Rocky Mountain News
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Part 1: Pollutants raining down on Rockies

Nitrogen buildup putting national park's ecosystem at risk - and it could get worse, research shows

Jim Erickson, Rocky Mountain News

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CHANGE IN THE AIR: FIRST IN AN OCCASIONAL SERIES ABOUT HIGH-ALTITUDE RESEARCH IN COLORADO

ESTES PARK - Airborne pollutants from Front Range tailpipes, smokestacks, crop fields and feedlots are damaging the prized mountaintop ecosystems of Rocky Mountain National Park.

If unchecked, the creeping accumulation of urban nitrogen compounds could acidify park waters and soils, posing a threat to fish, forests and vast expanses of rolling alpine tundra, National Park Service air-quality officials have concluded after reviewing more than 20 years of research.

As it is, the Park Service has concluded that a crucial threshold called a "critical load" has been crossed and that harmful changes are occurring. When plants and soil are saturated by a pollutant, runoff is next.

"When the fish are floating belly up, it's too late," said Christine Shaver, chief of the federal agency's air resources division. "We want to find some way to see if we can halt or reverse the harm we're seeing now, before it gets to that point," she said.

For two decades, park researchers have watched with alarm as levels of nitrogen compounds from Front Range auto exhaust, coal-fired power plants, gas and oil wells, crop fertilizers and livestock manure inched higher and higher.

Now, for the first time in its history, the Park Service will use the concept of critical loads to argue for reductions in emissions affecting a national park, Shaver said.

Last month, the Park Service began meeting with state health officials to look for solutions to the problem, which is known as nitrogen deposition.

One idea being floated by the Park Service is to add nitrogen deposition to ozone- and haze-reduction programs already in the works at the Colorado Department of Public Health and Environment.

If Colorado officials don't respond, the Park Service could ask the U.S. Environmental Protection Agency to force the state to take action.

"It is our responsibility - under our own statutory mandates - to preserve our resources unimpaired for future generations," Shaver said.

Established by Congress in 1915, Rocky Mountain National Park straddles the Continental Divide and is visited by more than 3 million people each year.

The 415-square-mile park boasts more than 110 peaks higher than 10,000 feet. More than 100 square miles of the park lie above tree line - a landscape of granite, ice and alpine tundra.

Periodic easterly upslope winds have been dumping urban nitrogen compounds onto the park for decades, where they fall in snow and rain, said Jill Baron, an ecosystems ecologist with the U.S. Geological Survey in Fort Collins.

If the problem continues to grow, researchers fear nitrogen pollution will mimic the effects of acid rain, which has killed forests and sterilized waterways in the eastern United States, central Europe and Scandinavia.

Pollution hits tipping point

Baron and her colleagues have monitored precipitation and surface water chemistry, weather and stream flow in the park's Loch Vale watershed since 1982. The Loch Vale study is one of the longest-running and most closely monitored studies of subalpine forest in the United States.

All of the changes detected to date are subtle responses to the fertilizing effects of nitrogen compounds.

Ammonium nitrate is a common crop fertilizer. It's also the explosive Timothy McVeigh used in the Oklahoma City bombing.

Ammonium and nitrate are two of the nitrogen compounds raining down on the Rockies. In the Loch Vale watershed, which hugs the east flank of the Continental Divide south of Bear Lake, the fertilizers have:

• altered the growth of 300- to 700-year-old Engelmann spruce trees;

• caused formerly rare types of algae to bloom in previously limpid alpine lakes;

• changed soil chemistry;

• flushed excess nitrogen into the streams.

These changes are imperceptible to the passing hiker, but park officials say they're consequential because the agency has a mandate to preserve wild places in a natural and unimpaired state.

"Natural is not treating those trees like a tree farm, where you dump extra nitrogen on them and they grow better," said Park Service ecologist Tamara Blett.

Nitrogen deposition has been increasing in the park by about 2 percent a year for the last two decades.

The current annual nitrogen deposition level in the park is about 3.92 pounds per acre. That's about 15 times higher than preindustrial levels, according to a fact sheet the Park Service began distributing at the Beaver Meadows visitor center.

The current levels of nitrogen exceed the critical load - the tipping point at which a pollutant begins to damage ecosystems, according to the Park Service.

Once that threshold is passed, plants and soils reach saturation. The excess pours into waterways.

Based on evidence from other parts of the world plagued by acid rain, the next step will be acidification of the park's highest-altitude streams.

Computer models suggest it won't happen for another decade or so, Baron said. But once it does, dead trout are sure to follow, she said.

Acids also can rob nutrients from the soils, weakening trees and making them susceptible to disease and insect attacks.

"It hasn't happened yet. Nevertheless, it's coming," said Baron, who heads the Loch Vale project. "We're at the beginning of a trajectory of change that will only get worse and worse.

"And if we keep increasing emissions, we will see acidification, we will see dead fish," Baron said.

'Place that inspires millions'

Park Service officials are still trying to nail down the exact nitrogen deposition level that constitutes a critical load for Rocky Mountain National Park.

In coming months, they will settle on a specific number, then use it to push for emissions reductions, Shaver said.

Vickie Patton, a senior attorney at the Boulder office of Environmental Defense, praised Park Service officials for using the critical-load approach because "it brings to bear the very best science available to inform public policy action."

But she said the Park Service is not moving fast enough or pushing hard enough to address nitrogen problems in the park.

Under the federal Clean Air Act, the Park Service is charged with an "affirmative responsibility" to protect places like Rocky Mountain National Park from the harmful effects of air pollution, Patton said.

"The Park Service can and should do more," Patton said. "We're talking about the crown jewel of Colorado and a place that inspires millions of Americans."

Douglas Benevento, executive director of the state health department, said his agency wants to help solve the park's nitrogen deposition problem.

But it might not be prudent to fold nitrogen deposition into the ozone and haze reduction programs, as Shaver suggested, he said.

It might make more sense to begin by measuring the effect those programs - along with the introduction of cleaner-burning gasoline recently mandated by the EPA - will have on nitrogen emissions along the Front Range, he said.

"We need to pinpoint where we're at now, and then from there determine if more needs to be done," Benevento said.

And though park researchers contend that Front Range nitrogen emissions are the main culprit, Benevento said he's not convinced.

"If we were to cut by half everything along the Front Range, I'm not sure that would solve any problem that exists at Rocky Mountain National Park," he said.

Westerly winds blow pollutants into Colorado from West Coast states and beyond, he said.

"There are a lot of out-of-state sources that we need to factor into this - California would be a good place to start - to try to determine what a solution would look like," he said.

Vehicle exhaust top offender

In addition to identifying the pollutants' origin, the Park Service and regulatory agencies need to get specific about the emissions sources that are to blame, said Frank Prager, managing director of environmental energy for Xcel Energy.

Xcel operates three coal-fired power plants in the Denver area and several others around the state.

Between 1995 and 2002, the company reduced nitrogen oxide emissions from its Colorado plants 27 percent by installing so-called low-NOx combustion technology, Prager said. The improvements cost $31.2 million and cut nitrogen oxide emissions by about 14,500 tons per year.

"If additional power plant reductions are necessary and required under the Clean Air Act to address this concern, we will be there, as we always have been," Prager said.

"But we want to make sure that the things we're going to be doing are actually going to result in preserving the park for future generations."

Baron and her colleagues believe the main source of the nitrogen compounds reaching Rocky Mountain National Park is the South Platte River Basin, home to about 2.9 million Coloradans - about two-thirds of the state's population.

Vehicle emissions account for 45 percent of the basin's nitrogen emissions, according to a new study by Baron and other researchers at Colorado State University's Natural Resources Ecology Laboratory.

Coal-fired power plants and other "point sources" of nitrogen emissions are responsible for about 34 percent of the nitrogen emissions.

Nitrogen compounds from synthetic crop fertilizers and ammonia from manure in feedlots account for 11 and 10 percent of the emissions, respectively. Winds scour the gases and particles off the crop fields and feedlots and blow them into the mountains.

Emissions still on upswing

By analyzing layers of sediment in high-altitude Rocky Mountain National Park lakes, researchers have concluded that nitrogen levels began to soar around 1950. The types of algae in the sediments remained essentially unchanged for the 14,000 years preceding 1950, then abruptly shifted in an apparent response to added nitrogen.

The widespread application of synthetic nitrogen fertilizers on irrigated cropland began in the late 1950s in the South Platte Basin. While the acreage devoted to crops has decreased by about 2 percent in eastern Colorado since 1950, irrigated acres increased by about 73 percent during that span, Baron and her colleagues found.

The rise in acreage devoted to irrigated corn and alfalfa hay accompanied an increasing demand for livestock feed in eastern Colorado over the last half century. During that time, the South Platte Basin became a national center for feedlot operations.

By 1995, the basin was home to 1.3 million cattle, 278,000 hogs, 327,000 sheep and 2.9 million chickens. More than half of those cattle are in Weld County.

Until the 1960s, the South Platte River Basin's economy was dominated by agriculture, and the region had about 800,000 residents. The population jumped from 1.9 million to 2.9 million between 1980 and 2000, with most of the growth along the urban corridor stretching from Denver and its suburbs north to Fort Collins.

As the basin's population grew, so did emissions of nitrogen oxides from vehicles, factories and coal-fired power plants. Urban and industrial processes replaced agriculture as the leading sources of nitrogen emissions, according to Baron and her colleagues.

Nitrogen emissions are still increasing in most of the 16 counties in the basin, they found.

Delicate ecosystems under assault

First dominoes begin to fall as acidity levels continue to increase

Jim Erickson

Sunday, August 29, 2004

NIWOT RIDGE - The dominoes are tumbling one by one, and the end point will be dead fish and dead trees in Colorado's high country, according to University of Colorado biogeochemist Mark Williams.

"The wilderness is not going to fall apart in the next year, but we're kicking over the first dominoes now," said Williams, a fellow at CU's Institute of Arctic and Alpine Research, known as INSTAAR.

He has studied the chemical changes in snowmelt runoff from the upper basins of the Green Lakes Valley near Niwot Ridge, about 30 miles west of Boulder.

The watershed, tucked up against the eastern boundary of the Continental Divide, is a significant contributor to Boulder's water supply.

Over the last 20 years, nitrogen compounds in the rain and snow have more than doubled there. As the snow melts, runoff acidity spikes, occasionally reaching concentrations strong enough to kill young fish, said Williams.

This "episodic acidification" was first detected in 1994 and usually lasts a couple of weeks. If the dominoes continue to fall, however, the Green Lakes Valley is heading toward chronic acidification, which can threaten the health of streams, forests and alpine tundra.

Along the way, wildflower diversity in the tundra is likely to decline as grasses and sedges replace flowers.

On the pH scale of acidity, distilled water has a neutral pH of 7.0. Rainfall is naturally somewhat acidic, with normal values between 5.0 and 5.6.

In the northeastern U.S., where emissions of sulfur compounds were blamed for acid rain that ravaged forests and waterways in the latter half of the last century, typical pH values range from 4.0 to 4.5, according to Meteorology Today by C. Donald Ahrens.

In the Green Lakes Valley, pH levels as low as 4.8 have been detected, Williams said. That's low enough to kill young trout, although there are no fish in the highest catchments where the most acidic water has been collected.

Other parts of the country, such as the Northeast, receive more nitrogen pollution than Colorado. But this state's alpine areas, with their granitic bedrock, sparse vegetation, thin soils and short growing season, are much more sensitive to even small nitrogen additions.

Unlike deciduous forests in the East, Colorado's alpine outposts just can't digest all that extra nitrogen.

Once chronic acidification spreads through the Green Lakes Valley, tainted waters will start moving downslope, into streams and lakes teeming with trout, said William Bowman, director of CU's Mountain Research Station.

More dominoes will fall, but the timetable is unclear. It could take decades.

"The acidification will become more sustained, rather than episodic," Bowman said. "The stream insects will begin to disappear, then you'll see a loss of the stream vertebrates - the fish.

"I doubt it would get all the way down to Boulder, but it could get into some heavily used recreational streams with trout," Bowman said during a recent hike to the top of 11,600-foot Niwot Ridge.

Scientists affiliated with the Mountain Research Station have been conducting climate research on the ridges since 1952. Some of the first stream chemistry work was done by INSTAAR researcher Nel Caine.

In 1997, Bowman and his colleagues began spraying ammonium nitrate fertilizer onto small test plots in the alpine tundra to see how nitrogen deposition is likely to affect that ecosystem in the future.

On Niwot Ridge, the alpine tundra is a mix of grasses, sedge, wildflowers and other forbs, moss, lichen and low shrubs such as dwarf willow and birch.

Three hundred forty species of plants have been described at Niwot Ridge, which shares 40 percent of its plant species with the Arctic.

"This is one of the most diverse herbaceous ecosystems in the United States," Bowman said. "In an hourlong drive, you can get into a biotic zone similar to northern Canada."

The wildflowers - violet-blue harebells with oblong, toothed leaves; buttercups; funnel-shaped Arctic gentian with creamy, green-speckled petals - bloom during a three-month growth spurt that starts in late May.

Though most of them are no more than 6- to 8-inches tall, these perennials can live for 70 years or more, eking out an existence in a punishing environment.

Bowman's fertilization experiments have shown that alpine blue grasses and a type of curly-leafed sedge are better able to take advantage of excess nitrogen than other plants. In the test plots, weedy grasses and sedges are driving out the wildflowers and taking over.

The same effect is beginning to be seen outside the test plots, on the open alpine tundra. Grasses and sedges are sucking up the Front Range nitrogen compounds falling from the sky.

The end result will likely be fewer wildflower species and a less dazzling visual display.

But the effects go beyond aesthetics.

As grasses and sedges proliferate, soil properties change and more nitrogen is released into streams, accelerating the progression toward acidification.

The time it takes for all the dominoes to fall depends, in part, on whether urban dwellers rein in the nitrogen emissions.

"The usual strategy in Colorado is that we'll deal with problems when we have dead fish and dead trees," Williams said.

"But the scientists are saying, 'We know we're perturbing the system now. Do we really want to wait until we have dead fish and dead trees until we do something about it?' "

Part 2: Going, going, gone?

Front Range glaciers declining; researchers point to a warming world

Jim Erickson, Rocky Mountain News

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CHANGE IN THE AIR: SECOND IN AN OCCASIONAL SERIES ABOUT HIGH-ALTITUDE RESEARCH IN COLORADO

"And Men shall fashion Glaciers into Greenness and harvest April rivers in the Autumn."

- *Inscription beneath a mural in the Colorado Capitol*

ARAPAHO GLACIER - The state's largest glacier is shrinking fast, and University of Colorado researchers suspect global warming is playing a role.

The surface of the 62-acre Arapaho Glacier along the Continental Divide west of Boulder has dropped 100 to 130 feet since 1960, according to recent CU reports.

A third CU analysis concludes that the surface of the 25-acre Arikaree Glacier, about five miles north of the Arapaho, has also sunk some 66 feet since 1965.

The three reports are the first to document significant present-day declines in Colorado's pint-size Front Range glaciers, which are clustered along the Continental Divide from Rocky Mountain National Park south to Interstate 70.

"We can argue about the rate of decline, but I think we can say confidently that both of them are losing ice - and they've been losing it fairly seriously," said CU hydrologist Nel Caine, author of the Arikaree report.

CU researchers say there is no reason to believe that other Front Range glaciers aren't experiencing similar declines. Some of them could be gone in a few decades.

Just two years ago, at the height of Colorado's multiyear drought, two year-round ice patches along the Continental Divide disgorged ancient bison horns that have been radiocarbon dated between 2,090 and 2,280 years old.

The animal remains suggest that, in some cases, ice along the divide has retreated to levels unseen since before the time of Christ.

"Over the last couple of decades, and especially over the last 10 years, we have entered a period of warming and retreat that is as great, or greater, than any we know of since the end of the last ice age" 10,000 years ago, said glaciologist Tad Pfeffer, of CU's Institute of Arctic and Alpine Research, or INSTAAR.

"The Front Range glaciers and snowfields could be gone in a couple of decades," Pfeffer said.

"Are we directly responsible for this? Is this the smoking gun that says this is caused by fossil-fuel emissions? That's a harder question to answer," he said.

Change in the high country

Water managers say the loss of the state's 14 named mountain glaciers and the hundreds of unnamed year-round snow patches along the Continental Divide would have little effect on municipal water supplies, since their contribution is small.

But the loss of glaciers and the so-called perennial snowfields would redefine places such as Rocky Mountain National Park. It would reduce habitat for fish that rely on late-summer runoff from glacial sources. Some alpine plants and high-altitude forests also could suffer.

And the extinction of the alpine ice would cut deeper, beyond what can be measured in tourist dollars or acre-feet of water. Those scattered scraps of flowing mountaintop ice are remnants of the last ice age, the last links to a vanished time, when mammoths roamed the landscape.

"Compare these mountains to a really dry mountain range in New Mexico or Arizona or Nevada. They're very different places," Pfeffer said. "And to the extent that we care about the landscape that we live in, that matters."

"Aesthetically and emotionally, they're worth a lot," he said.

Diminishing glaciers

Mountain glaciers have been retreating worldwide for a century, and there's no end in sight.

The declines are viewed by many scientists as strong evidence that global warming - caused, in part, by the buildup of carbon dioxide and other heat-trapping greenhouse gases emitted when fossil fuels are burned - is reshaping the natural world.

During the past 40 years, the total volume of mountain glaciers around the globe has declined by about 10 percent, according to INSTAAR glaciologist Mark Dyurgerov.

The losses have been especially severe in Alaska, the Alps, the Himalayas and the Andes.

Western U.S. glaciers also have suffered, especially in places such as Glacier National Park.

U.S. Geological Survey maps show 1,700 glaciers or perennial mountain ice patches in the West. Most are in Washington, Montana and Wyoming, but 34 are listed in Colorado.

The only known growing glacier in the contiguous United States was, until recent weeks, inside Mount St. Helens, said Portland State University glaciologist Andrew Fountain. Now that one is shrinking, too, he said.

While glaciologists have flocked to remote mountain glaciers to document their decline, Colorado's glaciers have been largely overlooked. There have been few systematic, long-term monitoring studies here, in part because the puny Front Range ice slabs barely qualify as glaciers.

Surprisingly little work has been done on the status of the glaciers in Rocky Mountain National Park, home to about half the Colorado glaciers named on U.S. Geological Survey maps. Park officials blame tight research budgets.

One unfinished U.S. Geological Survey study of the park's Andrews Glacier, however, suggests it has retreated a bit since 1991.

And Fountain recently embarked - with funding from NASA and the National Science Foundation - on a multiyear study of Western glaciers, including some in Rocky Mountain National Park.

He said the park's glaciers appear to be "holding steady," but that early assessment is based mainly on a review of archival glacier photographs.

Warming's effects disputed

INSTAAR researchers Caine, Pfeffer and Dyurgerov are among the few who have made an effort to study the local glaciers in detail.

Pfeffer compared the Arapaho Glacier's current surface elevation with measurements made in 1960 and determined that the ice surface has dropped 100 feet.

Caine has measured May-through-October runoff at Arikaree Glacier weekly since 1981. Combining his runoff records with data from two nearby weather stations, he calculated that the Arikaree has lost up to 66 feet in depth since 1965.

Dyurgerov used 2003 Arapaho Glacier measurements, weather records and some of Caine's Arikaree data to calculate a loss of about 130 feet at Arapaho Glacier since 1960.

Though the INSTAAR researchers are convinced the losses are real, they can't say for sure why the changes are happening.

But given the condition of mountain glaciers worldwide, it seems likely that global climate change is playing some role, Pfeffer and Dyurgerov said.

"We know the temperature is rising globally, and we know that glacial volumes are shrinking globally," Pfeffer said.

"My feeling is that global warming is probably involved.

"But I can't point at Arapaho - by itself, in isolation - and say this is evidence of global warming. You just can't do that.

"You have to look at these things in aggregate."

Boulder geologist and archaeologist Jim Benedict says it would be "bad science" to blame global warming for any of the Arapaho decline.

Benedict began photographing Arapaho Glacier annually in 1980. When he compares his pictures with an 1898 archival photograph taken by CU's R.S. Brackett, it's clear to him that "this poor thing has taken a beating, no question."

Archival photos reveal that the Arapaho lost a tremendous amount of ice between 1898 and 1960. The losses since then are less obvious in the photos, although the CU reports suggest declines are continuing.

Dyurgerov's "mass balance study" concludes that the Arapaho actually gained ice and snow from 1969 to 1975, but has been declining since 1976, with sharp drops during the current multiyear drought.

"We're losing this glacier," Benedict said as he mounted his Hasselblad camera on a tripod at the Arapaho Col overlook during an early September hike to the glacier. "It used to be big and convex. Now it's little, shrinking and sad."

Due to local peculiarities of weather and topography, however, the Front Range glaciers don't behave like typical mountain glaciers. So assumptions about the effects of global climate change simply don't apply here, he said.

"It's more difficult to interpret the effects of climate change here than it is in other places, because things are complex here, not straightforward," Benedict said.

State's temperature up

So why then are the Arapaho and Arikaree glaciers shrinking?

Are the declines simply a reaction to local and regional conditions, or is global climate change involved?

In general, mountain glaciers are considered sensitive indicators of temperature change: They advance when it gets colder and they retreat when it warms.

During the 20th century, the global average surface temperature increased by about 1 degree, according to the Intergovernmental Panel on Climate Change.

The IPCC was established by the World Meteorological Organization and the United Nations in 1988 and includes hundreds of climate researchers from around the world.

Some of that warming is likely due to natural climate variability.

But most of the observed warming during the past 50 years is probably the result of human activities, the IPCC concluded in 2001.

And Colorado has not escaped the warming trend.

The state's average annual temperature has increased 1.5 degrees during the past century, according to research meteorologist Martin Hoerling, of the U.S. Climate Diagnostics Center in Boulder.

Six of Colorado's 10 warmest years have occurred since 1981, according to temperature records from the National Climate Data Center.

"It's hard to pooh-pooh it and say that it doesn't look like a trend," said Assistant State Climatologist Nolan Doesken. "One can argue why it's there, but it's hard to deny that it's there."

Colorado contradiction

In some mountainous regions, including the Himalayas, Andes and Alps, the warming of recent decades is more pronounced at higher altitudes. But for reasons that remain unclear, that does not appear to be the case - at least not yet - along Colorado's Front Range, said Henry Diaz, another Climate Diagnostics Center meteorologist.

"In Colorado, there isn't any clear signal as far as (warming) differences between the elevations," Diaz said.

Weather data from CU's Mountain Research Station on Niwot Ridge, several miles northwest of Nederland, demonstrate that the warming picture is a bit muddled along the Front Range.

In 1951, CU biologist John Marr established weather stations at various elevations on the ridge to help clarify the Front Range ecology. Conditions at four of the stations - known as A-1, B-1, C-1 and D-1 - have been continuously monitored since 1953.

The C-1 station is in subalpine forest at an elevation of 9,973 feet.

Between 1976 and 2000, the average annual air temperature there increased by about 3 degrees, according to Mark Losleben, manager of the Mountain Climate Program at Niwot Ridge.

But the weather records from the highest station, D-1, tell a different story.

D-1 is in alpine tundra at 12,339 feet, roughly the same elevation as Arapaho Glacier.

The D-1 station has the longest unbroken high-altitude weather record in North America.

At D-1, which is about five miles north of Arapaho Glacier, near Arikaree Glacier, there's been no statistically significant temperature change since 1953, Losleben said.

During that span, annual precipitation has increased by nearly half an inch a year at D-1.

State Climatologist Roger Pielke Sr. and colleagues at Colorado State University have suggested that increased cropland irrigation and irrigated landscaping along the Front Range has boosted the amount of cool, wet air flowing into the mountains in recent decades.

Moister air and an accompanying increase in mountain cloudiness could be holding temperatures in check at places such as Niwot Ridge, Pielke and his colleagues have suggested.

So, if the average annual temperature at D-1 hasn't changed and precipitation is up, why are the Arapaho and Arikaree glaciers retreating?

Pfeffer suspects it's because the summer melting season is starting earlier and lasting longer.

Caine wonders if more and more dust is being blown into the high country, darkening the glacial ice and causing increased melting.

But no one knows for sure why it's happening.

"That's a puzzle," Caine said. "And it will probably remain a puzzle."

The long age of ice

During the Pleistocene Epoch, from 1.8 million to 10,000 years ago, the Front Range was lined with rivers of ice that flowed down mountain valleys as far east as present-day Nederland, Georgetown, Allenspark, Fairplay and nearly to Estes Park.

The Cache la Poudre Glacier, northwest of present-day Fort Collins, was the region's largest.

It sprawled nearly 30 miles from its source in the southern Medicine Bow Mountains and was up to 2,000 feet thick, according to Richard Madole, of the U.S. Geological Survey.

Scattered scraps of glacial ice persist today because west winds blow snow over the Continental Divide. In many cases, the snow collects in high, sheltered, bowl-shaped rock basins called cirques.

Over time, the snow is compressed into granules called firn, then pressure welds the granules into glacial ice.

The Arapaho is Colorado's largest survivor and the southernmost active glacier in the Rockies, according to INSTAAR researchers.

It is a cirque glacier, a tongue of ice and snow that creeps down the Silver Lake Valley at 3 to 6 feet a year.

But if the melting continues at its current rate, when will Arapaho Glacier disappear?

That depends on the thickness of the remaining ice slab, which has never been precisely measured.

To probe the depths of the Arapaho ice, seven researchers from INSTAAR and the National Snow and Ice Data Center in Boulder recently backpacked into the glacier - a six-mile round-trip hike - lugging a 170-pound portable radar system.

Affectionately known as the Wright Flyer, the radar contraption looks like a cross between the famous Kitty Hawk biplane and a high-tech dog sled.

Like a giant Lego toy, the Flyer's wobbly 12-foot framework is pieced together from segments of plastic PVC tubing. The frame rests on two cross-country skis, so it can be hauled back and forth across the glacier.

A radar transmitter, receiver and batteries are strapped to the frame, and fiber-optic cables send a digitized signal to a laptop computer.

The transmitter sends radar pulses through the ice to bedrock.

The time it takes for that signal to bounce back to the receiver - measured in milliseconds - tells researchers the depth of the ice.

Boulder geophysicist Ted Scambos supervised the effort, as several graduate student "Sherpas" lugged the Flyer across slushy snow, beneath towering walls and spires of ancient gray gneiss and granite.

The radar reflection appeared to show an ice/rock boundary at a depth of about 150 feet.

But the result was deemed inconclusive, and Pfeffer suspects the true depth is less. A previous attempt to probe the glacier with radar, conducted by the same group in 2002, yielded a depth of 73 feet.

"I'm not happy with either one of those numbers," Pfeffer said after the trip.

The Boulder researchers are planning a return visit, possibly next month.

If 150 feet is in the ballpark, then Arapaho Glacier has lost at least 40 percent of its thickness since 1960. It would last another 60 years or so if melting continues at its current rate.

But if the slab is just 73 feet thick, the glacier could be gone in half that time.

If the latter measure is accurate, Arapaho Glacier, a final vestige of the last ice age, could be gone from the face of Colorado within 30 years.

Melting glaciers reveal treasures of past

Thawing has yielded animal remains more than 2,000 years old

By Jim Erickson, Rocky Mountain News

Tuesday, October 26, 2004

Sculptor Bill Ikler was hiking along the edge of a snowfield near the Continental Divide when a friend picked up a cracked, waterlogged, gray-brown chunk of what looked like driftwood.

"We were probably 3 or 4 feet away from a snowfield, and my friend Janet picked up something and asked if it was wood or if it was bone," Ikler recalled.

Ikler, who had once studied a bison skull while doing research for one of his sculptures, recognized the 8-inch-long object immediately: It was the bone core from a bison horn.

"And then I looked down, and right near my hand was the other core, the other bison horn," he said, recalling the late-summer 2002 hike west of Nederland. "These had just melted out of the snowfield. They were literally pulled from the muck."

Samples were sent to the Lawrence Livermore National Laboratory for radiocarbon dating, and the results were surprising.

The bison-horn cores were 2,090 years old, said University of Colorado archaeologist Craig Lee.

In September 2002, a hunter found another ancient bison horn in the high country south of Rocky Mountain National Park. Once again, the remains were found melting from a perennial snowfield depleted by the multiyear drought.

But this specimen was a bison-horn sheath - the glossy, black exterior part of the horn. Horn sheath is made of keratin, the same fibrous protein found in fingernails.

"It's tough stuff, but it's very much weaker than bone," Lee said. "Once exposed to the elements, it would disintegrate within 10 years, easily, and probably a lot less."

Samples were sent for dating. And once again, the results jolted scientists: The horn sheath was 2,280 years old, Lee said.

In recent years, deer, elk, bighorn sheep and bison remains have been recovered from melting glaciers and snowfields in the Colorado high country. Some were a few centuries old, but none came close to the age of those bison horns recovered in 2002.

To Lee, the discoveries indicate that ice along the Continental Divide has retreated to levels unseen since the time of Christ.

"Skull fragments would not be able to sit out on the surface, unprotected, for two millennia," said Lee, a doctoral candidate in the CU anthropology department.

"They had been protected by the snow and ice for 2,000 years, and now they're melting out," he said.

Around the world, retreating mountain glaciers are creating a windfall for researchers such as Lee and his faculty adviser, CU archaeologist James Dixon. Lee and Dixon spend part of their summers scouring the fringes of retreating Alaskan glaciers, looking for ancient artifacts.

When they return to Colorado at summer's end, Lee heads to the high country to walk the edges of glaciers and snowfields.

What he'd really like to find is evidence - stone projectile points, for example - tying prehistoric hunters to big-game animals that ended up in the snowfields.

Prehistoric game drives and hunting blinds have previously been documented in the high country west of Boulder.

"At this point, we can't say that human beings had anything to do with these bison winding up in the snow and ice patches," he said. "But I think there might be a chance that prehistoric artifacts might be up in those patches, too."

While the discovery of 2,000-year-old bison horns leaves Lee wondering about the past, the find makes Ikler ponder the future of the Front Range.

Ikler, 56, has been hiking along the Continental Divide since the early 1970s.

"These things were very, very old," he said. "So this is a warning that these snowfields are melting fast. It just reinforces my feeling that we need to do something about global warming."

Glacial artifacts

• Bone cores from ancient bison horns: The horn cores are about 8 inches long, found melting from a snowfield by hikers near the Continental Divide west of Nederland in late summer 2002. They were radiocarbon-dated at 2,090 years old.

• Bison horn sheath: The glossy, black exterior part of a horn, the horn sheath is made of keratin, the same fibrous protein found in fingernails. A hunter found it in the high country south of Rocky Mountain National Park in September 2002. It was radiocarbon-dated at 2,280 years old.

Part 3: Bleak forecast for ski industry

Warmer temps may put resorts in deep freeze

By Jim Erickson, Rocky Mountain News

Saturday, March 19, 2005

CHANGE IN THE AIR: THIRD IN AN OCCASIONAL SERIES ABOUT HIGH-ALTITUDE RESEARCH IN COLORADO

ASPEN - Colorado's $2 billion ski industry could be dead by 2050 unless radical steps are taken to address global warming and save the state's prized champagne powder.

This is not a line from the latest Hollywood disaster flick about the impending climate apocalypse. And it's not the Chicken Little ravings of some kook on late-night talk radio.

This gloomy pronouncement comes from an executive at the Aspen Skiing Co., operators of a four-mountain ski mecca in one of the world's best-known and poshest destination resorts.

"Things look bleak," said Auden Schendler, the company's director of environmental affairs.

The most likely scenario for Colorado's 25 ski resorts, unless global emissions of heat-trapping "greenhouse" gases are reined in: "Gone in 2050 . . . Maybe - good case scenario - gone by 2100," he said.

Schendler's pessimism is based on numerous climate-change studies that predict declining mountain snowpacks in coming decades as the West warms.

"Most analyses project a decline, if not total demise, of downhill skiing by the mid or latter part of the 21st century," proclaims the federally funded Rocky Mountain/Great Basin Regional Climate-Change Assessment, a 240-page study produced by more than 125 researchers.

But uncertainty about the amount of warming, the reliability of computerized climate models used in such studies - and especially about how precipitation patterns will change in the Colorado Rockies - leaves plenty of room for speculation.

In the Colorado ski industry, opinions about the likely impacts of climate change run the gamut, and some observers reject Schendler's views as overly negative and unjustified.

Even so, few in the industry dismiss the climate-change issue completely.

Warming on radar screen

"Climate change is a potential risk in our industry. It's on all our radar screens," said Bill Jensen, senior vice president and chief operating officer for Vail Resorts.

"But I'm not as pessimistic as Auden," he said. "I think we'll be able to adapt."

Jensen envisions scenarios in which Colorado ski resorts could benefit from a few degrees of warming.

Schendler's boss at Aspen, President and Chief Executive Officer Patrick O'Donnell, called climate change "the most pressing issue facing the ski industry today."

But O'Donnell said he remains optimistic that global greenhouse emissions will be curtailed and the warming problem controlled.

And Aspen Skiing Co. is moving ahead with plans for a $400 million revamping of the Base Village at Snowmass, which suggests the resort's owners remain upbeat about the future of Colorado skiing.

Scientists acknowledge the limits of the computer models used to project future climate at the regional level. But despite the unknowns, certain changes seem unavoidable if warming continues, they say.

In the Rocky Mountain/Great Basin Regional Climate-Change Assessment, scientists concluded that some outdoor recreational activities, such as fishing and golf, could benefit because warmer temperatures would extend the summer season and make winters milder.

But downhill skiing would likely suffer, according to the study, released with little fanfare in February two years ago and published by the U.S. Global Change Research Program.

Likely major effects on the Colorado ski industry would include a shorter ski season and increased reliance on artificial snowmaking. The season would be squeezed at both ends, fall and spring, and attempts to make up for a natural-snow deficit with man-made snow could backfire due to warmer temperatures.

Models: variable, warmer

The two computerized climate models used in the regional assessment, known informally as the Hadley and Canadian models, project a 4.5- to 14.4-degree warming in the Rocky Mountains and Great Basin by 2100.

But most of the latest models suggest the West will warm between 3.6 and 10.8 degrees by 2100 as levels of heat-trapping gases continue to rise, according to Daniel Cayan, director of the climate research division at the Scripps Institution of Oceanography in La Jolla, Calif.

Even 4 degrees of warming in the Colorado mountains could have a "huge impact" on the ski industry, said Aspen's O'Donnell. The company attracts 1.3 million visitors each winter to its four mountains: Snowmass, Aspen Mountain, Aspen Highlands and Buttermilk.

The most damaging blow might be struck in the fall, when Colorado ski areas spray tons of artificial snow in a race to build the base layers needed to ensure a November opening.

Aspen starts blowing artificial snow in mid-October, using "every available hour" to lay down that base, O'Donnell said. Early-season conditions are critical, in part, because many out-of-staters make their winter vacation reservations based on late-November snow reports in the West.

"If somebody condensed my snowmaking period by a week or two, we'd have a real problem," O'Donnell said.

Warmer fall temperatures would hurt in several ways.

First, if mountain precipitation changes from rain to snow later in the season, there will be less natural snow on the ground.

Second, warmer temperatures could reduce the period when artificial snow can be made.

Third, making snow when temperatures approach the freezing point is costly, inefficient and produces inferior snow.

"What snowmaking allows us to do is to get open earlier, consistently, than we ever did before in the old days just relying totally on Mother Nature," O'Donnell said.

"It brings more cash flow in and gets more people interested," he said. "But if you haven't got the temperature, you can't make the snow."

Cutting the profit margin

In a good year, Aspen operates for about 140 days. It takes about 100 days to pay the resort's expenses, so all the profits come during the last 30 to 40 days - in March and part of April, O'Donnell said.

If climate warming starts compressing the Colorado ski season on both ends, he said, "It's going to be an economic disaster."

Last year, the four Aspen mountains spent $600,000 on snowmaking, including $388,000 for electricity and $115,530 for water. High-pressure spray guns made about 650 acre-feet of artificial snow, enough to cover one square mile to a depth of a foot.

The snowmaking campaign consumed 162.4 million gallons of water. That's enough water to supply the needs of nearly 1,000 Denver Water customers for a year. And it's more than three times the amount of water Aspen Skiing Co. used last year in its lodges, restaurants and hotels.

The optimum temperature for making artificial snow is 15 degrees, Schendler said. As the temperature rises, more compressed air and water must be forced up to the spray guns, increasing electricity costs and water consumption while producing heavier, lower-quality snow.

Snowmaking can continue up to 28 or 29 degrees, O'Donnell said. But the Aspen Skiing Co. avoids doing it, when possible, because it's so expensive. If climate change pushes fall temperatures near the upper limit of snowmaking, costs would skyrocket, he said.

Snowmaking more expensive

And then there's the question of water availability. Ski areas can't assume they will be able to get all the water they would need to expand snowmaking operations.

At Snowmass, for example, water use has been the subject of bitter conflicts - including several lawsuits - dating to 1978. Water used for snowmaking at Snowmass comes from Snowmass Creek, a tributary of the Roaring Fork River, which flows into the Colorado River.

A court ruling already limits the amount of water the ski area can pump from the creek, and it forces Snowmass to quit making snow each winter on Dec. 31.

Colorado's current population of 4.6 million is expected to swell to 7.2 million by 2030, a 55.5 percent increase. In the coming decades, competition for Colorado's water will intensify and water costs are likely to rise.

So water could cost more at a time when ski areas will need more of it for snowmaking. The seemingly inevitable result: increased operating costs.

"Let's be realistic about it. Those extra operating costs, in some form or another - at least a portion of it - are going to get passed on to the consumer," O'Donnell said. "You could end up pricing yourself out of business."

An Aspen four-mountain daily lift ticket costs $74. Vail charges $77.

Colorado typically leads the nation in annual skier visits, with an average of 11.5 million skiers per year, according to Colorado Ski Country USA, a nonprofit trade organization representing 24 of the state's 25 ski resorts.

But the annual number of Colorado skier visits has grown less than 1 percent since the 1993-94 season. It hit a high of 11,979,719 visits in 1997-98 and a low of 10,892,263 visits the following year.

The high cost of lift tickets may be partly responsible for that slow growth, and climate warming could add to the problem, said ecologist Frederic Wagner of Utah State University, co-coordinator of the Rocky Mountain/Great Basin regional climate assessment.

"If skiing is now at the expense level where it's shutting off moderate-income people - and I don't know that that is the case; this is a hypothetical - then they're going to get fewer and fewer people coming out to ski," Wagner said.

Downhill skiing contributes $2 billion to $2.5 billion to the Colorado economy annually, according to Colorado Ski Country USA.

"I can't say that this is absolute certainty, nor put a probability figure on it, but I think it's a distinct possibility that we're going to lose the snowpacks in the West and with that the ski industry," Wagner said.

Wetter may not be better

Most of the latest climate models show little or no change in annual precipitation for the West in the coming century, Cayan said.

The latest version of the Community Climate Systems Model from the National Center for Atmospheric Research in Boulder, for example, calls for a "slight annual increase" in precipitation over the Colorado Rockies by 2100, said Gerald Meehl, a senior scientist at the lab.

But no one knows for sure what will happen.

And even if it does get wetter here, warmer temperatures would likely reduce the length of the ski season because much of the extra mountain precipitation would fall as rain in autumn and spring.

The snow line would rise and the lowest-elevation Western resorts would be hurt first.

"The survival probability of lower-elevation resorts would still be low," despite an annual precipitation increase, according to the regional assessment.

But Vail's Jensen said Washington state's loss could be Colorado's gain.

The high elevations of many Colorado ski resorts could act as a temporary buffer against the damaging effects of climate warming, he said.

Think of warming temperatures as a rising sea that will inundate the lowest-elevation resorts first. If that's how it plays out, then ski areas in Europe, New England, the Pacific Northwest, the Midwest and even California's Sierra Nevada will be under water long before the high-altitude Colorado resorts.

As conditions deteriorate at lower elevations, skiers may seek higher ground in Colorado, Jensen said. During the next several decades, the Colorado ski industry could benefit, he said.

"What do you think the chances of us having snow in 40 years are, compared to Snoqualmie Summit, outside of Seattle, or ski areas that are outside of Boston that are at 1,200 feet?" Jensen said.

The Summit at Snoqualmie, a ski resort 52 miles east of Seattle in the Cascades, has elevations ranging from 2,610 feet to 5,420 feet above sea level. The resort has been closed most of the 2004-05 season because of lack of snow, and it received 8.5 inches of rain in a four-day period in January.

The base elevation of Vail ski resort is at 8,120 feet and the summit is at 11,570 feet.

"The base elevations of the Colorado resorts give us an advantage - certainly in the near term, if you define the near term as the next 50 years," Jensen said.

Warming controls destiny

In fact, a temperature increase of 4 degrees could result in higher snowfall totals during the coldest winter months at Vail and other Colorado resorts, said Jensen, who has worked in the industry for 31 years. Vail receives an average of 346 inches of snow per year.

Average low temperatures on Vail Mountain in December, January and February were 6.6 degrees, 6 degrees, 7.5 degrees, respectively, between 1973 and 2003.

When the temperature dips below 10 degrees or so at Vail, storms don't deliver much snow, Jensen said. If it warmed 4 degrees during those months, mid-winter skiing conditions could improve, he said.

"I would probably argue from a ski resort's perspective - a selfish ski resort's perspective - that it actually would lead to more snow in Colorado, because many times we're too cold to have it snow any significant amounts," he said.

But in the long run, significant warming would have "tremendously negative" effects on the industry, Aspen's O'Donnell said.

The solution is to cut global emissions of carbon dioxide and other heat-trapping gases that climate scientists say are warming the Earth.

"But it's out of our control," O'Donnell said. "The worldwide emissions of greenhouse gases is controlling our destiny."

Skiing green on colorado's slopes

energy-saving steps vital to industry's future, says aspen skiing co.

By Jim Erickson

Saturday, March 19, 2005

Imagine 1.3 million skiers and snowboarders schussing down the slopes, each hauling a 17-pound sack of coal.

The Aspen Skiing Co. operates a four- mountain ski resort, 15 restaurants and two hotels. Last year, the energy needed to keep it all humming released nearly 28,000 tons of heat-trapping carbon dioxide into the air, according to the company.

If each of the Aspen Skiing Company's 1.3 million annual visitors had to shoulder an equal share of the carbon in those emissions, it would amount to about 17 pounds of coal per skier and snowboarder.

"People need to know - whether they are skiing or commuting to work or flying to Europe - what that means in terms of emissions, and this makes it tangible," said Auden Schendler, director of environmental affairs at the Aspen Skiing Co.

In the grand scheme of things, ski resorts are not major contributors to the global buildup of carbon dioxide and other "greenhouse" gases linked to climate change.

But since skiing has no future without cold winter weather and snow, few industries have more to lose if dire climate-warming predictions prove true.

That's why Aspen Skiing Co. decided to set an example for the rest of the ski industry, said company President and Chief Executive Officer Pat O'Donnell.

In 2001, Aspen became the first U.S. ski resort to announce a climate-change policy that includes a commitment to reduce its own greenhouse gas emissions 10 percent by 2010, based on a 1999 baseline.

In case you've never skied Aspen, there are no belching smokestacks on the hillsides.

When company officials talk about cutting emissions, they really mean conserving electricity so less coal has to be burned at power plants.

The company also strives for increased use of alternative-energy sources such as wind, and cutbacks on gasoline, diesel fuel and natural gas.

Each year, it publishes a report that details energy consumption during the previous year and progress toward the 10 percent reduction.

Several energy efficiency and alternative-energy projects have been completed or are underway at Aspen.

They include:

* An onslope micro-hydroelectric system that uses the Snowmass snowmaking system to channel spring runoff through a turbine, generating electricity. The first of its kind in the ski industry, the pilot project is expected to produce enough energy to power 40 homes this spring.

* Two buildings that have achieved energy-efficiency certification through the U.S. Green Building Council's Leadership in Energy and Environmental Design program. The buildings are the Sundeck Restaurant atop Aspen Mountain and the new Snowmass Golf Clubhouse.

* Extensive lighting and compressor retrofits. In the parking garage beneath the company-owned Little Nell Hotel, for example, 110 metal halide lamps were swapped for energy-efficient T-8 fluorescent fixtures. The change prevents the emission of 150 tons of carbon dioxide each year and saves $10,600 annually, according to the company. Lights also were switched in the hotel kitchen.

* The company buys 5 percent of its electricity from renewable sources - mainly wind farms - each year.

* It uses 260,000 gallons of biodiesel fuel for its snowcats each year, reducing air pollution. The fuel mix contains conventional diesel and fuel made from soybean oil.

Charter for Sustainable Slopes

Now the company's leaders are no ski-slope Pollyannas, hoping to save the world by changing a few light bulbs. They realize that their efforts alone will not measurably reduce the explosive global rise of heat-trapping greenhouse gases produced mainly by the burning of fossil fuels.

"It's a small, small, small, borderline-irrelevant piece of the (global) puzzle," Schendler said of the energy-saving measures.

"But it's done in good faith, and it gives us credibility when we talk to Congress and to the governor, which we do," he said.

And Aspen is not alone in its green pursuits.

In 2000, ski areas across the country adopted an environmental charter commonly known as the Sustainable Slopes program. It proclaimed climate change a potential threat to the industry and identified voluntary steps - energy conservation, waste reduction and public education - that participating ski areas can pursue.

To date, 177 resorts have endorsed the charter, said Geraldine Link, director of public policy at the Lakewood-based National Ski Areas Association. The group represents 326 ski resorts.

Seventy-one of the resorts have signed letters endorsing the McCain-Lieberman Climate Stewardship Act, which would reduce emissions of greenhouse gases from industrial smokestacks.

"Our view is that if we're going to ask other people to make changes, we have to make changes ourselves," Link said. "And for our effort to be credible, we have to be the most sustainable operations we can be."

But a 2004 study by two public policy analysts found that, in many cases, participation in the Sustainable Slopes Program was more show than substance.

Participating ski areas "appear to be displaying rather opportunistic behavior, expecting to improve their 'green' reputation" without reducing environmental impacts, Jorge Rivera and Peter de Leon wrote in The Policy Studies Journal.

The practice they describe is sometimes called "greenwashing."

"The vast majority of the Sustainable Slopes program is, I believe, abused by the ski industry as a green-marketing tool," said Jeff Berman, executive director of Colorado Wild, a Durango-based conservation group that publishes an annual environmental scorecard on Western ski resorts.

'We're not a land trust'

Not so, Link said.

Electricity-conservation efforts under the Sustainable Slopes program have saved the equivalent to 90.2 million pounds of carbon-dioxide emissions, she said. Thirty of the participating resorts now purchase "green energy" sources such as wind and solar.

"Since when is that green-washing?" she said.

"And just for your background, the scorecard is developed by a group of environmental activists who sue ski areas," she said. "That's what they do for a living. They are not neutral. They're not objective."

Despite its reputation as an environmental leader, the Aspen Skiing Co. is moving ahead with plans for a new $400 million Base Village at Snowmass.

The development includes 349 condominiums, 246 hotel rooms and 64,000 square feet of new shops and restaurants.

Plans for the new village, proposed by Canada's Intrawest Corp. and Aspen Skiing Co., were approved by Snowmass Village voters last month.

If energy conservation is such a high priority for the company, why not adopt a zero-growth policy and make do with existing facilities?

"We're not an environmental group or a land trust," O'Donnell said.

"I run a for-profit company. My challenge is to find a balance between economic viability and environmental sustainability," said O'Donnell, former president and chief executive officer of the Patagonia clothing company.

Skier visits at Snowmass have been declining for several years. Snowmass needs a revitalized base village with plenty of "support amenities" to compete with other resorts, O'Donnell said.

"I can't let Snowmass die."

Part 4: Heating up the high country

Look ahead to the end of this century and climate change could dramatically alter the state's signature Rockies. Blame it on global warming, scientists say.

By Jim Erickson, Rocky Mountain News

Wednesday, April 20, 2005

CHANGE IN THE AIR: FOURTH IN AN OCCASIONAL SERIES ABOUT HIGH-ALTITUDE RESEARCH IN COLORADO

CRESTED BUTTE - Physicist-turned-ecologist John Harte says he's glimpsed the future of Colorado's high country under global warming, and it's not a pretty sight.

Sagebrush will drive out wildflowers as the state's prized alpine meadows dry up, the ski industry will founder within 50 years, and property values in mountain resort towns will plummet, Harte predicts.

The Berkeley, Calif., researcher has spent the past 14 years using electric heaters to simulate a warmer world on a hillside meadow at 9,600 feet in Gothic. The former mining town is several miles north of Crested Butte, designated the Wildflower Capital of Colorado by the state legislature.

Harte's climate-manipulation experiment was the first to use overhead heaters to mimic some of the expected effects of global warming on a natural ecosystem. The heaters have been operating continuously - 24 hours a day, year-round - since January 1991.

"Places like this will look much more like the sagebrush meadows around Gunnison," Harte said during a visit to his research plots at the Rocky Mountain Biological Laboratory in Gothic.

"We're talking about a completely different future for this region," Harte said as he hiked up a hillside cloaked in a riotous, multihued tangle of blooming wildflowers. "I hope I'm wrong."

Some climatologists and Colorado ski industry officials dismiss Harte's bleak outlook. And the folks at the Crested Butte Wildflower Festival aren't rushing to rename the event in honor of the hardy sagebrush shrub.

But key findings of Harte's federally funded meadow experiment - earlier springtime snowmelt, drier summer soils and sagebrush encroachment into alpine meadows - are viewed as likely scenarios in several studies of the potential impacts of global warming on the Rocky Mountain region.

The most comprehensive study to date is the 240-page *Rocky Mountain/Great Basin Regional Climate-Change Assessment,* prepared for the U.S. government. More than 125 researchers - including climatologists, hydrologists and ecologists - contributed to the report.

In it, scientists looked at the likely impacts of various future climate scenarios, based largely on the projections of two computerized climate simulations called general circulation models.

Both models predicted a surge in regional temperatures that would trigger transforming changes by 2100. The impacts, according to the study's authors, could plausibly include:

• Big reductions in the mountain snowpacks that provide most of the region's water. As temperatures increase, fall and early winter precipitation will likely continue as rain later in the year. Spring melting would start earlier.

"Marked temperature rise and winter precipitation changing to rain would likely reduce the magnitude and season length of snowpacks, even to the point of eliminating them" in some parts of the Rocky Mountain/Great Basin region.

• Significant summer drying and reduced soil moisture in Colorado's mountain forests, along with lower summer flows in rivers and streams. "Only those (plant) species that could disperse upward in elevation will be able to secure the necessary cooler, wetter conditions . . . Some native species would be lost."

• An earlier wildfire season, more droughts, more large-scale insect outbreaks in forests.

• Reduced habitat for native cold-water fish such as the cutthroat trout. The problem would be exacerbated by competition from nonnative fish species, which typically can tolerate higher temperatures.

"There is a distinct prospect of extinction among some cold-water endemic fish species which are already threatened or endangered."

• Shorter ski seasons and a higher snow line, placing low-elevation resorts at risk. "All analyses based on significantly higher temperatures project reduction or disappearance of skiing" in the region, according to the report.

Glimpse of warmer world

During the 20th century, the global average surface temperature increased about a degree, according to the Intergovernmental Panel on Climate Change.

The panel was established by the World Meteorological Organization and the United Nations in 1988. Hundreds of researchers around the world contribute to its periodic assessments.

Some of the 20th century warming probably was due to natural climate variability. But most of the observed warming in the past 50 years likely occurred because of the human-caused increase in heat-trapping "greenhouse" gases such as carbon dioxide, the climate panel concluded in 2001.

Later that year, a National Academy of Sciences report endorsed that intergovernmental panel finding, saying that it "accurately reflects the current thinking of the scientific community on this issue."

"Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise," according to the academy report, requested by the White House.

"Human-induced warming and associated sea level rises are expected to continue through the 21st century," the panel wrote.

Historian Naomi Oreskes analyzed more than 900 climate-related research papers published in peer-reviewed scientific journals between 1993 and 2003. She summarized her findings late last year in the journal *Science*.

"There is a scientific consensus on the reality of anthropogenic (human caused) climate change," the University of California at San Diego researcher wrote. "Climate scientists have repeatedly tried to make this clear. It is time for the rest of us to listen."

The world is warming.

And Colorado has not escaped the trend.

The state's average annual temperature increased 1.5 degrees during the past century, according to research meteorologist Martin Hoerling of the Climate Diagnostics Center in Boulder.

Six of Colorado's 10 warmest years occurred since 1981, according to temperature records from the National Climatic Data Center.

If atmospheric levels of carbon dioxide and other heat-trapping greenhouse gases continue to increase as projected - due mainly to the burning of fossil fuels - the planet is expected to warm another 2.5 to 10.4 degrees by 2100, according to the Intergovernmental Panel on Climate Change.

Most continents would warm more rapidly than the global average. North America could see warming in the range of 6.3 to 13.5 degrees by 2100 under high-emissions scenarios, according to panel.

The two computer models used in the 2003 Rocky Mountains/Great Basin assessment, known informally as the Hadley and the Canadian models, projected regional warming of 4.5 to 14.4 degrees by 2100.

More up-to-date models now call for somewhat less Western warming by century's end - somewhere in the range of 3.6 to 10.8 degrees, said Daniel Cayan, director of the climate research division at Scripps Institution of Oceanography in La Jolla, Calif.

But some scientists view these climate projections as little more than high-tech guesswork. One prominent critic once compared general circulation models to Ouija boards.

Colorado State Climatologist Roger Pielke Sr. says the models are incomplete and unreliable, especially when used to forecast climate change at the regional level.

"My feeling is that the climate system is so complex that we can't predict with skill what will happen in the future," Pielke said.

"There's general acceptance that humans are altering the climate system," he said. "And I think we should probably control CO2 (carbon dioxide). But to try to base it on these models is not solid. It's not good science.

"This report grossly overstates our ability to confidently predict regional climate change and therefore the impacts that are inferred from that," Pielke said of the Rocky Mountain/Great Basin regional assessment. "It gives the illusion of authority and scientific accuracy."

Utah State University ecologist Frederic Wagner, co-coordinator of the regional assessment, called Pielke a maverick who is "almost ideologically committed" to criticizing global climate models.

"I think he's irrational on this whole subject," Wagner said. "I know he's a man with some credentials and qualifications, but I don't know anybody else who takes the stand that Pielke does."

In response, Pielke pointed to a November 2001 policy statement on climate change from the American Association of State Climatologists. "Climate predictions have not demonstrated skill in projecting future variability and changes in such important climate conditions as growing season, drought, flood-producing rainfall, heat waves, tropical cyclones and winter storms," it states in part.

Big changes on horizon

Boulder climatologist Linda Mearns served on the six-person Assessment Team that oversaw the Rocky Mountain/Great Basin report.

Mearns is a senior scientist at the National Center for Atmospheric Research, known as NCAR. She is a lead author of two chapters in the next intergovernmental panel assessments, scheduled for publication in 2007.

Climate models are not crystal balls. The scenarios outlined in the regional assessment present a range of "plausible futures," not hard-and-fast predictions, she said.

"I wouldn't necessarily disagree with Roger that we really don't know the details about what will happen, let's say, in the Front Range," Mearns said. "It's true. We don't know the details . . . But that doesn't mean we know nothing."

Astronomers don't need the Hubble Space Telescope to see giant craters on the moon's surface. And climate modelers don't need to resolve the finest regional details to spot some of the big changes on the horizon, Mearns said.

If the explosive increase in heat-trapping greenhouse gases continues unchecked, warming will accelerate, leading to far-reaching changes in the Colorado Rockies, she said.

The climate models, despite their shortcomings, help researchers and potentially affected parties - water managers, foresters, fisheries, farmers and ranchers, ski industry officials and others - explore the range of potential impacts, Mearns said.

Critical snowpack at risk

The Rocky Mountain/Great Basin region was home to eight of the nation's 10 fastest-growing states between 1995 and 2000. Colorado's current population of 4.6 million is expected to swell to 7.2 million by 2030, a 56.5 percent increase.

Residents in this region, which ranges from semi-arid to arid, derive 85 percent of their water from surface sources, and 85 percent of that surface water comes from snowpack runoff.

Any climate changes affecting either water availability or the timing of snowmelt runoff could have profound social, economic and ecological repercussions.

And the ripple effects would be felt far beyond the Rockies and the Great Basin. Snowpacks in the region form the headwaters of the Columbia, Missouri, Colorado, Rio Grande, Platte and Arkansas rivers, providing water for millions of people living hundreds of miles downstream.

Western snowpacks are expected to decrease as the climate warms - even though some models forecast a slight increase in annual precipitation - for two reasons.

First, warmer temperatures will result in more of the the precipitation falling as rain rather than snow, pushing the snow line higher. Second, the snowpack will develop later in the year and melt earlier in the spring, according to *Climate Change Impacts on the United States*, a 2000 report from the U.S. Global Change Research Program.

Denver climatologist Gregory McCabe was the lead author of a snowpack study cited in that 2000 report, which is known as the national assessment. McCabe and colleague David Wolock used the Hadley and Canadian computer models to examine likely changes in snowpack in the Rockies, the Sierra Nevada and the Pacific Northwest by 2100.

The models suggested that the Southern Rockies, including southern Colorado, could see a 55 to 98 percent reduction in April 1 snowpack by 2100.

The outlook for the Central Rockies, including the northern Colorado mountains, was less clear. One model showed no significant snowpack change, while the other pointed to a 75 percent reduction.

But like Pielke, McCabe questions the reliability of forecasts based on global climate models.

"They show some pretty drastic changes, but you have to realize that there's a lot of uncertainty with those projections," said McCabe, a U.S. Geological Survey scientist.

Altering water resources

As the snowpack shrinks, peak runoff will arrive earlier and earlier. Winter and early spring floods could become more common, straining reservoir capacity in the West at a time when public antipathy to building dams makes the construction of new ones "an unlikely solution," according to the regional assessment.

Denver Water serves 1.2 million customers. The utility draws roughly half its water from the South Platte River watershed and half from the headwaters of the Colorado River.

It relies on a network of pipelines, canals and reservoirs to transport and store mountain runoff.

If climate change causes snowmelt to run off the mountains earlier and quicker than it does today, the flows could overwhelm those canals and pipelines, said Marc Waage, a water resource engineer at Denver Water.

"We'd lose water that we would be able to deliver today because the snow now melts at a slower rate," Waage said.

A shift to an earlier runoff peak could also throw a monkey wrench into the state's Byzantine water-rights system, which is based on the assumption of a static climate.

"There are water-right decrees with fixed dates in them for when they can start to divert water out of the river or put that water into storage," Waage said. "If the whole runoff cycle is shifted earlier in the year, how will the administration of these water rights be affected?"

Next year, Denver Water will update its Integrated Resources Plan, the utility's long-range water supply and conservation document. For the first time, it will include an assessment of the possible effects of climate change on the Denver Water system.

"We're quite concerned about it," Waage said.

"We've already got our hands full with trying to provide enough water to the region to keep up with population growth," he said. "To add the additional problem of climate change just exacerbates an already difficult situation."

Earlier spring runoff

Reduced snowpacks and an earlier peak in springtime runoff have already been observed in some parts of the West, most notably in the Pacific Northwest and lower elevations in California's Sierra Nevada. But it is unclear if those changes, which span several decades, are tied to natural climate variability or greenhouse-induced warming, the Scripps Institution's Cayan said.

In Colorado, statewide April 1 snowpacks have been below average 14 of the last 19 years. But again, natural climate variability could explain it.

In general, the higher altitudes and colder temperatures of the Colorado Rockies should provide a buffer against some of the snowpack and runoff changes.

For now.

But in a 2004 paper in the journal *Climatic Change*, California climatologists used computer models to look at likely future changes in the timing of snowmelt runoff in western North America.

The biggest shifts are expected in the Pacific Northwest, the Sierra Nevada and the Rocky Mountains, according to the paper by Iris Stewart and two colleagues, Michael Dettinger and Cayan.

In the Colorado Rockies, springtime runoff is expected to peak two to five weeks earlier by 2100, according to the study.

An earlier runoff peak would result in lower summer flows. That means less water for fish as well as urban lawns and irrigated farmland. Agriculture uses about 80 percent of Western water and relies heavily on summer irrigation.

More rain would help, but that doesn't appear to be in the cards.

The two computer models used in the Rocky Mountain/Great Basin regional assessment did, in fact, call for big annual increases in precipitation - a jump of anywhere from 54 to 184 percent.

But most of the current models show little or no change in annual precipitation for the West in the coming century, Cayan said.

For example, the latest National Center for Atmospheric Research model calls for a "slight annual increase" in precipitation over the Colorado Rockies by 2100, said Gerald Meehl, a senior scientist at the Boulder lab.

Experts say river and stream levels could drop in the summer even if the Western climate gets a bit wetter.

How is that possible?

Higher temperatures will evaporate more water, negating the effects of any extra rain in all but the wettest scenarios.

In a study of the Colorado River Basin, California researchers Peter Gleick and Linda Nash calculated that if temperatures warm 7.2 degrees, a 15 to 20 percent annual precipitation increase would be needed just to maintain current streamflow levels, due to losses from evaporation.

Threat to meadows

In the high country, alpine meadows and tundra will be among the ecosystems most vulnerable to future warming, according to several key reports:

• Rocky Mountain meadows are "likely to face extreme stress and disappear in some places," said one assessment.

• "Unique natural systems such as prairie wetlands, alpine tundra and cold-water ecosystems will be at risk, and effective adaptation is unlikely," according to another.

"Effective adaptation is unlikely" is another way of saying that mountaintop tundra will vanish because it cannot migrate to higher altitudes to escape warming.

On Colorado's highest peaks, the alpine tundra community is a ground-hugging mix of grasses, sedge, wildflowers and other forbs, moss, lichen and low shrubs such as dwarf willow and birch.

In general, the trees in Colorado's mountain forests are expected to shift to higher elevations as the climate warms.

As the tree line moves up, much of the state's tundra is expected to disappear, said Ron Neilson, a U.S. Forest Service bioclimatologist who uses computer models to study likely vegetation changes in a warming world.

"Basically, the forests go off the top of the mountains," Neilson said.

Park subject to change

Colorado State University researchers estimated that the tree line in Rocky Mountain National Park could rise 244 feet for every degree of warming. At that rate, 5 degrees of warming would force the tree line 1,220 feet higher.

The park, which draws about 3 million visitors each year, straddles the Continental Divide and boasts more than 110 peaks higher than 10,000 feet. More than 100 square miles of the park lie above timberline - a stark landscape of rock, ice and alpine tundra.

According to CSU estimates, a 3.6-degree rise would eliminate about 20 percent of the park's tundra. More than half of it would disappear if the climate warms by 5.4 degrees, and all of it would vanish if the temperature climbs 9 to 10.8 degrees.

The tree-line shifts would likely occur over several centuries. Long before the conifers completed their upslope march, the tundra would be invaded from below by grasses and other rapidly colonizing plants, according to the Colorado State study.

But U.S. Geological Survey ecologist Thomas Stohlgren, co-coordinator of the Rocky Mountain/Great Basin regional assessment, rejects the vanishing tundra scenarios.

"The tundra isn't going to disappear," he said. "The extent might change, but it will survive.

"There are some really big believers in rapid change, and there are others who believe that it might not be so rapid, or that there might be some mitigating circumstances," he said.

"I'm in the latter group. I'm in the group that believes there is more uncertainty."

The Rocky Mountain National Park study concluded that warming would harm creatures that rely on tundra, such as the white-tailed ptarmigan. Yellow-bellied marmots and pikas also could be impacted.

At lower elevations, warmer temperatures would likely reduce winter mortality among young elk in the park, exacerbating an existing overpopulation problem. Aspen, willow and other elk foods would likely suffer.

The Colorado State-led study said warming could help efforts to boost the number of native greenback cutthroat trout in the park's waters, allowing them to spawn earlier and in streams that currently are too cold for breeding.

But the authors of the Rocky Mountain/Great Basin report concluded that, regionwide, warming is likely to reduce habitat available to cold-water fish such as trout. Warm-water species such as minnows and suckers would likely benefit.

The lynx and the Uncompahgre fritillary butterfly are two other Colorado-dwelling creatures considered especially sensitive to climate warming.

Sagebrush future?

Below the tundra, in Colorado's high-elevation forests, alpine meadows could face threats from shrubs creeping upslope. Warmer, drier summers would favor the upward expansion of shrubby plants with tap roots that can probe for deep soil moisture.

Such as sagebrush.

Because shrubs like sagebrush have much shorter life spans than most trees, sagebrush encroachment could occur relatively quickly, serving as one of the "early indicators of climate change" in the region, according to the regional assessment.

Which brings us back to John Harte, a professor of environmental science at the University of California at Berkeley, and his experimental Gothic plots.

For 14 years, Harte has continuously warmed five 330-square-foot plots, resulting in a 3- to 4-degree increase in soil temperature. That's roughly what would be expected by 2040, he says, if current trends in the emission of heat-trapping greenhouse gases continue.

Five nearby control plots remain unheated.

The meadow project is funded by the National Science Foundation, which pays the $300 monthly electricity bill, among other things.

In the heated plots, spring snows melt up to two weeks earlier than in the control plots, Harte explained to a visitor last summer. Soils near the surface are drier, favoring deep-rooted plants.

Wildflowers - the Crested Butte area has more than 100 species of them - generally have shallow roots and have not fared well in Harte's plots.

The result: Sagebrush is taking over the heated plots.

"At some point, we're going to lose the diversity of wildflowers we see in the meadows" around Colorado mountain resort towns like Crested Butte, Vail, Aspen and Telluride, said University of Maryland ecologist David Inouye.

Inouye has monitored the blooming of Gothic-area wildflowers each year since 1973, when he first visited the Rocky Mountain Biological Laboratory as a graduate student.

"This place may become a base camp for people working at higher altitudes, where the wildflowers have shifted up to," Inouye said while checking one of his monitoring plots near the Gothic lab last summer.

"The meadows may shift up until they reach the top of the mountain and get pushed off the mountain and disappear.

"So I enjoy it while I can. Because it may not last."

Story by Jim Erickson • Photos by Judy Walgren • Rocky Mountain News

A Change in the Air: Vital Signs

Taking the pulse of climate change in the Colorado Rockies

By Jim Erickson, Rocky Mountain News

Tuesday, December 13, 2005

CHANGE IN THE AIR: FIFTH IN AN OCCASIONAL SERIES ABOUT HIGH-ALTITUDE RESEARCH IN COLORADO

"It is not the strongest of the species that survive, nor the most intelligent, but the most responsive to change." - **Charles Darwin, 1835.**

GOTHIC — The marmot was holding his own until the second coyote blindsided him.

The coarse-furred, groundhog-like rodent emerged from his hibernation burrow last April onto a thick crust of snow that blanketed this former mining town several miles north of Crested Butte.

A band of coyotes had been hanging around, and one of them pounced on the marmot. The feisty rodent rose to his hind legs and batted at the coyote with his clawed front paws, like a boxer, as he struggled to escape.

But a second coyote bounded in from behind and joined the fray. The two canines killed the marmot, then dragged him off.

To University of Maryland ecologist David Inouye, this grisly account serves as a cautionary tale about — believe it or not — the potential perils of global climate change.

Around the world, scientists are looking for biological red flags, signs that global warming is already affecting high-altitude plants and animals and could imperil fragile mountaintop ecosystems.

In the Colorado high country, that work includes studies of three seemingly unrelated phenomena: the shifting hibernation pattern of marmots, subtle changes at the forest tree line, and the chemical fingerprint of mountaintop air molecules trapped in glass flasks.

Results from all three research efforts, examined in this special section, suggest that life in the Colorado Rockies is already responding to climate change, though some scientists question the findings.

A matter of marmots

The yellow-bellied marmots of Gothic, home to the Rocky Mountain Biological Laboratory at 9,300 feet, are among the most thoroughly studied high-altitude creatures on the continent.

University of Kansas biologist Kenneth Armitage began monitoring the animals in 1962, and behavioral ecologist Dan Blumstein of the University of California at Los Angeles is continuing the work.

Detailed lab records show the Gothic marmots now emerge from hibernation about a month earlier than they did 30 years ago.

During that interval, the average April low temperature in nearby Crested Butte rose 5.9 degrees Fahrenheit, according to Inouye, a fellow Gothic researcher who analyzed National Weather Service records.

Inouye blames global warming for the rising temperatures and suggests the balmier April air is tricking the marmots into exiting their burrows before the snow has melted, leaving them potentially vulnerable to starvation and predation.

It's one of many examples of how a warming climate is disrupting the environmental cues that plants and animals around the world use to determine the timing of events such as hibernation, migration, breeding, flowering and pollination, Inouye said.

If the warming accelerates in coming decades, as climate models predict, nature will be forced to adapt quickly, he said. Plants and animals living at higher elevations — like those in the Colorado Rockies — will have fewer options and could be at greater peril than lower-dwelling species that can simply move to more agreeable locations.

"There are a lot of people who consider marmots as nothing more than moving targets for rifle practice," said Inouye, a wiry, soft-spoken academic who has spent his summers in Gothic since 1971. "So if we were talking about just this one species, then many people might not be particularly concerned.

"But the bigger issue is that it's not just marmots," he said. "They are representative of a larger number of species out here that we're also at risk of losing.

"And when you get many, many observations of this kind all over the world, and everybody's seeing the same sorts of trends, then it makes sense in the context of global warming."

Biological indicators

The Earth has warmed about 1 degree Fahrenheit over the past century. Most scientists agree that human activities — mainly the burning of fossil fuels, which emits heat-trapping carbon dioxide gas — have contributed to the temperature rise.

Most climate scientists say receding mountain glaciers, declining global snow cover, thinning summer sea ice in the Arctic and rising sea levels are environmental indicators of a warming climate.

Since plants and animals are exquisitely attuned to the environments that sustain them, certain biological changes might also provide early warnings of a warming world.

But attributing biological changes to global warming is a tricky and contentious endeavor.

Especially when claims are made about changes in the behavior of a single species, such as yellow-bellied marmots, at a single location, such as Gothic.

First, it's impossible to prove that the April warming in Crested Butte has anything to do with global climate change. The growth of the town in recent decades could be partly to blame and natural climate variability might also explain it.

Second, Inouye and his colleagues, who published their marmot findings in a peer-reviewed article in the *Proceedings of the National Academy of Sciences*, can't be sure the heavyset rodents' earlier emergence from hibernation is a response to warming April temperatures.

There could be some other explanation. Maybe the marmots are driven to find mates sooner. Maybe they're getting hungry earlier. Who knows?

"Changes in plants and animals at single locations . . . cannot be unambiguously linked to anthropogenic (human-caused) climate change," biologists Camille Parmesan and Hector Galbraith wrote in a November 2004 report, *Observed Impacts of Global Climate Change in the U.S.*

The best approach is to examine reported changes in many far-flung plant and animal species and look for trends that fit with global warming predictions, Parmesan and Galbraith wrote.

'Strong evidence' of link

For their report, sponsored by the Pew Center on Global Climate Change, Parmesan and Galbraith reviewed 40 studies that drew a possible tie between climate warming and ecological change in the United States. In more than half the cases, the researchers concluded there was "strong evidence of a direct link" between warming and the observed changes.

The two main types of trends involved phenology and range shift.

Phenology is the study of the timing of key biological events, such as the onset of spring growth, migration and breeding. Range shift refers to a geographical change in the distribution of plant and animal species.

In a warming world, many spring- time phenological events would likely occur earlier in the year. In the Northern Hemisphere, range shifts would be northward or to higher elevations.

According to Parmesan and Galbraith, the most convincing U.S. examples of biological changes that seem linked to a warming climate include reports that:

• **Tree swallows** at 3,400 nest sites across the United States now lay their eggs an average of nine days earlier than they did in 1959.

• **Mexican jays** in the Chiricahua Mountains of southeastern Arizona now breed 10 days earlier than they did in 1971.

• **The sachem skipper butterfly** has expanded its range northward 420 miles, from California into Washington, in the past 35 years. It has moved into areas where winters were previously too cold for it to survive.

• **The rufous hummingbird's** winter range has shifted northward dramatically in recent decades. Thirty years ago it wintered mainly in Mexico, and there were never more than 30 winter sightings per year in the United States. In 1996, 1,643 U.S. winter sightings were reported.

On a global scale, two independent research teams concluded in January 2003 that they had found the "fingerprint" of global warming in hundreds of plant and animal species around the world whose behavior or distribution has changed in recent decades. The two reports were published in the journal *Nature*.

In one of the articles, a team led by Terry Root of Stanford University reviewed 143 studies of biological changes in nearly 1,500 plant and animal species around the world. About 80 percent of the species that displayed significant changes were shifting in the direction expected with warming temperatures.

Root's team concluded that "a significant impact of global warming is already discernible in animal and plant populations."

Another group, led by Parmesan, reviewed long-term studies of more than 1,700 species. Eighty-seven percent of the significant phenological changes and 81 percent of the significant range changes matched climate-change predictions.

The researchers concluded they'd uncovered "a globally coherent fingerprint of climate change impacts across natural systems."

Skeptics unconvinced

But some scientists don't buy it.

Plants and animals have adapted to climate change for millions of years. Tree lines have crept up and back down mountainsides, and animals have migrated to more favorable territories in response to natural climate swings.

So it's not surprising to see nature responding to present-day temperature changes. In fact, it would be shocking if plants and animals weren't, said Tom Stohlgren, a U.S. Geological Survey ecologist based in Fort Collins.

What Inouye, Root, Parmesan and like-minded researchers cannot show is that these changes are linked to fossil fuel emissions and human-caused climate change, Stohlgren said.

"Species do change with climate. That shouldn't be a shocker," he said. "But linking it to global climate change resulting primarily from human activities is just a stretch."

Stohlgren said nature will face far more urgent threats than climate change in the coming decades: habitat loss, pollution, emerging diseases, invasive species and overharvesting, to name a few.

"I don't want to denigrate their work. They're doing fabulous research. But I'm not sure we have our priorities right," he said.

"There just aren't many things on the endangered species list because of climate change. Zero, in fact."

Root acknowledged that pinning the biological trends to human activities has been a challenge. But scientists are making headway.

In a May 24 article in the *Proceedings of the National Academy of Sciences*, Root and her colleagues describe a computer-modeling study that enabled them to link some regional phenological changes directly to human-caused warming.

And yes, plants and animals have adjusted to past climate changes.

But two major differences distinguish the current situation, Root said in an interview.

First is the rate of change. One degree Fahrenheit of warming over the past century may not sound like much, but it's likely the quickest global temperature change of the past 1,000 years, according to the Intergovernmental Panel on Climate Change.

Computerized climate models suggest the planet will warm another 2.5 to 10.4 degrees by 2100. The extent of the warming depends largely on future rates of fossil-fuel emissions, according to the IPCC, the world's most authoritative source on climate research.

"The projected rate of warming is much larger than the observed changes during the 20th century and is very likely to be without precedent during at least the last 10,000 years," the IPCC concluded in 2001.

So plants and animals may have to adjust fast. But urbanization, agriculture and other land-use changes have created barriers that didn't exist during earlier climate swings, Root said.

"It's not that species can't move. They can. But now they have to cross our freeways and our farms and our Kmart parking lots," she said. "The habitat isn't continuous the way it used to be."

And the plants and animals trapped on mountaintops are especially vulnerable because they have no escape route.

"I honestly believe that we are standing at the edge of a very, very large mass extinction, and top-of-mountain species are going to be the first ones to go," said Root, a senior fellow at Stanford University's Center for Environmental Science and Policy.

To which Stohlgren replies: "Many species have adapted to climate change — warm and cold periods — throughout the Earth's history. . . . I guess I'm just not as much of an alarmist as some."

Birds, bees, butterflies

Back at the Rocky Mountain Biological Laboratory in Gothic, marmots aren't the only creatures showing noteworthy changes, Inouye said.

American robins, which spend the winter at lower elevations, now return to Gothic about two weeks earlier than they did in 1981, he said.

Anecdotal evidence suggests that a species of bumblebee has migrated to higher elevations in recent years; that the timing of the Milbert's tortoiseshell butterfly's emergence has changed; and that chipmunks and ground squirrels may be emerging from hibernation earlier.

At Gothic, the early bird doesn't always get the worm.

Both the robins and the insomniac marmots now face longer periods of foraging over snow-covered ground, when food is scarce, Inouye said.

"As the environment is changing, cues like temperature and snowmelt that once made sense for timing biological events like hibernation, migration and flowering are becoming unreliable," he said.

"The historical synchrony of these events is breaking down."

While Inouye's interpretations are open to challenge, the climate data he's using in the ongoing marmot study seem rock-solid, said research climatologist Nolan Doesken of the Colorado Climate Center.

At the request of the *Rocky Mountain News*, Doesken reviewed National Weather Service temperature records from Crested Butte between 1970 and 2004.

He confirmed that April overnight low temperatures have increased by 5.9 degrees over that span.

Similar increases were seen at two nearby weather stations — at Taylor Park Reservoir and in Gunnison — he said.

"The warming trend for April minimum temperatures was quite dramatic at all three stations since 1970," he said. "And he (Inouye) is seeing a pretty nice-looking correlation between locally observed temperatures and local behavior of wildlife.

"The only stretch in any of this discussion is whether this is due to anthropogenic global warming," Doesken said. "And I can give you a very solid 'I don't know.' "

Doesken said natural climate variability, along with the growth of Crested Butte and Gunnison, could partly explain the warming observed at those sites. And the weather stations in both towns have been moved several times, which affects the reliability of long-term records, he said.

"I respect him (Inouye), and he can say boldly that what he's seeing is due to global warming," Doesken said. "I can't quite say that, but I'm paying close attention to it."

As for the idea that the marmots are emerging earlier because they sense the warmer April air, that's all it is: an idea.

The Gothic-area marmots have been studied continuously since 1962 — nearly as long as Jane Goodall has followed the Gombe chimps in Tanzania.

But even now, researchers can't say for sure exactly what makes them end their winterlong snooze, said UCLA's Blumstein.

A self-styled "marmoteer," Blumstein has been live-trapping, tagging, probing and prodding many of the 200 or so Gothic-area marmots since 2001. He has studied marmots from British Columbia to Pakistan for 17 years.

Blumstein is a behavioral ecologist whose main interests are marmot evolution, behavior and communication.

But he also wonders how climate enters the mix.

"I'm not entirely convinced, but I'm not dismissive of it, either," Blumstein said of Inouye's global-warming assertion.

As he spoke, he sprinkled a molasses-and-oats mix into marmot traps scattered around the clustered wooden cabins that constitute the Rocky Mountain Biological Laboratory campus.

The best bet is that springtime emergence involves an interplay between climate and sexual competition for mates, he said. The emergence date can affect a marmot's chances of finding a mate and successfully breeding, as well as its ability to find food, re-establish territory and avoid predators such as coyotes, foxes, badgers and bears.

A bad spring for marmots

Last spring, after the first above-normal winter snowfall in several years, Gothic-area marmots emerged on April 17 to a snow-covered landscape. Food was scarce and the marmots' vast network of escape burrows remained plugged with snow.

As a result, some of them starved and others were picked off by predators, Blumstein said.

"We saw all sorts of carnage this year," he said. "Animals got up early because it was warm, but there was tons of spring snow. And we saw animals competing for food, but there was no food, so they were competing to chew on the branches of trees.

"They were either starving or being killed by predators," he said.

"And that's the cost of coming up early," he said. "So if in fact it is getting warmer, that's how there can be a demographic consequence to this. The population can decline because animals get nailed."

But again, Blumstein said he's not sure global climate change contributed to the 2005 Gothic marmot massacre.

Despite the doubters, Inouye remains adamant that global warming is already at work in Gothic.

"That's how I interpret it," he said. "We have enough of a history here to be pretty confident that there are significant changes taking place," he said.

As further evidence, he points to his plant-monitoring plots.

Inouye has chronicled the blooming of Gothic-area wildflowers every spring since 1973. It is one of the longest unbroken studies of high-altitude plants in the United States.

The Crested Butte area is home to more than 100 species of flowering plants and was designated the Wildflower Capital of Colorado by the state Legislature. About 60 percent of those plants are represented in Inouye's 30 meadow plots.

Every other day throughout the growing season, Inouye and his assistants record the number of flowers of each species in every plot.

Over most of the past three decades, the number of species in the plots remained remarkably stable, Inouye said.

Until five years ago.

Since then, the once-common tall bluebell has vanished from all 30 plots. A species of early-season mustard is nearly gone, and another mustard seems to be declining.

"Those plants were in my plots for 25 years and now, in the last five years, they've just disappeared," he said.

"So yeah, I think we're beginning to see some changes, not just in phenology but also in abundance and distribution."

But again, forces other than global warming could be to blame.

Colorado and much of the West were in the grip of a multiyear drought for the first part of this decade. The drought may have caused the changes seen in Inouye's plots, and the drought may have been unrelated to global warming.

In addition, a long-term fluctuation in Pacific Ocean sea-surface temperatures, called the Pacific Decadal Oscillation, could be responsible for recent milder, drier conditions in parts of the West.

A shift in the oscillation might also explain the Gothic plant declines.

Even so, when you look at the scores of changes being observed in plants and animals worldwide, it seems clear that global forces are at work, Root said.

"We will never have outright proof that plants and animals are responding to human-caused climate change. We will only, always, have circumstantial evidence," Root said.

"I liken it to evidence in a trial. You have to wait until you have enough circumstantial evidence for it to support your case," she said.

"And I think we're there. We can say beyond a reasonable doubt that plants and animals are being affected by humans warming the planet."