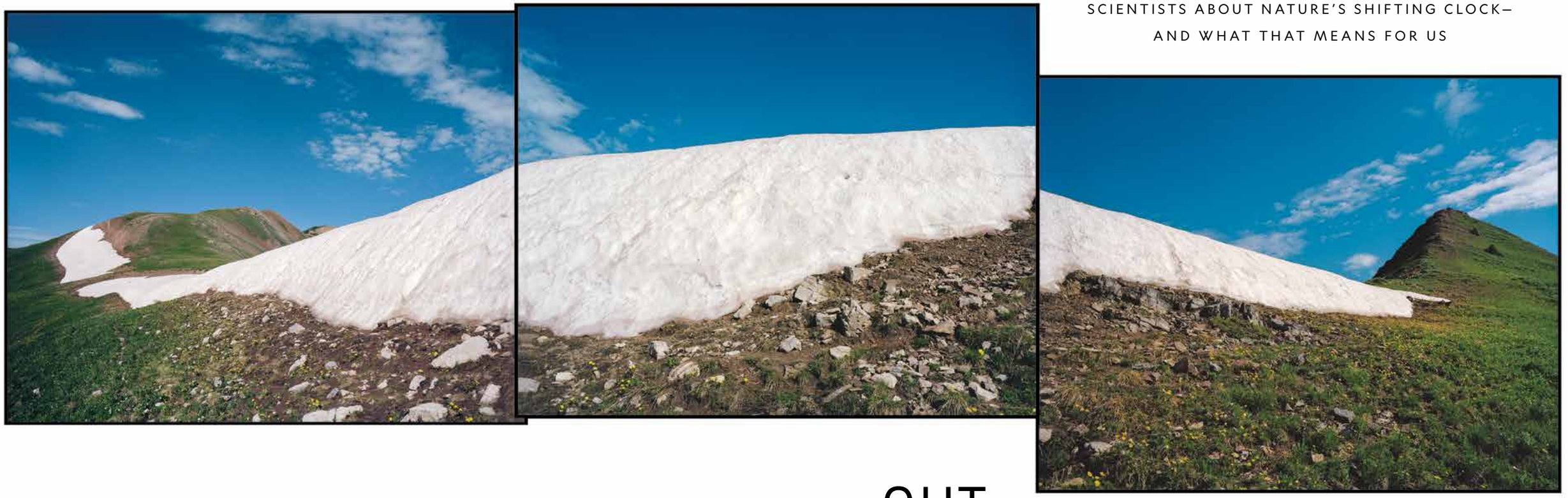
SEASONS

BY **CRAIG WELCH**

PHOTOGRAPHS BY **ELLIOT ROSS**

WHAT BIRDS AND BEES ARE TELLING SCIENTISTS ABOUT NATURE'S SHIFTING CLOCK— AND WHAT THAT MEANS FOR US



A snowbank lingers into July in Colorado's West Maroon Basin, home to rolling fields of larkspur, columbine, paintbrush, and fireweed. Climate change is upending nature's timing, bringing early melt to the snows that propel summer wildflower seasons and rearranging life in unpredictable ways.

OUT OF SYNC

Scientist David Inouye, at far right, in beige shirt, has spent 50 summers tracking flowers, hummingbirds, and insects in high-alpine meadows at the Rocky Mountain Biological Laboratory in Gothic, Colorado, just outside Crested Butte. Here, Inouye and his scientist son, Brian Inouye, stretch a measuring tape across a research plot while other scientists catalog a field of aspen sunflowers.

Everything in nature responds to timing cues—from seasonal shifts in the vegetation that pikas drag into their dens, to summer flowers, to the snows of Mount Bellview and the turning of aspen leaves in autumn.

Even the first emergence of green shoots from the monument plant, whose flowering is linked to precipitation that fell four years earlier, lives by the clock. Climate change is contorting these rhythms.















ANCHOR
THE MARMOT WAS
SURPRISINGLY
CALM, CONSIDERING
A STRANGER
HAD JUST SWABBED
HIS CHEEK.
IT WAS A COOL,
CRISP EVENING
IN WEST-CENTRAL
COLORADO,
AND THE
11-MONTH-OLD MALE
YELLOW-BELLIED
MARMOT
HAD WANDERED
INTO A
METAL CAGE TRAP.



The Elk Mountains, carved by glaciers, so overflow with flowers in summer that this region is known as Colorado's wildflower capital. Flowers bloom four weeks earlier than they did 30 years ago.



The National Geographic Society, committed to illuminating and protecting the wonder of our world, has funded Explorer Elliot Ross's photography work around climate since 2019.

ILLUSTRATION BY JOE MCKENDRY

Now a couple of scientists sampled his DNA to measure how fast this fur ball was growing.

Since 1962, scientists in this high mountain meadow have been mapping marmots' social lives. But lately researchers have also turned their attention to tracking how a warming planet is shifting nature's schedule and, perhaps, affecting marmot health.

Each spring marmots rise from their winter slumber. They mate, give birth, and spend summers chowing down before they hibernate again. "It's get fat or die," Conner Philson, a Ph.D. candidate at UCLA, told me as he held Anchor in a dark Kevlar bag so the animal couldn't slice a finger with his huge incisors. After she ran a square of foam through the marmot's mouth for cell samples, Philson's colleague, UCLA master's student Mackenzie Scurka, used calipers to measure one tiny paw. Then Philson thanked his subject for not dousing us in feces. "It's much nicer when they poop in the trap and not on us," he said.

Marmots' behavior is changing. Because of climate change, they now emerge from winter about a month earlier, which forces them to scrounge for food sooner. Yet most marmots, as researchers also would learn with Anchor, actually still wind up big and healthy. Early emergence gives them extra time to eat, which lets them get fatter and helps them produce more offspring.

Nature's shifting calendar for marmots thus far seems to have been an asset. But that's almost certainly the exception, not the norm.

Timing is everything in nature. From the opening notes of a songbird's spring chorus to the seasonal percussion of snapping shrimp, every important ecological process lives and dies by a clock. Flowering. Egg laying. Breeding. Migration. It's as true on the Mongolian steppe as it is in the Arabian Sea or a Costa Rican rainforest. Centuries of evolution honed these patterns. Now climate change is recalibrating them.

And that is reshaping life for almost everything. In every ocean and across every continent, seasons are in flux. Earlier warmth, delayed cold, and shifts in the frequency and fierceness of precipitation are toying with established rhythms in both predictable and unexpected ways.

So researchers the world over are straining to



A team led by ecologist Rebecca Irwin (at left, with Jade McLaughlin) tracks the flight times and shifting demographics of pollinators in a meadow. Many types of bees are netted, nudged into plastic vials, identified, and then marked with color to help prevent recapture.



David Inouye has caught and banded thousands of hummingbirds to track migrations and behavior. He learned that the arrival of broad-tailed hummingbirds from Mexico once coincided with blooms of glacier lilies, whose nectar they require. Today lilies often begin to bloom before the hummingbirds show up.

document the timing of life cycle events, a scientific discipline known as phenology. That timing is being upended by our fossil fuel emissions.

Changes are discovered almost everywhere scientists look. The timing of leaf appearance and leaf dropping has already shifted dramatically across more than half the planet. Humpback whales in the Gulf of Maine are gathering 19 days later than they once did, while jack mackerel, hake, and rockfish are spawning earlier in the North Pacific. In North Dakota's Red River Valley, scientists found 65 of 83 bird species arriving earlier, some by as much as 31 days. South Carolina's dwarf salamanders are arriving at breeding grounds 76 days later.

What's harder to grasp is the severity of the consequences—for plants, animals, and us. If everything shifted in the same direction and by roughly the same amount, our new calendar might prove insignificant. As with daylight saving time, we'd muddle through together. But that's not how nature works. "Species are not

FROM A SONGBIRD'S SPRING CHORUS TO A SNAPPING SHRIMP'S SEASONAL PERCUSSION, EVERY IMPORTANT **ECOLOGICAL PROCESS LIVES AND DIES BY A CLOCK.**

responding identically," said David Inouye, a University of Maryland professor emeritus and leading phenology researcher.

Too many patterns are shifting at the same time, each influenced by countless others, which are themselves also in motion. It's everything, everywhere, all at once. Even beings that don't appear to be changing are seeing their world change around them. Snowshoe hares, Siberian hamsters, collared lemmings, and long-tailed weasels all turn white in winter as a form of protective camouflage in snow. Now they're often out of sync with their surroundings. Many are increasingly seen with halogen-bright white bodies crouched in green forests or brown brush or on yellow tundra. That's because snow is arriving later and melting earlier, but their color transition is triggered by seasonal shifts in daylight, which, of course, isn't changing at all.

So what happens then, when we revamp nature's schedule in every wild system on Earth at once, altering timing for some things but not others? Few understand the implications better

than Inouye. "Study any species in isolation, and you may know if they're changing," he told me one June morning as we stood in a meadow in thin air near 10,000 feet. But to understand why that change is happening—and what it means—scientists must cast a wider net. "No species lives in isolation."

Inouye and I strolled through cool green fields of wild parsnip and false skunk cabbage as we toured the nearly century-old Rocky Mountain Biological Laboratory, one of the most important phenology research sites in the world. It's no ordinary field station: Science labs and housing are tucked into aging buildings—all that remains of board-and-batten Gothic, an abandoned 19th-century mining town eight miles north of Crested Butte. Around us, hummingbirds wing-whistled among the lupines, aspen sunflowers, and dwarf larkspurs.

"Try this," he said, handing me the green leaf from a glacier lily. He popped a strand into his mouth, and I did the same, tasting earthy sweetness, like spinach. Inouye warned me with a sly smile to avoid the corn lilies, which contain toxic alkaloids that can make ewes birth lambs with a single centered eye, like a Cyclops. (I looked it up; he's right.) Nearby, graduate students counted bumblebees by netting and loading them into plastic vials. To avoid tallying any bee twice, they dotted each fuzzy thorax with a marker, then set the insect free.

Inouye has tracked biological cycles here for 50 years. He speaks in the tranquil, measured tones of someone who has spent a lifetime counting flowers. Thin, tall, with a bearded angular face reminiscent of Abe Lincoln's, Inouye, 73, can name on sight 150 or so of the valley's wildflower species. He can identify which bird, wasp, bee, or fly spreads their nectar. He knows this place better than I know my living room.

Inouye arrived in the early 1970s to take field courses, returning in 1972 to study hummingbirds. Then he discovered "hummingbirds get up very early," he said. In 1973, he and other young scientists decided instead to track which



In her lab in Gothic, Irwin hovers over boxes of bees her team has collected and pinned. Irwin has helped identify about 200 species of native bees, each an important pollinator with a specific biological clock and seasonal pattern.

CHANGE OF PACE

Across much of the United States rising average temperatures are pushing spring to speed up its arrival. Plants and pollinators found at high elevations in the western U.S. are especially affected. To better understand how species are interacting and responding to these changes, scientists are tracking the timing of biological events—a field known as phenology.

Change in date of leaf emergence
1981-2010, 1991-2020

14 days earlier — no change — 4 days later



Seasonal shifting

Earlier snowmelt in high-altitude meadows has caused many species to adjust to earlier springs. For 50 years researchers at the Rocky Mountain Biological Laboratory have collected data showing that plants such as the glacier lily are flowering sooner, and some of their pollinators, including hummingbirds migrating from Mexico, have sped up their arrival schedules.

Approximate snowmelt
2016-2021 — *23 days earlier* — 1975-1980
May 4 — May 27
First bloom, western spring beauty*

Broad-tailed hummingbird
12 days earlier
May 5 — May 17
First arrival

Glacier lily
17 days earlier
May 21 — June 7
First bloom

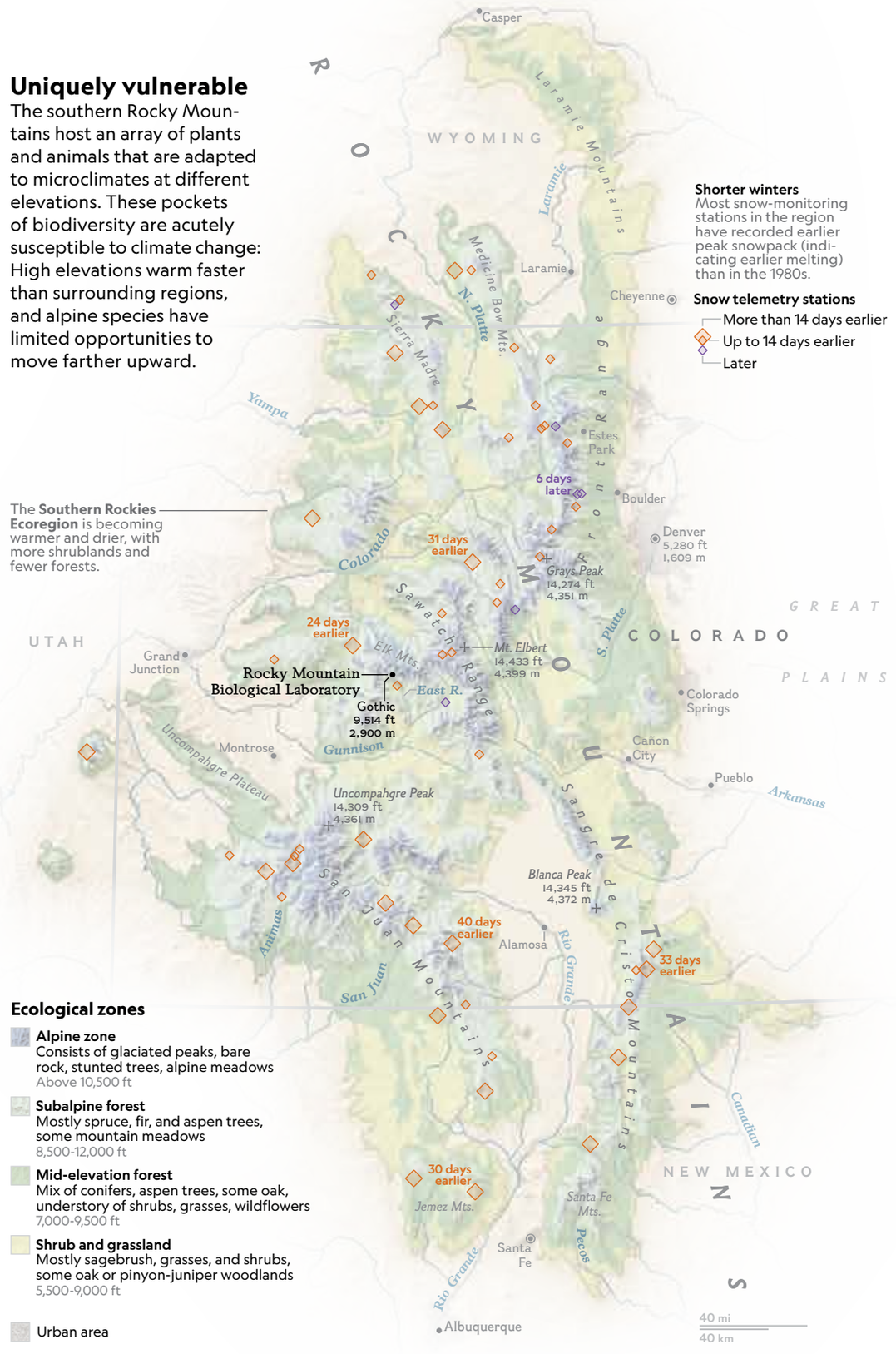
May 4 — 31 — June 1 — 15

*THE WESTERN SPRING BEAUTY IS USED BY RESEARCHERS AS A PROXY FOR SNOWMELT.

Uniquely vulnerable

The southern Rocky Mountains host an array of plants and animals that are adapted to microclimates at different elevations. These pockets of biodiversity are acutely susceptible to climate change: High elevations warm faster than surrounding regions, and alpine species have limited opportunities to move farther upward.

The **Southern Rockies Ecoregion** is becoming warmer and drier, with more shrublands and fewer forests.



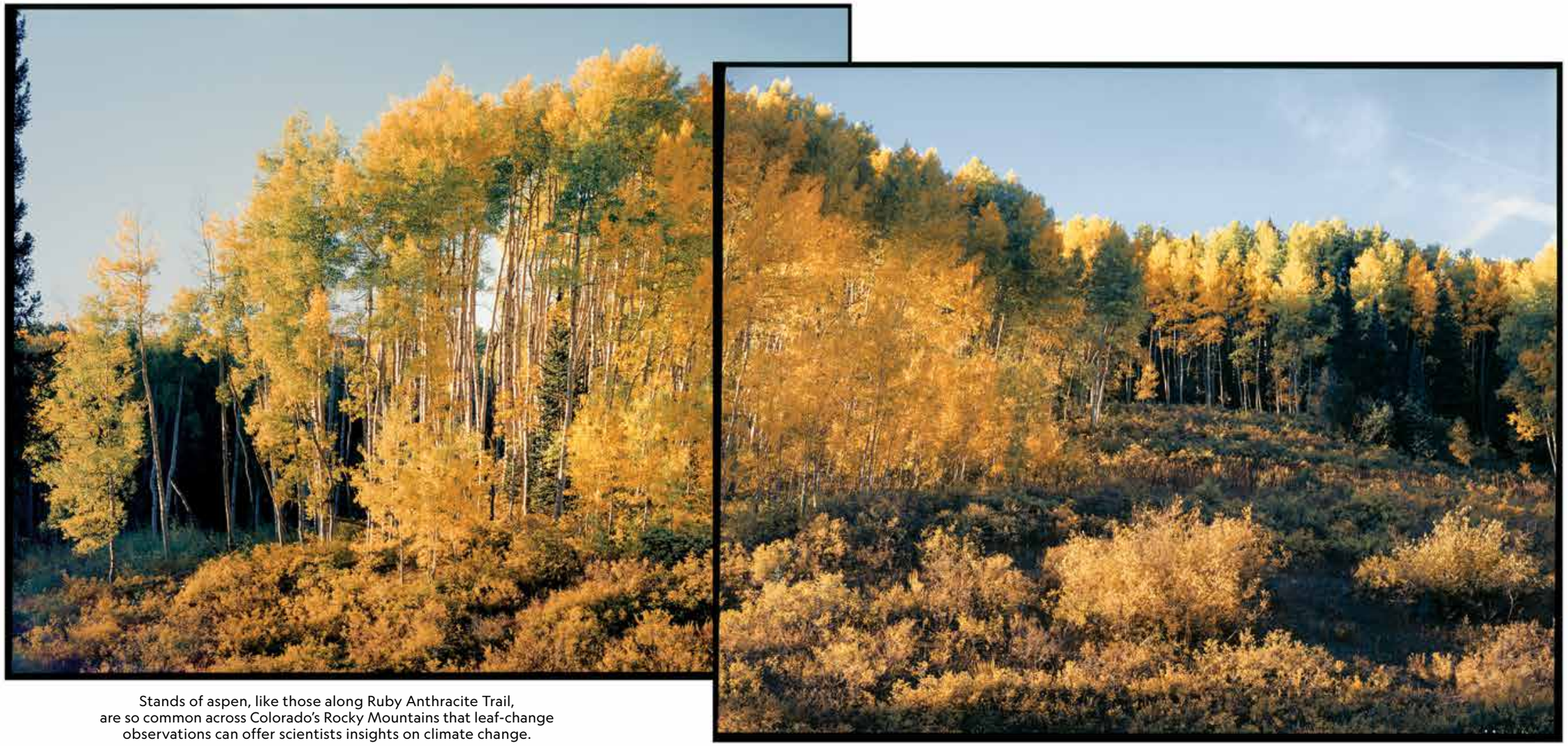
Shorter winters
Most snow-monitoring stations in the region have recorded earlier peak snowpack (indicating earlier melting) than in the 1980s.

Snow telemetry stations
- More than 14 days earlier
- Up to 14 days earlier
- Later

Ecological zones

- **Alpine zone**
  Consists of glaciated peaks, bare rock, stunted trees, alpine meadows
  Above 10,500 ft
- **Subalpine forest**
  Mostly spruce, fir, and aspen trees, some mountain meadows
  8,500-12,000 ft
- **Mid-elevation forest**
  Mix of conifers, aspen trees, some oak, understory of shrubs, grasses, wildflowers
  7,000-9,500 ft
- **Shrub and grassland**
  Mostly sagebrush, grasses, and shrubs, some oak or pinyon-juniper woodlands
  5,500-9,000 ft
- Urban area

KATIE ARMSTRONG, LUCAS PETRIN, AND RILEY D. CHAMPINE, NGM STAFF. KELSEY NOWAKOWSKI. SOURCES: BRIAN D. INOUYE, FLORIDA STATE UNIVERSITY; BILLY BARR; ROCKY MOUNTAIN BIOLOGICAL LABORATORY; USA NATIONAL PHENOLOGY NETWORK; EPA; GLENN E. GRIFFITH, USGS; USDA



Stands of aspen, like those along Ruby Anthracite Trail, are so common across Colorado's Rocky Mountains that leaf-change observations can offer scientists insights on climate change.

plants were available for each pollinator. Inouye would start with flowers and bumblebees. Bumblebees, he'd learned, keep reasonable hours.

Every other day all summer, he walked with pencil and paper, noting bloom times and chronicling floral visitors. Colleagues eventually drifted away, but each summer, Inouye and his wife, Bonnie, returned. They adored Colorado's beauty and how different each summer felt. "There was always a sense of anticipation, wanting to know what the new season would bring," he said. He came back, decade after decade, raising two sons along the way.

Initially, climate change played no part in his thinking. Over time, without intending to, Inouye and his colleagues in Gothic would compile one of the longest continuous detailed accounts of subalpine change on Earth—data so influential that it has become a sort of foundational text.

Few can top their firsthand observations of the ways planet warming is contorting nature's timing. In 2000, before anything like it had been done in North America, the group, which by then included his ecologist son, Brian, showed migrating American robins were arriving 14 days earlier. In 2008, Inouye found that climate-driven changes to the growing season have paradoxically increased frost events, killing more sunflowers and lavender-hued daisies. (Rather than staying continuously cold until June, the ground now warms and refreezes and repeats that pattern several times before summer.) By 2013, having documented by hand two million flowers over 39 years, Inouye and others showed blooming can start roughly four weeks earlier, even as flowering across the landscape, from first bud to last, can take 36 days longer.

This intimate view of one small place gave them insight into the sometimes surprising ways climate change strains interactions between species. By killing daisies, those climate-driven frosts reduce nectar needed by Mormon fritillary butterflies, driving down the tawny winged creatures' populations. In the 1970s, first blooms of that drooping, yellow glacier lily once coincided with the arrival from Central America of broad-tailed hummingbirds, which depend on the lily's nectar. By the time I showed up in Gothic, however, those blooms often started 17 days earlier, while hummingbirds generally arrived 12 days earlier. "At some point, if trends continue, the flowers may be done by the time the birds arrive," Inouye said.

The discoveries in Colorado come amid budding global interest in timing as researchers start cataloging profound costs. For example, from 2015 to 2016, up to a million common murres, large seabirds sometimes dubbed flying penguins, starved to death along the United States' West Coast, their emaciated carcasses washing up on beaches. A severe ocean heat wave made more likely by climate change had altered timing cycles for their food. Musk oxen in Alaska are increasingly born smaller as melting snow refreezes, coating in ice the vegetation pregnant



Billy barr, who spells his name without capital letters, has lived in Gothic since the early 1970s—much of that time without electricity or running water and sometimes as the only winter resident. A data geek, he began measuring his environment, including snow depth and temperature. While his cabin is now solar powered and his gear more sophisticated, barr still regularly documents nature.

cows need. (Previously, winters stayed so cold and dry they could paw through snow to eat greenery below it.) With sea ice melting earlier, polar bears spend more time on land. Grizzly bears already are venturing farther north. The two species have occasionally mated in the past, but hybrid "pizzly" bears, while still rare, are now expected to become more common.

THERE ARE RISKS FOR US TOO. Globally, markets for insect-pollinated crops, such as cacao, watermelon, cumin, and coriander, are worth up to $577 billion annually. Changes to nature's clock also may influence agriculture in dozens of hidden ways, not all of which can be addressed by shifting planting or harvest seasons. Farms may be exposed to more frosts or previously unseen crop-killing pathogens.

There is much we don't yet know: Can timing changes alone drive significant extinctions? What is nature's capacity for adaptation? And why is it so hard to see what's coming next?

WE'RE ALL PART OF A GIANT EXPERIMENT.
THE POTENTIAL FOR NEGATIVE CONSEQUENCES IS MAGNIFIED.
BUT THE WORLD MAY ALSO SURPRISE US.

Teasing apart so many disparate changes takes an incredible amount of work. Documenting what influences the schedule of each organism in a single ecosystem requires countless studies of a wide variety of nearby life. Through the years, Inouye has joined up or shared insights with hundreds of scientists. During my week in the valley, I witnessed a delightful cross section of their research, which merely highlighted the difficulty of predicting the future.

Below the granite of Gothic Mountain, Rebecca Irwin, a North Carolina State University ecologist, pointed out a parasitic cuckoo bee. When spring comes early, it seems, bumblebee queens grow weaker, and cuckoo bees have more luck stinging them to death and usurping their worker bees. "In these early snowmelt years, the queens are just more stressed," Irwin told me. "They need more food. They have to forage more often." But after 13 years working with bees in Gothic, she sees no clear long-term survival trend among the region's 200 bee species.

We're also still learning why animals do what they do. The following day, Mary Caswell Stoddard, a Princeton University associate professor, led me through meadows above Colorado's East River. A few years earlier, she'd found that broad-tailed hummingbirds see a far wider color array than humans, which probably influences which blossoms they visit. She showed me where she set up camera traps to see how climate change's reorganization of flowering may alter hummingbirds' "sensory perception"—and behavior.

Of course, one Inouye collaborator stands out: billy barr. A Colorado legend, barr (who does not capitalize his name) has been profiled on television, in newspapers, books, and films. He visited Gothic as a Rutgers University student and came back for good in 1973—and holed up in a mining shack without electricity or running water. In the summer there were scientists, including Inouye, but through spring and fall and the bitter, blustery winter, he lived in the Elk Mountains alone.

So barr measured things—temperature and snowfall and snow depth. He tracked moisture content and noted in spring when snow melted. (He used a yardstick and a scale.) He heard each year's first birdsong and recorded his first marmot spotting. He jotted it all in notebooks. "I was just there, and I just wrote down what I saw," he told me. "I mean, I had all day long."

Less modern-day Thoreau than restless data geek, barr enjoyed comparing year-to-year observations. And while barr and Inouye knew one another, it wasn't until the late 1980s that the two chatted in depth about barr's records. Inouye, intrigued, asked to take a look.

The notebooks astounded Inouye. They could show, in detail, reductions in snow seasons. It was barr who first noticed robins arriving early, barr who provided data that helped others link marmot emergence with early spring. As far back as 1991—just three years after NASA scientist James Hansen told Congress that greenhouse gases are warming the planet—Inouye and a colleague used barr's notebooks to show how reduced snows could change flowering in the mountains, potentially harming bees and hummingbirds.



Five decades of data, painstakingly kept by barr in a series of handwritten journals, are now critical to our understanding of climate-driven changes in Colorado's snowfall and temperature. They affect everything from wildflower seasons to the first appearance of American robins and yellow-bellied marmots.



First light hits Gothic Mountain in early February, when much of life hibernates. What happens next as nature's schedule continues to shift in every wild system? We're about to find out.

"I started working on his data, plotting his first-sighting data against his snowmelt data and snowpack data," Inouye said. The relationship was clear. Snowmelt was a key trigger in alpine systems, kicking off an avalanche of timing changes. And it was a link discovered by happenstance—because a bored barr was a stickler for details and happened to live where Inouye was working.

INOUYE'S NEWEST COLLABORATION may reshape the field of phenology even more. Along with son Brian and daughter-in-law Nora Underwood, both biologists at Florida State University, and one of their students, the team synthesized decades of data from Gothic. They took 45 years of hand-collected details documenting 10,812 timing events for 30 plants, 13 types of insects, 16 bird species, two mammals, and one amphibian.

The results were idiosyncratic, contradictory—and unexpected. While most birds arrive earlier as snow melts earlier, red-winged blackbirds and Steller's jays show up later. (Many migratory species' journeys are triggered by environmental cues thousands of miles away.) A wet summer a year before can help delay spring activity for some burying beetles while advancing it for some butterflies; a warm summer the year before may help postpone flowering for tall bluebells. Warm fall temperatures slow spring egg laying for tiger salamanders, but their spring activity may also be influenced by rain and snow the fall before that.

It's a riotous, mixed-up world, with species colliding in new ways. Far more forces influence the timing of events than even Inouye had imagined. Too many factors are at play.

We're all now part of a giant experiment, with everything that is familiar in motion. The potential for negative consequences is magnified. But the world may also surprise us.

As long as birds have insects and nectar to eat, maybe they won't care if the smorgasbord changes. Some pollinators may simply switch to different plants, while others may not. Then again, insects too are in stark decline, even in Gothic. And although marmots are mostly winning, staying fat with plenty of food during longer, warmer summers, ever lighter winter snows can diminish the cocoon effect that insulates their burrows. Some have actually frozen to death while hibernating.

How timing mismatches may reorganize systems remains unclear, even in Gothic, where scientists have now tracked nearly six million flowers. In most ecosystems on Earth, we've only just begun to look closely enough to notice.

"We've forgotten what we used to do, which is watch—just observe things," Nora Underwood told me. "I hear it at meetings: Everybody now wishes they started counting things 50 years ago." ▯

Senior writer **Craig Welch** wrote about the future of forests in the May 2022 magazine. **Elliot Ross** took photographs for a story about the value of shade in a warming world for the June 2021 issue.