quick to point out that if there is no dark matter, galaxies shouldn't bend light as much as they appear to. Nevertheless, the idea has garnered adherents, including reputable scientists who didn't want to believe it at first. "I sometimes wish I hadn't gotten involved with MOND," says astronomer Stacy McGaugh of the University of Maryland, College Park, a former student of Rubin's and a specialist in charting the speeds of galactic gas clouds. "But then it showed up in my data." Indeed, for 16 years, MOND equations have explained data collected on clouds in orbit around more than 100 galaxies.

That was until a new player in the galactic lineup threw MOND a curve. Low surface brightness (LSB) galaxies are loose collections of stars weighing less than 20% of our Milky Way (no heavyweight in its own right). Applying MOND's equations, one should see gas clouds racing at speeds that—if MOND were wrong—would require a titanic dark matter halo to achieve.

When the data on LSB clouds began trickling in, MOND at first seemed on target. Then last year, Dalcanton and Rebecca Bernstein of the Observatories of the Carnegie Institution of Washington in Pasadena, California, used optical and infrared telescopes to nap the velocities of gas clouds orbiting 50 ıewly identified LSB galaxies. At a July 999 meeting of the Astronomical Society of the Pacific in Paris, they reported that the clouds were moving at velocities that could be explained by reasonable amounts of dark matter. MOND, on the other hand, could explain the cloud movements only if the galaxies were much lighter than expected—that is, if their stars were lighter than predicted by current theories of stellar evolution (xxx.lanl.gov/abs/astro-ph/9910219). Dalcanton thinks that's very unlikely. Milgrom, however, is withholding judgment until the data appear in a peer-reviewed journal. "That claim is only the latest in many, many such earlier attacks, all of which turned out to be based on errors in the data or misinterpretation," he says.

Realizing that further data on gas cloud velocities are unlikely to settle the debate, McGaugh has proposed a make-or-break test for MOND. Cosmologists think that hot bubbles of matter and light in the early universe left behind a pattern of bright and dim patches in the cosmic microwave background. Both MOND and standard theory predict that most patches of microwave light should span about 1 degree of sky as seen from Earth, an area that amounts to about twice that of the full moon. However, the competing approaches disagree on the odds of finding patches smaller than 1 degree. If the universe is mostly cold dark matter, one should expect to find many more minute patches than MOND predicts, McGaugh wrote in the 1 October 1999 issue of *Astrophysical Journal Letters*.

Measurements of the microwave background by the Cosmic Background Explorer satellite and by several recent balloon flights have mapped the 1-degree patches, but the extent of smaller patches is still in doubt because it's difficult to count them. Upcoming satellite missions in the next few years should provide a patch census accurate enough to discriminate between MOND and dark matter.

Physicist Michael Turner of the Fermi National Accelerator Laboratory in Batavia, Illinois, who makes no secret of his dislike for MOND, is confident about the final outcome: "I think that MOND will turn out to be the Bode's law of our era," he says. Bode's law, proposed by the 18th century German astronomer J. D. Titius, held that the distances of all the known planets followed from a sequence of doubled numbers: 0, 3, 6, 12, 24, etc. Adding four to each number in the sequence and dividing by 10 gives the orbital radii of all the planets out to Saturn in astronomical units. (One unit equals the distance from Earth to the sun.) It was only when Neptune and Pluto were found far from their predicted positions that astronomers recognized Bode's law for what it is: an amusing coincidence.

Although even enthusiasts are puzzled by the meaning of MOND, they aren't ready to write it off as mere coincidence. "People have taken potshots at it for 16 years," says Jerry Sellwood, a physicist at Rutgers University in New Jersey. "They haven't killed it off yet." —MARK SINCELL

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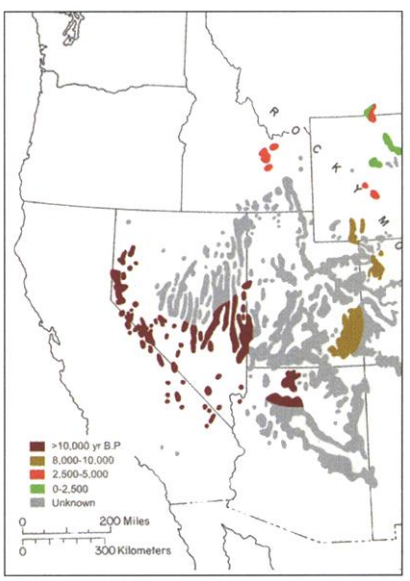
RESTORATION ECOLOGY

Returning America's Forests To Their 'Natural' Roots

New data on how North American forests looked centuries ago are fueling a debate on what ecologists should aim for when restoring ailing ecosystems

The flames licked high into the sky above a stand of Utah junipers in the foothills of Wyoming's Bighorn Mountains. Phil Shepard stood for a while admiring his handiwork, which ended up incinerating 283 hectares of Tensleep preserve. No arsonist, Shepard, an ecologist who manages the preserve for The Nature Conservancy, had set the fire to beat back the junipers that had overrun lush grassland and to thin out a ponderosa pine forest that had accumulated dead and diseased wood. One lightning strike could have touched off a devastating blaze, he says, if his group had not struck first.



Advances and retreats. New data on the spread of Utah juniper have prompted scientists to rethink restoration goals in parts of the Western United States.

Shepard views the Bighorn's overgrown forests as more than a fire hazard, however. The juniper and pine, he says, are driving out aster and other plants that flourished before people of European descent and their livestock settled this rugged land more than a century ago. The controlled burn was part of an effort to turn back the clock on the preserve's ecosystem. And Shepard isn't alone in his nostalgia for a wilderness of yore: Plenty of other ecologists view prescribed fires and other interventions, such as selective logging, as essential stratagems for repairing ailing ecosystems. The goal, as Interior Department Secretary Bruce Babbitt puts it, is to restore these lands "to a presettlement equilibrium."

The need to reduce the risks of widespread conflagration in the nation's forests is adding urgency to such efforts: Last month, the U.S. Forest Service reported that about 17 million hectares of national forest in the western United States are at "high risk of catastrophic wildfire," a fragility brought on by years of zealous efforts to stamp out natural fires. The forests "have become a tinderbox ready to explode," says the service's Chris Wood. Last year, federal agencies torched 931,000 hectares, more than twice the average annu-

al burning over the last decade.

But as scores of projects to save the forests get under way, a debate is smoldering among ecologists about how much controlled burning and logging is needed. The core issue is just what Babbitt's presettlement forests ought to look like. In the Bighorn basin, for instance, Julio Betancourt, a paleoecologist with the U.S. Geological Survey in Tucson, Arizona, and his colleagues have found that although grazing and fire suppression may abet the rapid advance of Utah juniper and ponderosa pine, the major culprit is probably climate changes spanning 5000 years. "Many land managers and ecologists tend to assume that all change in the 20th century is unnatural," Betancourt says. "That's not necessarily true."

In trying to reconstruct how ecosystems looked centuries ago, Betancourt and others hope to offer a handle on how much change is natural. He and two paleoecologists at the University of Wyoming, Laramie—Stephen Jackson and Mark Lyford --took a stab at this for the lowlands of the central Rocky Mountains. They examined plant remains embedded in fossilized packrat middens, or dung-filled nests, preserved in caves and rock shelters. After analyzing hundreds of middens, they discovered that regional warming about 4500 years ago drove Utah juniper northeast into dry canyon habitats in Wyoming and Montana. Cooling over the next 2 millennia took out much of these stands, leaving isolated patches of juniper in Wyoming. Then another warming trend kicked in about 2000 years ago, apparently allowing the species to recapture lost ground.

A recent acceleration of the juniper's migration, they say, may be due to three possible factors: grazing, fire suppression, and warming since the Little Ice Age ended around 1850. "If the trend is because of grazing and fire suppression, you can try to reverse it," Betancourt says. "But if it's a natural invasion because of climate change, how do you restore a migrating ecosystem?" Their as-yet-unpublished findings have persuaded Shepard to cut back on burning Utah juniper in Tensleep preserve. Betancourt applauds that decision, arguing that managers should first consider a forest's ecological history before taking aggressive measures to reduce a fire hazard or to restore a presettlement look.

Another hot spot where critics question the methods and goals of restoration is the 890,000-hectare Coconino National Forest, which surrounds Flagstaff, Arizona. Decades of fire suppression have left the Coconino's ponderosa pine itching to burn, says Wallace Covington, a restoration ecologist at Northern Arizona University in Flagstaff. His solution is the Fort Valley Restoration project, a massive effort that aims to return a 40,470-hectare swath of the Coconino to the way it looked before European peoples first settled the area around 1876.

Back then, Covington says, pine forests in Arizona were sparser—averaging 57 trees per hectare, according to population analyses based on annual tree rings. Holding the trees in check over the millennia, he presumes, were wildfires that kill off seedlings. Today, with as many as 2100 trees per hectare in some areas, the tightly packed stands are prone to disease and catastrophic wildfires that could even threaten Flagstaff.

The Fort Valley project, slated to get under way this spring, would use controlled fires and selective logging to thin out ponderosa pine. Testing this approach in the Coconino several years ago, Covington found that culling led to a greater diversity of plants in the forest understory, healthier old-growth trees, and a reduced risk of crown fires, in which flames race through a forest by leaping from treetop to treetop. Based on these findings, the project calls for logging up to 90% of the trees on some acreages. The plan has strong support. Not only the Coconino, but many North American forests must be thinned drastically if they are to be restored to their pre-European luster, argues Thomas Bonnicksen, a forest ecologist at Texas A&M University in College Station. "And I don't care if they use burning, girdling, or a laser beam to do it."

CREDIT: S. JACKSON/UNIV. OF WYOMING

Dung no longer unsung. By studying packrat middens, researchers can puzzle out what forests looked like centuries ago.

Although nobody disputes the need to reduce the risk of fire, some scientists question Covington's presettlement model of the Coconino. Based on analyses of weather data and tree rings, Melissa Savage, a geographer at the University of California, Los Angeles, has deduced that populations of ponderosa pine near Flagstaff surged, or regenerated, in the early 1800s, then again in the early 1900s. "If you pick a particular date for restoration, as [Covington] has with 1876, then you don't account for any episodic regeneration that may have occurred since then," she says. A better approach, Savage says, would be to nudge an out-of-control forest back into "the envelope of variability," rather than push restoration further toward a perceived ideal. That would be enough to reduce the fire hazard and let nature take over from there, she says. Covington counters that the presettlement model is merely a starting point. Although their prescriptions may differ, Covington says he shares Savage's goal of healing the forest: "We just want to get the ecosystem into the ballpark of natural conditions and then let nature take care of the rest."

Dogging the debate is whether restoring a forest to its presettlement state is even a legitimate goal, considering that Native Americans were shaping the land long before European settlers arrived. "There is no such thing as presettlement, at least not the way most people define it. It's all been settled since 10,000 to 20,000 years ago," says Charles Kay, a wildlife ecologist at Utah State University in Logan. Bonnicksen agrees, arguing in a new book, *America's Ancient Forests: From the Ice Age to the Age of Discovery*, that "the forests and the people who lived there formed an inseparable whole that developed together over millennia." Other experts, however, play down the impact of Native Americans. "It's an overgeneralization to say that everywhere you look is the hand of man in the presettlement era," says Thomas Swetnam, a fire ecologist at the University of Arizona in Tucson. In particular, he takes umbrage at Bonnicksen's view that Native Americans thinned Northern Arizona's pine stands: Rather, he says, fires triggered by lightning strikes were the major landscape architect before European settlers arrived. The best strategy, Swetnam says, is to use fires and logging judiciously to return forests to a state in which frequent, small, natural fires can help tend the forests.

Although scientists debate what forces, in what proportions, kept North American forests healthy in presettlement times, they concur that each restoration project must be justified in part based on the emerging data about regional ecological histories. The questions, says Swetnam, have become "where and how to do [restoration], and to what extent should you use the past?" Scientists and policy-makers must act quickly to try to achieve a consensus on these issues, says Savage, before it's too late for ailing ecosystems: "The next 10 years will determine the future of the forests."

–KEITH KLOOR

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