species' range, populations are likely to thrive and expand there.

Q ***It sounds like species need space to move.***

The fossil record shows that species have often responded to climate change by adjusting their ranges. They died out in some locations and pioneered others. By maximizing the size and diversity of management units and keeping land uses flexible, managers might make it possible for species to adjust to climate change by moving.

Managers could also consider species introductions in areas where climate change is encouraging habitat growth congenial to the species in question. These sites may not have been occupied by the species in the recent past, because the site's ecosystem was different. This should be done only after careful assessment of the species' history and potential effects of introducing a species to a new environment.

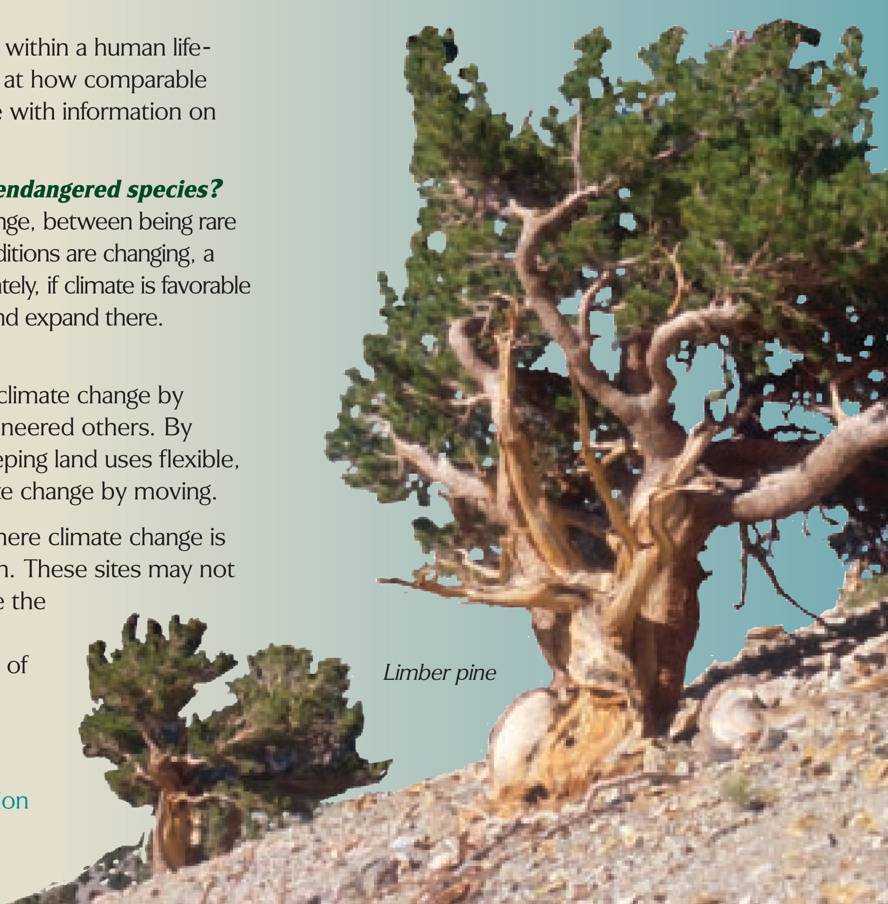
Making Diagnoses: In some cases, climate change is the primary stress on an ecosystem, but fire, disease, and other secondary factors may veil climatic effects.

Choosing Restoration Targets: Pre-settlement conditions may be inappropriate targets since climates changed radically over the past 100 to 150 years.

Anticipating Change: Managers should anticipate future climate change and ecosystem response when formulating plans.

Determining Restoration Locations: A non-native site may be the best place for restoration. Consider similar habitats that once hosted the species under climatic conditions anticipated for the near future.

Conserving Species: Let species adapt naturally to climate change by giving them space to move. Increase the size and flexibility of management units.



Limber pine

Scientist Profile


Photo: Wally Woolfenden

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Connie Millar studies responses of forests to climate change, both dramatic and subtle. Summer research finds her near the crest of the Sierra Nevada and Great Basin ranges measuring the advance and retreat of mountain meadows and snowfields or coring gnarled, weather-beaten pines for tree rings to decipher high-elevation climate change.

A research geneticist with the PSW Research Station since 1987, Millar joined with other station scientists to form the interdisciplinary Sierra Nevada Research Center (SNRC) in 2002. Within the SNRC, Millar's research group focuses on climate as an ecosystem architect: how it affects forest structure and species composition. With her collaborators, Millar also looks at how climate catalyzes and combines with other natural agents of change such as fire, disease, insect infestations, and flooding, as well as with human-related impacts such as grazing, fire suppression, and timber harvest.

Millar is especially interested in working with forest managers to plan restoration and conservation efforts from a climate change viewpoint, including anticipated global warming. Her long-term commitment to integration of scientific research with forest policy includes the "Building Bridges Between Science and Management" program she developed in 1993 while on sabbatical on the Inyo National Forest. Millar also served as a team leader for the Sierra Nevada Ecosystem Project, a comprehensive assessment of California's most extensive mountain range.

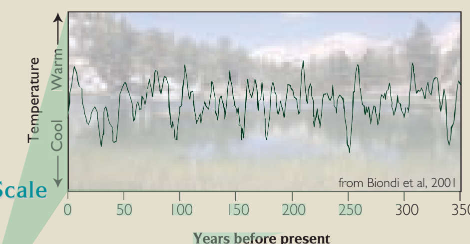
Millar received her Ph.D. in Genetics and M.S. in Wildland Resources Science from the University of California, Berkeley. She also holds a B.S. in Forest Science from the University of Washington. Millar is a PEW scholar in Conservation and the Environment. Prior to her interest in climate change research, Millar focused on forest genetics, especially the way genes ebb and flow across landscapes over time. She is a recognized expert in the evolutionary dynamics of pines.

Continued from front page

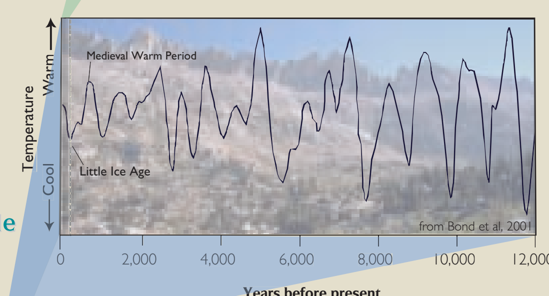
Century Scale: Oscillating on a larger scale, century-level variations correspond to the interplay of oceanic and atmospheric circulation with sun spots and other solar variability. Because forests and even individual trees span many centuries, oscillations this long are critical to forest management, especially since they can occur abruptly. Century-scale oscillations were an underlying cause of the Little Ice Age, which began about 500 years ago and terminated rapidly in the late 1800s. Worldwide, historic documents describe this period as an endless winter.

Millennium Scale: Even longer cycles are clearly evident over the past 2 million years, with 50 extended glacial periods interspersed with warmer interglacial episodes like that present today. These result from complex regular changes in the earth's orbit. Despite the relatively longer duration of cold periods, transitions remain abrupt, on the order of years to decades. Such cycles set in motion important genetic and evolutionary paths, Millar explains.

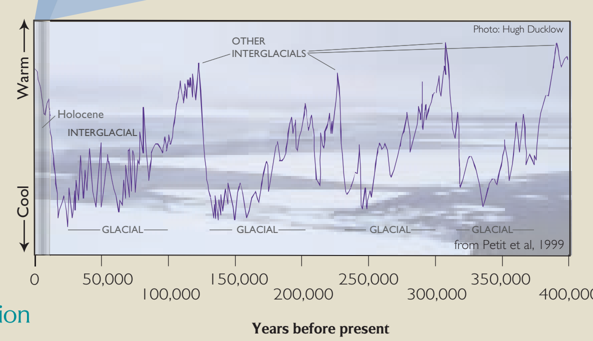
Decade Scale



Century Scale



Millennium Scale



Writer Anne M. Rosenthal holds B.S. and M.S. degrees in Biological Sciences from Stanford University and a Certificate in Technical Writing from San Jose State University. A science writer based in the San Francisco Bay Area, she served as editor of *Jasper Ridge Views*, a publication of the Stanford University Jasper Ridge Biological Preserve, for ten years. Her articles have been published in *Scientific American* online, *Astrobiology Magazine* (NASA), and *California Wild* (California Academy of Sciences).

Unless otherwise noted, all photos taken by Connie Millar

What's Next

The Sierra Nevada Research Center, part of the Pacific Southwest Research Station, is spearheading an assessment of regional climate change. Millar and colleagues are proposing a multi-year study to model future Sierra Nevada climate and its consequences. The study, abbreviated SNCCAP (pronounced "Snowcap"), would be interdisciplinary, involving scientists from many fields including ecology, geology, and hydrology. A number of universities and research institutes would participate.

As proposed, SNCCAP would

- Model future Sierra Nevada climate, at a variety of geographic and time scales.
- Assess how climate change may affect the Sierra Nevada and its associated rural communities. For example, the models would help predict changes in river flow and forest health and consequences for local economies.
- Compile case studies, databases, models, and decision-making tools to assist land-use planning throughout the Sierra Nevada.
- Provide sample strategies and management plans for integrating climate assessment into conservation efforts.

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For Further Reading

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