

## Science

FINDINGS

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issue ninety three / may 2007

*“Science affects the way we think together.”*

Lewis Thomas

## THE MYSTERIOUS DEMISE OF AN ICE-AGE RELIC: EXPOSING THE CAUSE OF YELLOW-CEDAR DECLINE



*Yellow-cedar decline is often more intense near sea level, where snow cannot protect the trees.*

*“The words of truth are  
always paradoxical.”*

—Lao Tzu

The white skeletons of dead yellow-cedars stand in vivid contrast to the lush green rain forest of southeast Alaska. They are evidence of the mysterious decline of yellow-cedar—a tree death whose cause has confounded researchers for decades.

Among specialists, the term “forest decline” is reserved for situations when a species of tree dies over large areas and long timeframes. More than that, most true forest declines—and there are many throughout the world—are mysteries. An inscrutable cause of death is what makes a decline distinct from all the run-of-the-mill reasons trees die. If and when the

mystery is solved, the cause is nearly always a complicated interaction of events. Yellow-cedar decline is a prototypical forest decline.

“Yellow-cedar mortality has been mapped at over 2,500 sites covering more than 500,000 acres of southeastern Alaska,” explains David D’Amore, a soil scientist at the PNW Research Station in Juneau, Alaska. “By dating the death of snags, we can tell that the decline began some time in the late 19<sup>th</sup> century and has continued for over a hundred years.” Until recently there was no credible theory as to the cause of the decline.

Yellow-cedar would seem an unlikely victim. The tree has an extensive ecological strategy of defense. According to Paul Hennon, a forest pathologist at the Juneau Lab, yellow-cedar

### IN SUMMARY

*For more than a century, yellow-cedar has been inexplicably dying throughout the northern coastal rain forests of the Pacific Northwest. Yellow-cedar mortality has been mapped on more than a half-million acres in southeastern Alaska, yet until recently the cause of death was a stubborn mystery. Researchers are hopeful, after several decades of investigation, that they have finally exposed the cause of yellow-cedar decline.*

*Biotic factors were systematically eliminated as causes of cedar decline during the 1980s and 1990s. More recently, a risk factor analysis provided evidence that seasonal air and soil temperature were associated with the decline. Researchers at the Pacific Northwest Research Station in Juneau, Alaska, now believe that the mechanism of tree death is a form of freezing injury related to cedar’s premature loss of cold resistance in spring. Trees exposed by sparse canopy cover experience soil warming early in the spring, which triggers their metabolism to begin the growing season. Tree roots and foliage are then especially vulnerable to late-season freeze. The presence of snow in February through April interferes with this scenario by either protecting shallow fine roots from spring freezing or by delaying the loss of freezing resistance until after the last spring frost has occurred.*

tolerates the harshest sites where competition is at a minimum, it puts relatively few resources into growth and reproduction, but achieves great longevity, often living a millennium or longer. The yellow color and distinct aroma of its heartwood comes from powerful natural biocides, which protect the tree from infestation and decay. Even the foliage contains volatile leaf oils that restrict insect feeding.

“It reminds me of the legend surrounding Homer’s Achilles,” says Hennon, “invincible, except for one hidden vulnerability.”

When it comes to the mystery of yellow-cedar decline, Hennon is the topic’s principal sleuth. He has been investigating the decline for about 25 years.

When Hennon began as a student in the 1980s, there was suspicion that a root disease was the source of the problem—perhaps the same fungus-caused root disease that was killing Port Orford-cedar in southern Oregon. Over the next few years, Hennon helped rule out that particular theory. The fungus *Phytophthora* does not affect yellow-cedar in Alaska.

Beetle damage was the next theory. But again, yellow-cedar was found to be resistant, only succumbing to beetles if a tree had been previously weakened. Over the years, Hennon and other pathologists took a very methodical approach, ruling things out one by one. “We started by dismissing the higher fungi, then insects, and then viruses and nematodes. Even the impact of bark-feeding bears was

KEY FINDINGS	
•	Early research ruled out biotic causes of yellow-cedar decline, established the date of onset in about 1880 to 1900, and associated the problem with particular site features such as poor soil drainage. The cause of yellow-cedar decline remained a mystery, however.
•	A risk factor study provided evidence that seasonal air and soil temperature were consistently associated with yellow-cedar decline, but saturated soils, acidic soils, aluminum toxicity, and calcium deficiency were not.
•	The mechanism of tree death appears to be a form of freezing injury to roots related to premature dehardening (the loss of freezing resistance) in spring. Trees exposed by inadequate canopy experience early soil warming that triggers dehardening, which leaves them vulnerable to freezing in February through April.
•	The presence of snow in late winter and spring protects shallow fine roots from freezing, or delays dehardening until after the last spring frost has occurred. Maps of yellow-cedar decline indicate strong patterns of occurrence on the landscape where snow accumulation is lowest, which is consistent with the concept that snow provides protection for yellow-cedar.

considered. Using a deductive approach over many years, we went through all the likely suspects. Eventually we became convinced that no organism causes this problem,” says Hennon.

Now, a decade later, Hennon and D’Amore have led an impressive collaboration of researchers to a hypothesis that they believe explains yellow-cedar decline. True to the nature of all forest declines, their explanation is complicated and, at times, paradoxical.



*Yellow-cedar is a slow-growing defensive tree that has very few important insect and disease enemies.*

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### *Purpose of PNW Science Findings*

To provide scientific information to people who make and influence decisions about managing land.

*PNW Science Findings* is published monthly by:

Pacific Northwest Research Station  
 USDA Forest Service  
 P.O. Box 3890  
 Portland, Oregon 97208  
 (503) 808-2137

Send new subscriptions and change of address information to [pnw\\_pnwpubs@fs.fed.us](mailto:pnw_pnwpubs@fs.fed.us)

Sherri Richardson Dodge, editor  
[srichardsondodge@fs.fed.us](mailto:srichardsondodge@fs.fed.us)

Keith Routman, layout  
[krouman@fs.fed.us](mailto:krouman@fs.fed.us)



## TRACKING TEMPERATURE LEADS TO A THEORY

The path to their current hypothesis included several blind alleys. Take, for example, the fact that mortality seems to spread out from a central location over time. On its face, this would seem to indicate a contagious pathogen slowly moving from one tree to the next. So it's no surprise that early researchers focused on finding the responsible organism, only after years of study were they confident in ruling this theory out.

This left environmental factors as the probable culprit. On first examination, it seemed that wet soils were more commonly associated with mortality. This, plus the fact that root damage always precedes foliage damage kept their focus underground. Hennon and D'Amore designed a project to systematically examine site conditions along a gradient of soil conditions and levels of tree mortality.

"As it turned out, soil hydrology, acting alone, was not a strong risk factor," says D'Amore. "The soil water table measurements over a wide range of cedar decline showed that mortality was present in both saturated and unsaturated soils."

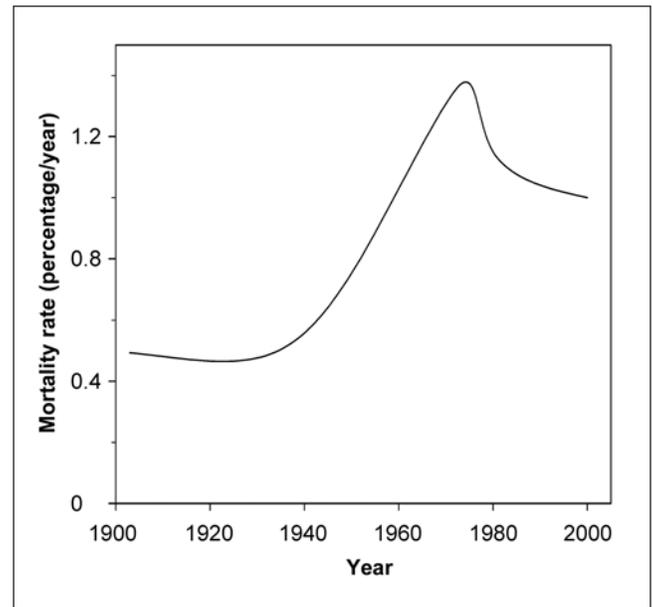
"Air and soil temperatures emerged as the leading possible risk factor," he explains. "The forest zones with abundant dead yellow-

cedar had temperatures that were higher in the spring and summer, lower in winter, and had greater daily ranges."

From here, a new hypothesis began to gel. Soil temperatures respond primarily to exposure. And soil exposure is heavily influenced by canopy cover, which acts as insulation, moderating variations in temperature.

"Where soils are saturated, tree canopies are sparse and the roots are near the surface. This means they are more exposed to temperature changes," explains Hennon.

Therefore, cedars on wet soils experience greater incidence of mortality than those on drier soils, even though the moisture has no direct effect. Similarly, the apparent contagiousness of mortality seems to be associated with canopy loss occurring on adjacent trees. When a tree's neighbor dies and loses its canopy, the surrounding soil temperature begins to fluctuate more



By dating dead yellow-cedar snags, researchers can estimate the rate of mortality.

widely. In time, it too succumbs, which, in turn, increases the vulnerability of its other neighbors. This trend continues in what becomes a slow spread of cedar mortality, often creeping out of wet sites where canopies are already sparse on to sites with better drained soils.

## A UNIQUE VULNERABILITY

Why would temperature fluctuation matter? What is the mechanism killing the trees? And why just the cedars?

"As we got closer to the root of the problem, we began speculating that freezing damage was involved," says Hennon. "We began collaborating with experts in freezing damage and cold tolerance working in Vermont: Paul Schaberg and Gary Hawley. Throughout this project, collaboration with outside experts has been our key to success."

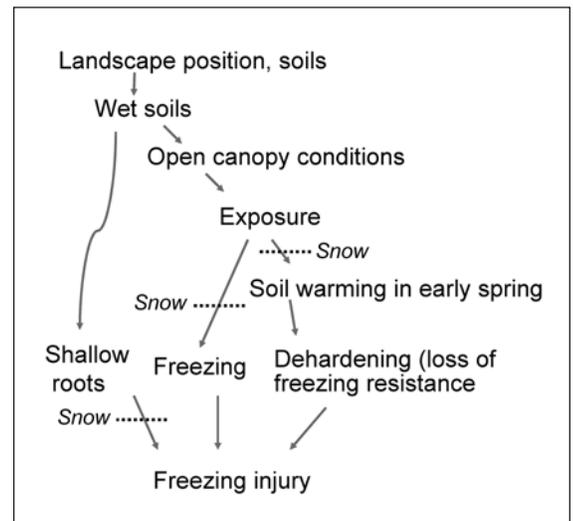
Together, they focused on freezing injury and a botanical phenomenon called dehardening. Yellow-cedar trees, like all conifers in cold climates, have an active growing season and a dormant season. In autumn, in anticipation of short days and cold temperatures, trees begin to shut down and reconfigure their cells to protect against freezing damage. They are finding the cedar trees are exceptionally cold hardy in the fall and early winter. The trees stay dormant until cues from the environment signal the coming of spring, at which point the cells deharden and begin to metabolize. It is important that the tree doesn't deharden too

early, or else freezing temperatures can be lethal to fine roots and foliage. Wait too long to deharden and grow, and trees risk losing the competition with neighbors that get an early start.

Unlike other conifers, yellow-cedar relies heavily on temperature to cue the dehardening process. This is its unique vulnerability, its Achilles' heel.

"Many other species rely primarily on photoperiod, or the amount of sunlight in a day, to cue dehardening after mid-winter," says Hennon. "But yellow-cedar relies more on temperature, which is less reliable and makes it is more likely to deharden early. So, paradoxically, it appears that warming may be the indirect cause of freezing damage."

The teams from Alaska and Vermont have bolstered confidence in their hypothesis by bringing the problem into a controlled environment. Using seedlings in a nursery, they have learned that roots are



The causes of forest declines are typically complicated; yellow-cedar decline is no exception. This diagram shows the cascading factors that form the leading hypothesis for the cause of yellow-cedar decline. The manner in which snow disrupts this process, thereby protecting yellow-cedar, is illustrated with dotted lines.

dehardened as early as February and they have experimentally replicated yellow-cedar decline in miniature.

## PROTECTION FROM A BLANKET OF SNOW

Still, another question remained: Why are most of the dead trees at lower elevations?

“We had been speculating for a while that snow was somehow implicated in the problem,” says Hennon. “Then Dave Albert of The Nature Conservancy approached me after a presentation and told me that he had built a new map of regional snow distribution. When I looked at Dave’s snow map side-by-side with our map of cedar decline, I had a bit of a ‘eureka’ moment: there was an obvious fit between places without snow and places that cedars were dying.” Now they are monitoring snow depth along with other measurements of air and soil temperature.

“Snow appears to offer some sort of protection against freezing injury by either delaying the dehardening process, or protecting the fine shallow roots from freezing,” says D’Amore. “In either case, the presence of snow through March and April apparently allows yellow-cedar to pass through the vulnerable period that affects trees growing without snow.”

A tight association with snow is consistent with the evolutionary history of yellow-cedar. This is why yellow-cedar is found at high elevations throughout most of its range. In fact, many of today’s yellow-cedar trees established during the Little Ice Age, a period that began roughly 500 years ago. The abundance of snow allowed the species to expand without the risk of freezing damage caused by early dehardening. Snow has always protected yellow-cedar and that’s why it never relied heavily on photoperiod to dictate dehardening.



Automated cameras are used to record daily snow depths. This helps researchers predict where tree death may occur and where conservation and restoration are likely to be successful.

Not surprisingly, the warming trend that began at the end of the 19<sup>th</sup> century coincides with Hennon and D’Amore’s estimate of the start of the decline. They speculate that continued climate warming would likely result in increased cedar decline because even in a warmer climate there are still freezing events in spring. “Yellow-cedar decline appears to be an excellent example of how a minor shift in climate can trigger large ecological change,” says Hennon. “It illustrates the challenge

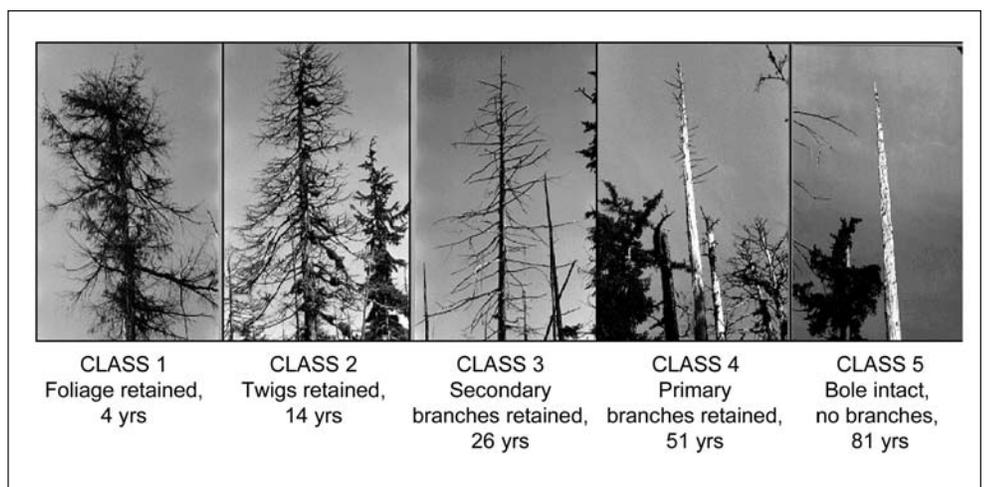
of managing long-lived tree species in a changing climate.”

Recall that forest declines, by definition, have complex pathways to tree mortality. And that’s certainly what we have here. It’s not simply freezing that is killing yellow-cedar. It is warmer temperatures in the spring within those forests not insulated by dense canopies or snow that leads to premature dehardening, which, in turn, leaves the tree vulnerable to freezing damage. Complex indeed.

## AN ENIGMA GIVES WAY TO A ROBUST HYPOTHESIS

Hennon and D’Amore will not say that the mystery of yellow-cedar decline has been solved. Instead, they say that they’ve developed a robust hypothesis and, thus far, all available data are consistent with that hypothesis. Not surprisingly, they have a long list of yellow-cedar research that they continue to pursue and initiate.

In particular, they are researching the feasibility of salvaging timber from cedar on sites that have already succumbed. “Wood and bark from yellow-cedar have historical and contemporary cultural value to Native People in Alaska, and its wood is consistently the most commercially valuable of any tree species grown in the state” says D’Amore. Therefore, cedar decline has obvious cultural and economic implications.



A snag classification system was developed to estimate the time since death. This has been useful for ecologists investigating the history and trends of mortality and for foresters judging the potential to salvage dead yellow-cedar for timber.

“On the bright side, thanks to its heartwood chemistry, yellow-cedar is uniquely resistant to decay,” Hennon explains. “This offers tremendous opportunities to salvage trees long after they have died. In fact, research with scientists from the Forest Products Laboratory shows that the properties of yellow-cedar wood are largely unchanged 25 years after death. And more remarkable still, the strength properties are not altered even 80 years after death.”

Their study of salvage potential dovetailed nicely with the historical analysis of the decline. Through these studies, they have developed a technique for ageing the time since death through a visual assessment of the snag. This is a boon for quickly assessing both ecological history and economic potential.

With regard to the future of yellow-cedar, Hennon and D’Amore are collaborating with scientists at University of Alaska, Fairbanks, and The Nature Conservancy to develop methods for predicting where future mortality will occur based on patterns of forest decline inferred from the past, current favorable habitat for cedar, and changes expected with a warming climate. They are able to identify sites where yellow-cedar may be safe to conserve and plant, a worthwhile endeavor given the potential great longevity of the tree.

Much of the new research focuses on questions of management and conservation. Indeed Hennon, D’Amore, and other collaborators have advanced a long way from the process of elimination that marked the beginning of cedar decline research.

For Hennon it’s been a long journey full of surprises: “This is a tree known for resistance and longevity, and it’s dying in all the places that it was thought to be most competitive. How paradoxical to learn that freezing damage resulting from climate warming is at the crux of the problem. Who would have guessed?”

*“There is always an easy solution to every human problem—neat, plausible, and wrong.”*

—Henry Lewis Menchen



## LAND MANAGEMENT IMPLICATIONS



- Yellow-cedar decline can be managed by partitioning the landscape into areas where conditions are no longer favorable for cedar. Other tree species should be favored in these areas.
- Landscape mapping and modeling can be used to determine areas where yellow-cedar is currently well suited; climate models and snow forecasting can be used to predict areas of long-term suitability for yellow-cedar.
- In areas of current yellow-cedar decline, there are opportunities to salvage highly valuable timber. The properties of wood are largely unchanged 25 years after death and many strength properties are not altered, even 80 years after death.
- In areas judged to be suitable for long-term yellow-cedar survival, accounting for warmer climate and less snowpack, yellow-cedar can be conserved regionally by planting and actively managing the species



*Yellow-cedar regeneration is being promoted in areas of adequate late-winter and spring snow, where the effects of climate change are less likely to result in further declines.*

## FOR FURTHER READING

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## WRITER’S PROFILE

*Jonathan Thompson is a science writer specializing in natural resource issues and ecology. He lives in Corvallis, Oregon.*

U.S. Department of Agriculture  
Pacific Northwest Research Station  
333 SW First Avenue  
P.O. Box 3890  
Portland, OR 97208-3890

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## SCIENTIST PROFILES



PAUL HENNON is a research plant pathologist with a dual appointment in Forest Health Protection, State and Private Forestry, Alaska Region and the Managing Disturbance Regimes Program, PNW Research Station. He received his Ph.D. from Oregon State University in 1986. His research in southeast Alaska is on the ecology and management of diseases and tree death

and in shaping the structure of hemlock-dominated forests, as well as all aspects of yellow-cedar and its decline.



DAVE D'AMORE is a research soil scientist with the Resource Management and Productivity Program of the Pacific Northwest Research Station in Juneau, Alaska. He received his M.S. in soil science from Oregon State University in 1994. He is currently working on a Ph.D. at the University of Alaska Fairbanks. His research work concentrates on the interaction of soil biogeochemical cycles

and forested ecosystems in the coastal temperate rain forests of southeastern Alaska.

*Hennon and D'Amore can be reached at:*

Pacific Northwest Research Station/U.S. Forest Service  
Forestry Sciences Laboratory  
2770 Sherwood Lane, Suite 2A  
Juneau, AK 99801-8545

Hennon:

Phone: (907) 586-8811 ext. 277  
E-mail: [phennon@fs.fed.us](mailto:phennon@fs.fed.us)

D'Amore:

Phone: (907) 586-8811 ext. 255  
E-mail: [ddamore@fs.fed.us](mailto:ddamore@fs.fed.us)

## COOPERATORS

Adelaide Johnson and Rick Kelsey, PNW Research Station

Bessie Woodward, Patricia Lebow, and David Green,  
Forest Products Laboratory, U.S. Forest Service

Paul Schaberg, Northern Research Station, U.S. Forest Service

Dustin Wittwer, Chris Dowling, Sheila Spores, and Melinda Lamb,  
Alaska Region, U.S. Forest Service

Glenn Juday, Colin Beier, and Scott Sink, University of Alaska Fairbanks

Gary Hawley, University of Vermont

Dave Albert and John Caouette, The Nature Conservancy