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A Breath of Cold Air: Surprising Forest Patterns Hint at Climate Change Refuges

Air temperature typically decreases with elevation—anyone who has hiked up a mountain is likely to have noticed that the air temperature drops towards the top. Occasionally, however, cold, dense air settles in low-lying valleys and creates an inversion in the temperature gradient. In these locations, lower elevation areas are temporarily cooler than areas higher up. This fine-scale process, called cold-air pooling, is not fully understood and is often missed in climate modeling.

To better understand and characterize the frequency and strength of cold-air pooling in New England, Melissa Pastore and Jane Foster, researchers with the U.S. Department of Agriculture, Forest Service, Northern Research Station and Southern Research Station, respectively, and colleagues collaborated to fully measure cold-air pooling at three sites that represent different types of topography. Their results may help predict future forest patterns and identify locations that can sustain cold-adapted species and ecosystem functions as the climate changes.

KEY MANAGEMENT CONSIDERATIONS

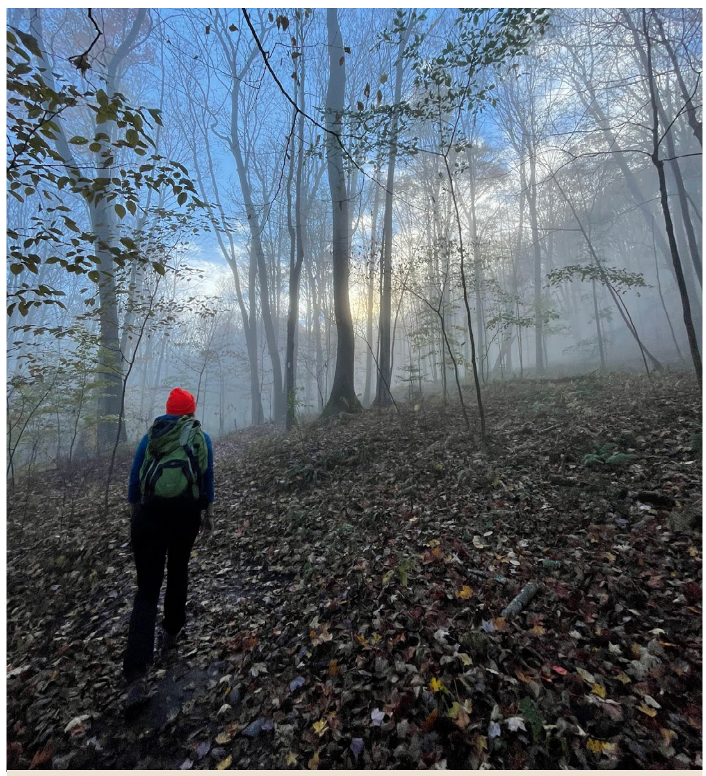
- Cold-air pooling creates temperature inversions, where valley bottoms become colder than mountaintops.
- Across New England, temperature inversions are a strong and regular occurrence throughout the year and at different times of day.
- In areas where cold-air pooling was found to be strongest, more cold-adapted tree species were present at low elevations; warm-adapted species were present at higher elevations.
- Given the importance of climatic microrefugia in the past, networks of cold-air pooling areas may help cold-adapted species survive in a changing climate and facilitate range shifts to new locations.

Identifying Temperature Inversions

Pastore, Foster, and their team monitored temperature inversions to identify cold-air pooling on two sites in Vermont and one site in New Hampshire. The sites differed in topography: one was a shallow basin, one was a mountain valley with medium relief, and one was a mountain valley with deep relief. These topographies are typical of New England.

The researchers established three transects at each site along an elevation gradient. Each transect consisted of five or six plots. The team recorded the overstory and understory tree species in each plot to determine whether frequency or strength of temperature inversions might have influenced tree species composition, and they measured different site variables, including the depth, water content, pH, and nitrogen concentrations of soil, to rule out other explanations for tree species composition.

Two temperature sensors were installed under the tree canopy in each plot. The sensors measured the air temperature every hour for 6 to 10 months. Temperature inversions in the transects—which occur when the temperature at higher elevations is higher than at lower elevations—would indicate the presence of cold-air pooling.


Co-author Karin Rand hiking up a transect during a cold-air pooling event. USDA Forest Service photo by Melissa Pastore.

In their analysis of the hour-by-hour data, the scientists determined whether a temperature inversion was present and measured the strength of the inversion. They also considered the temperature preference of species present in each plot and quantified whether the plots represented more cold- or warm-adapted species.

Cold-Air Pooling Is Common

The scientists found that temperature inversions occurred throughout the year and at all times of day. Temperature inversions occurred between 19 and 43 percent of the hours recorded, depending on the site and season. The temperature drop with declining elevation ranged from 0.5 to 1.7 °C per 100 meters, on average. These results show that cold-air pooling is a relatively common phenomenon in New England.

In transects where temperature inversions occurred more often, the researchers found that the tree species composition corresponded to the inversion temperatures: Cold-adapted species like spruce (*Picea* spp.) and balsam fir (*Abies balsamea*) were present at low elevations, and warm-adapted broadleaf species, such as sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and American beech (*Fagus grandifolia*) were present at higher elevations.

Cold-Air Pooling Microrefugia

Many climate models do not account for temperature inversions and consequent cold-air pooling, which may lead to inaccurate predictions of vegetation change with climate change. These models may fail to identify microrefugia—small locations where cold-adapted tree species could survive longer—as the surrounding air temperatures rise.

Spruce and fir tree species are cold-adapted species that could benefit from the microrefugia provided by cold-air pooling. Spruce-fir forests provide critical wildlife habitat, store soil organic carbon, and are valued for recreation, tourism, and logging. Cold-air pooling could prolong the survival of these forests under anticipated climate change.

“They’re not the entire answer,” Pastore says of cold-air pooling areas as microrefugia for cold-adapted tree species, “but they may be the best chance some populations have, allowing them to persist longer than expected in a changing world.”

A cold-air pool dissipating on an autumn morning near the top of one of the transects in Camel’s Hump State Park, Vermont. USDA Forest Service photo by Melissa Pastore.

PROJECT LEADS

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FURTHER READING

Pastore, Melissa A.; Classen, Aimée T.; D'Amato, Anthony W.; English, Marie E.; Rand, Karin; Foster, Jane R.; Adair, E. Carol. 2024. Frequent and strong cold-air pooling drives temperate forest composition. Ecology and Evolution. 14(4): e11126. https://doi.org/10.1002/ece3.11126.

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