

SKYVIEW

The background of the cover is a photograph of a sunset. The sun is a bright, glowing orb in the center, casting a warm orange and yellow light across the sky. In the distance, a range of mountains is visible. In the foreground, the dark silhouette of a tree with bare branches is on the right side, and some evergreen trees are visible in the lower half of the image.

Fall 2013 | Science Journalism Project | University of Arizona

Rebalancing Nature

Bighorn sheep return to the Catalinas

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PAGE 10 | REACH FOR THE SKY

Sky School connects Tucson students to science on Mount Lemmon



UNDER PRESSURE

Heat and pressure transformed this 1.7-billion-year-old section of Oracle granite in the Santa Catalina Mountains into a swirl of sinuous layers and deformed crystals.

PHOTOGRAPH BY KATHLEEN COMPTON



Rising Above the Clouds

The

The teenager sitting next to me on the plane badly wanted a window seat, so I swapped with him. I was planning to read a book anyway. He and I happily ignored each other from the moment we left Dallas until as we started crossing the Santa Catalina Mountains on the northern edge of Tucson.

"There's snow on the mountains!" he exclaimed.

I peered over his shoulder. I'd missed the mountains all week, and I wasn't about to pass up the opportunity for a sky view. Masses of dark green conifers interspersed with patches of pure white undulated below the plane.

For a moment, my neighbor and I grinned at the Catalinas together. Then the plane shifted slightly, and the window framed blue sky. I leaned back to my side of the armrest.

Many Tucsonans share an affection for the Catalinas, the mountain range visible from much of town. The Catalinas are one of about 65 mountain ranges that arc through Arizona, New Mexico and Mexico, rising thousands of feet above the surrounding valleys to form what desert nature writer Weldon Heald called "sky islands" because of how different they are ecologically from surrounding desert and grassland.

Those of us lucky enough to move to Tucson for the University of Arizona quickly discover that some of the best classrooms and laboratories are in the mountains—more specifically, they are the mountains. Research in the Catalinas covers everything from inches-long insects to unfathomably vast solar systems. When it comes to experiential learning, students range from local schoolchildren to amateur photographers with serious cameras.

What's more, learning is a continuous process in the Catalinas, year round, 24 hours a day. Just ask the researchers who collect data using the world-class astronomical facilities on Mount Lemmon. And there is always more to discover.

In the following pages the University of Arizona Science Journalism class taught by Carol Schwalbe highlights some of the research and outreach happening in the Catalinas. Big questions, such as the reintroduction of bighorn sheep and the storage of carbon in mountain soils, have answers lurking in our mountain classrooms.

Undoubtedly you have enjoyed a view of the Catalinas before, whether from a daily commute in town or through the window of a plane. We hope you also enjoy sharing this close-up view of research and outreach with us—and maybe even feel inspired to take a trip into the mountains for some exploratory learning of your own.

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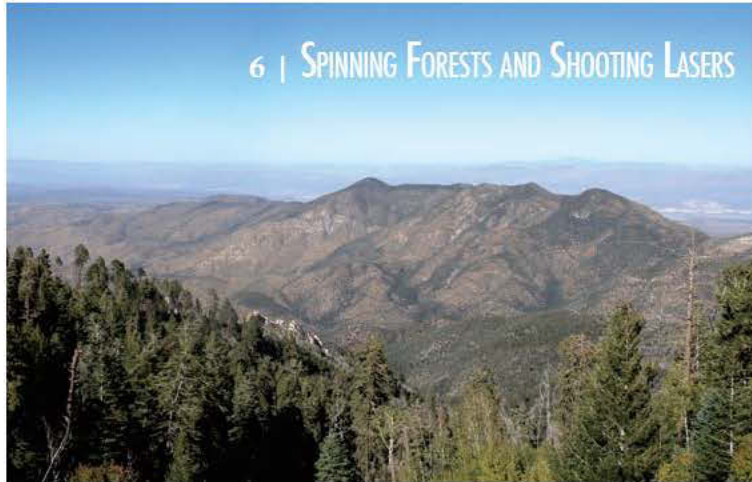
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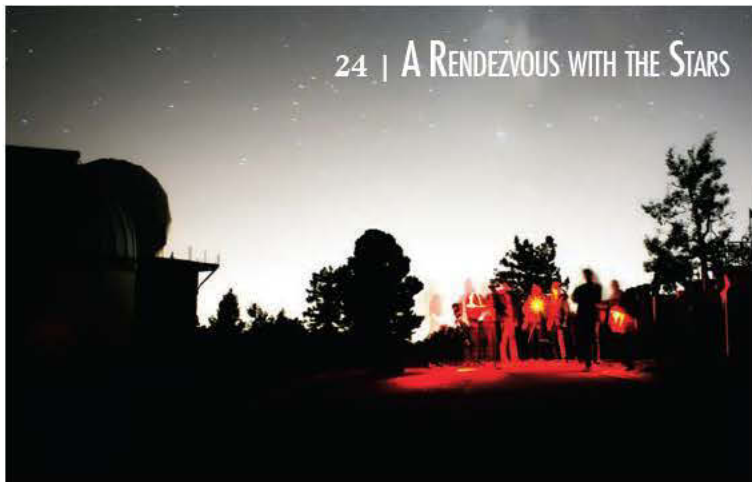
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FRONT COVER: The sun sets behind the Quinlan Mountains, the home of Kitt Peak National Observatory. **PHOTOGRAPH BY CATHY ROSENBERG**

BACK COVER: The Orion Nebula is a star-forming region visible to the naked eye as a fuzzy blob of light in the "sword" of the constellation Orion. **PHOTOGRAPH COURTESY OF ADAM BLOCK/MT. LEMMON SKYCENTER/UNIVERSITY OF ARIZONA**

TOP: PHOTOGRAPH BY NOELLE HARO-GOMEZ
MIDDLE: PHOTOGRAPH BY CATHY ROSENBERG
BOTTOM: PHOTOGRAPH BY SUSAN E. SWANBERG



INTO THE DARKNESS

A dark, starry sky peers through the dome of the 32-inch Schulman Telescope atop Mount Lemmon.

PHOTOGRAPH BY DANIELLE HERRINGTON

A Front Row Seat to the Heavens

A bright rim of ionized hydrogen forms the boundary of the Cave Nebula, about 2,400 light-years from Earth.
PHOTOGRAPH COURTESY OF ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

By Josh Workman

I was tired and nauseated and colder than any person in Southern Arizona should be, and I could not have been happier. Finally, after years of staring at the stars, I was going to get a picture of a nebula. I shivered up Mount Lemmon, slipping across patches of ice and stumbling through the darkness as I made my way to the large telescope.

It was a cold weekend in February, and it was my first experience as an astronomer. In spring 2013 I was taking a course that allowed University of Arizona astronomy minors to experience field research firsthand. Five other students and I were loaded into a rented van and forced to make awkward small talk as we wound our way from Tucson to the tip of Mount Lemmon.

Once at the Mt. Lemmon SkyCenter, we unloaded our gear and settled into our rooms for the weekend. We were staying in former Army barracks, and our rooms had all the comfort of a dilapidated mental asylum. Despite the barracks' obvious charm, the other students and I decided to leave our rooms and gather to discuss our projects.

I was there to take a picture of a nebula. My entire life, I'd been obsessed with celestial bodies, especially nebulae. Everything else in the sky, such as stars, planets and galaxies, could be seen, at least somewhat, with the naked eye. But nebulae, like the giant rats populating our rooms on Mount Lemmon, were nothing I had ever seen before.

I wanted to have a picture of a nebula,

something I could show off and say, "That is mine. I plucked it from the sky."

In preparation for the long night ahead, the other students and I began making dinner. I heated up a frozen dinner in an ancient microwave roughly the size of the Large Hadron Collider.

My nebula, the Orion Nebula, would not be high enough in the night sky to be captured by our telescope until 4:23 a.m., so after dinner I settled down with my computer, planning to do some research on the celestial body. As I powered up my MacBook, I discovered there was no Wi-Fi, so I spent the next few hours watching movies and thinking about all the research I would have been doing if I had an Internet connection.

One bad movie later, I bundled up and prepared for the cold outdoors. The heavy barracks door swung shut behind me, taking the warm light with it. We were not allowed to use any lights outside, as they could interrupt the telescopes' research. The Mt. Lemmon SkyCenter uses very advanced telescopes. Any light, even the small amount that spills out from the headlights of a car or an open window, can leak into the telescopes, blurring or dimming the stars.

Well, that was fine. I could still see by the light of the stars, right? I looked up and saw a thick, gray quilt covering the sky. Oh.

I trudged through the darkness and slipped into the observatory, hoping for

the best. When I reached the telescope control room, my professor, Dr. Thomas Fleming, shook his head slowly. His dark hair flopped in front of his eyes, and I followed its example by flopping into a chair.

"I'm sorry," he said. "There's too much cloud cover for your nebula."

I would like to paint myself as having a stiff upper lip and saying, "Oh, well, jolly good. I'll just pop off for a cuppa."

But I'm not English. I don't have a stiff upper lip. I'm American. We complain often and about everything. As we walked back to the dorms, I complained about the clouds and the cold and the fact that I felt a little sick.

It wasn't until after I said good-night to Professor Fleming that I realized the gift I'd been given: I had truly experienced the life of an astronomer. Astronomers live in fear of clouds, which can arise suddenly and ruin night after night of observation. For a moment, I had lived that life.

Instead of showing others a small picture of some gas millions of miles away, I could look them in the eye and say I was an astronomer. I had felt the pain and heartache that comes with the profession. In astronomy, as with any science, there are setbacks and mistakes. Science is learning from those mistakes and not giving up.

As I stood out in the cold, watching the clouds roll overhead, I realized a truth I had been missing. It turned out that I wanted to be a scientist more than I wanted a picture of a nebula.

Mapping Goes High-Tech in the Catalinas



PHOTOGRAPH BY JASON DAVIS

By Maya L. Kapoor

Tyson Swetnam spins an image on his computer screen. It's the outline of a box, and inside it, three-dimensional trees glowing in red, yellow, green and blue rotate and flip from right-side-up to sideways, a chunk of multicolored forest rolling against a black background.

Swetnam, a postdoctoral researcher with the University of Arizona's Department of Soil, Water and Environmental Science, created this glowing forest using LiDAR. A combination of "light" and "radar," LiDAR stands for "light detection and ranging." By combining laser and GPS technology in a machine attached to the belly of an airplane, remote sensing experts use aerial LiDAR to quickly produce maps of forests so accurate that individual branches on trees can be picked out, yet so enormous that the contours of the landscape become illuminated.

Because of its detail, scope

Sun-loving quaking aspens colonized open areas in the Santa Catalina Mountains after the 2003 Aspen Fire, which roared for a month and destroyed almost two-thirds of the forest. Remote sensing experts use LiDAR, a combination of "light" and "radar," to help explain why devastating blazes like this are becoming all too common.

and speed, LiDAR is changing the way we manage our forests. "It used to be you'd spend tens of thousands of dollars to inventory a couple of football fields of forest, and it would take you and your friends all summer," Swetnam says. "Now, you can inventory an entire forest in a few hours."

In the Santa Catalina Mountains north of Tucson, Swetnam and other researchers are using LiDAR to understand long-term forest dynamics, such as how forests recover after fires and how much carbon the forests absorb as they grow.

LIGHT ECHOES

Attached to each research plane is a LiDAR machine that shoots a laser at the Earth. Like a bat echolocat-

ing its position in space by listening for the echo of its calls, the LiDAR machine times how long it takes the laser to bounce back. "Since we know the speed of light, we can calculate a distance," said Caitlin Orem, a geosciences doctoral student at UA. These distance measurements are used to draw the Earth's shape, down to the foliage on its trees.

Of course, these calculations require knowing the plane's exact position in space at every moment. "LiDAR is old, but now we have the internal navigation systems to keep track of the plane's position," said Wim van Leeuwen, director of UA's Arizona Remote Sensing Center.

LiDAR planes typically fly back and forth across a

study site in stripes. "It's kind of like when you're mowing the lawn," Orem said. "Usually, you do a little bit of overlap so you don't end up with a weird, thin line of grass." Similarly, with LiDAR, each stripe of measurement is slightly overlaid so all the images can be stitched together later.

FOREST CRAYONS

In the days, weeks and even months after a forest wildfire, it's not hard to see changes. Small green plants, such as grasses, wildflowers and shrubs, will have burned away. If the fire stayed at ground level, the bigger trees might be sooty but healthy. But if the fire was severe, even mature trees might have snapped and burned into jagged logs.

In the years following a major forest disturbance such as a fire, lasting effects might be subtler. LiDAR can help illuminate patterns of long-term forest dynamics, revealing changes that occur even decades after fire, flooding, hurricane damage or other disturbances.

Swetnam demonstrates this application with another colorful image, this one of experimental logging in the Pinaleño Mountains 80 miles northeast of Tucson.

Swetnam's computer is hooked up to two monitors. On the left one he pulls up a U.S. Forest Service map of logging roads, drawn without the help of LiDAR. On the right monitor glows a colorful map of the same section of forest, made with LiDAR-generated data from 2008.

Swetnam points to differences between the roads on the two maps. "You can

see the National Forest Service maps are a little off," he says.

He clicks the right screen, zooming in, and a blur of jumbled crayon colors distills into distinct puffballs. Each is a tree measured by LiDAR from above.

The Forest Service issued logging permits for specific stands of public land in the Pinaleños to private contractors, but there is no record of whether contractors logged their stands or what logging strategies they used, Swetnam says. The 2008 LiDAR data can be used to understand the history of logging in the Pinaleños. Patterns of forest regrowth, indicated by configurations of primary color puffballs, point to logging strategies employed on the Forest Service land parcels.

With long-term, landscape-level results like these in

hand, forest managers can make better decisions about what kinds of logging to permit in the Pinaleños. And they can use similar approaches to deciding how to manage logging in the Catalinas.

MANAGING FORESTS

One area in which LiDAR has growing application is fire management. In 2003 the Aspen Fire roared for a month, burning almost two-thirds of the Catalinas and destroying most of the town of Summerhaven.

Researchers have used LiDAR to partly explain why devastating blazes such as the Aspen Fire are becoming all too common. By way of illustration, Swetnam swivels back to the two monitors perched on his desk and opens a LiDAR map of a present-day New Mexico forest, then zooms in on a puffy

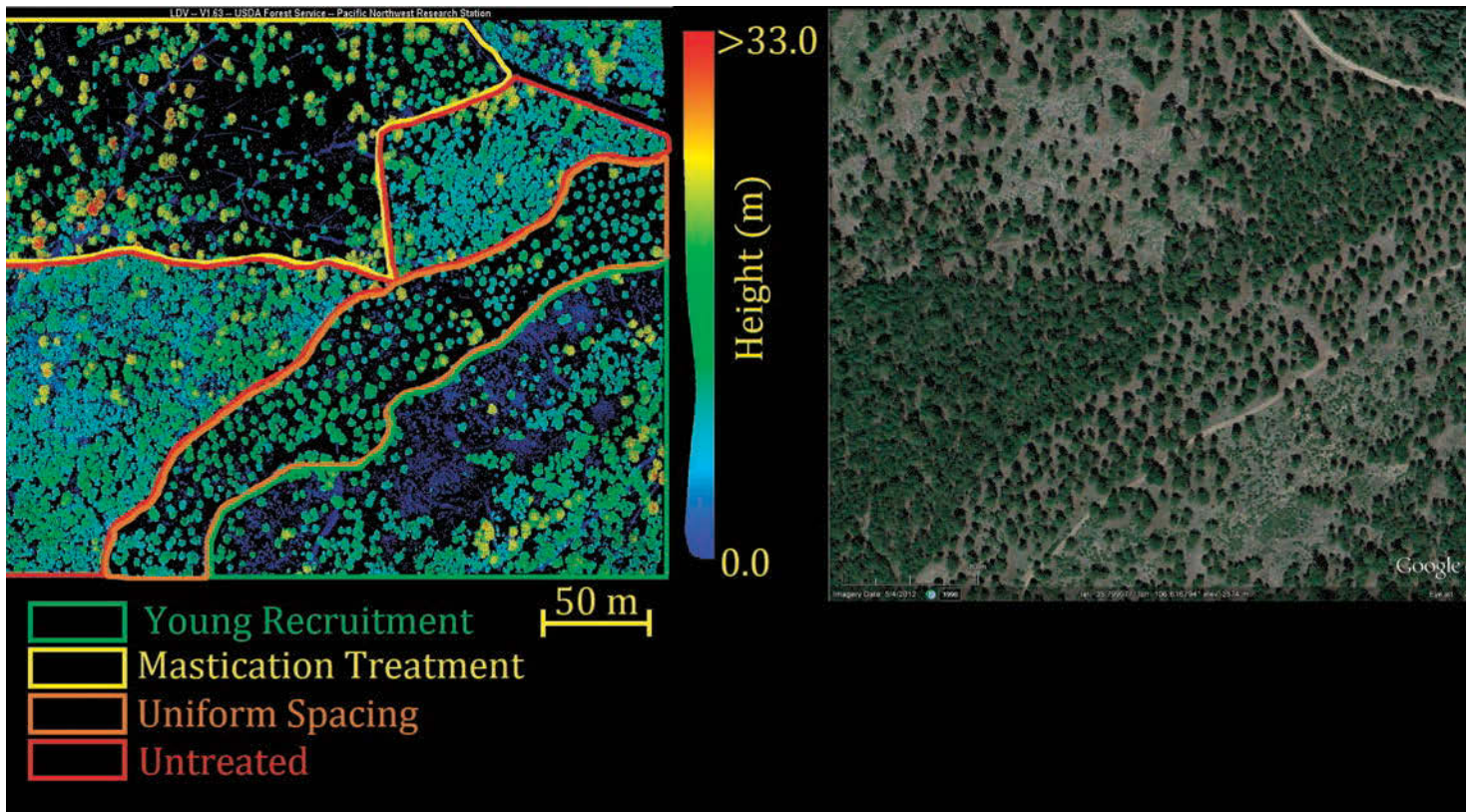
red form. A tree from above.

Swetnam zooms in closer on a rotated version of the tree, revealing two smaller blue puffballs nestled below. "There are two baby trees under there," Swetnam explains.

All those LiDAR puffballs growing into each other are ladder fuels, such as tall seedlings and low-growing branches of mature trees, which accumulate after years of fire suppression. When ladder fuels catch fire, the flames can climb the ladder and spread right into the forest canopy.

Canopy fires, which whip through forests, are much more catastrophic than the ground fires that historically burned in Southwestern pine forests, such as those cloaking the Catalinas. Canopy fires are, Swetnam says, "impossible to control."

Before humans started suppressing wildfires,



GRAPHIC COURTESY OF TYSON SWETNAM

Foresters in New Mexico's Jemez Mountains used LiDAR to investigate the long-term effects of four different forest-thinning strategies. On the left is a LiDAR map of the area pictured on the right. Study results might help manage forests across the Southwest.



frequent low-level burns prevented seedlings from growing tall enough to become ladder fuels. “Fire opened a stand up,” Swetnam says. “It kept killing back the little guys. If you were a big guy with 3 inches of bark and your lowest branches were 10 feet off the ground, you were unlikely to die in a fire.”

Now, the only way to prevent such catastrophic conflagrations is by manually thinning ladder fuels to create a gap between ground-level flames and the branches of old-timer trees.

“LiDAR helps identify problem areas and quantify them,” Swetnam says. “Down the road someone could say, ‘How much is it going to cost to thin?’ And I could count the trees and extrapolate.”

But thanks to computer algorithms and LiDAR, Swetnam will not be manually counting puffballs on his computer screens or, even more time consuming, actual trees on the ground. He will be able to write a computer code that quickly counts and categorizes trees according to the fire risk they pose.

BANKING THE CATALINAS

A decade after the Aspen Fire, one of its enduring signs is, as it turns out, aspens. The fast-growing, sun-loving trees crowd open areas in the Catalinas created by the fire. Researchers use LiDAR to quantify how much and how quickly forests grow. In fact, for Swetnam one of the most exciting applications of LiDAR is in measuring the amount of living matter, or biomass, that a forest contains.

Growing forests are sponges that soak up carbon dioxide, a greenhouse gas. They hold onto the carbon to build tissue and release oxygen back into the air.

Since there is no practical way to directly measure the carbon in a standing adult tree, foresters have developed ways to estimate how much biomass a tree contains. “Based on the height of a tree, you can estimate what its biomass would be if you folded it into a cylinder,” says Swetnam, who has worked in forestry. “LiDAR can help with that.”

If all the needles on a pine tree were folded against the twigs, and the twigs folded against the branches, and the branches against the trunk, you would end up with something roughly like a long cylinder, pointy end toward the sky.

As part of his doctoral research at UA, Swetnam developed a computer program that uses LiDAR to quickly and accurately estimate cylindrical tree measurements for every tree in a forest. “LiDAR lets us view the forest as a carbon bank account,” Swetnam says, one where known amounts of carbon can be withdrawn through logging or controlled burns, or deposited through tree growth, healthy soil development and charcoal accumulation, for the benefit of a world increasingly affected by climate change.

CACTUSES FROM THE SKY

The average aerial LiDAR survey measures 10 to 100 laser points per square meter of Earth, adding up to billions of points of data per study



TO ACCESS LiDAR DATA

Visit [OpenTopography.org](https://opentopography.org). The National Science Foundation maintains this website. All data collected using federal funds become available for free within a few years.

To learn more about Tyson Swetnam's work and see his LiDAR imagery, visit his website at <https://sites.google.com/a/email.arizona.edu/tyson-swetnam/home>

site. The resulting data are "incredibly accurate to 1 meter," said Caitlin Orem, the geosciences doctoral student. But as the applications of LiDAR to natural resource management grow, so too does the desire for more precise data.

As the Catalina foothills flatten to the valley floor, trees give way to cactuses, shrubs and rocks. At these

lower elevations, most of the dominant plants are less than 1 meter in diameter, and this points to an area where the original Catalina LiDAR flights have shortcomings.

These flights were commissioned by Pima County after the Aspen Fire to study the rockslides that resulted from the loss of vegetation cover on the mountains. For that project, a resolution of 1 meter was sharp enough.

"Everybody has their own data specification requirements to be able to take advantage of these technologies," said van Leeuwen of UA's Arizona Remote Sensing Center. "We wanted to use LiDAR to see between different life forms—shrubs, trees, saguaros—but the LiDAR resolution wasn't high enough."

In one of van Leeuwen's images of a saguaro as depicted by the Catalina LiDAR maps, all that shows up is a smattering of blue points floating in black space over a rippled white surface. Likewise, in another image a jojoba shrub in front of a mesquite tree doesn't look like a plant at all. Instead, the image shows a few dots of purple, blue, green

and yellow levitating over a white carpet. The plants are narrow enough that the LiDAR lasers missed them for the most part during the Catalina flyover.

But now, new airborne LiDAR systems can record 200,000 laser points per second during flights—if someone can match the price tag, upward of a million dollars per flight. "You're paying the employees to travel to your area to then fly a plane for possibly a week to two weeks, depending on weather conditions, go all the way back to home base, process your data, make all of these products for you, and then send it to you," Orem said. "It's a lot of money."

"The possibilities of LiDAR are great," van Leeuwen said. These days, scientists using hyperspectral cameras are even producing LiDAR maps color-coded by tree species. "From my perspective, I think every state should have a good [LiDAR] system that could be employed continuously, but especially when you have a disaster like fire and drought. But that's wishful thinking."

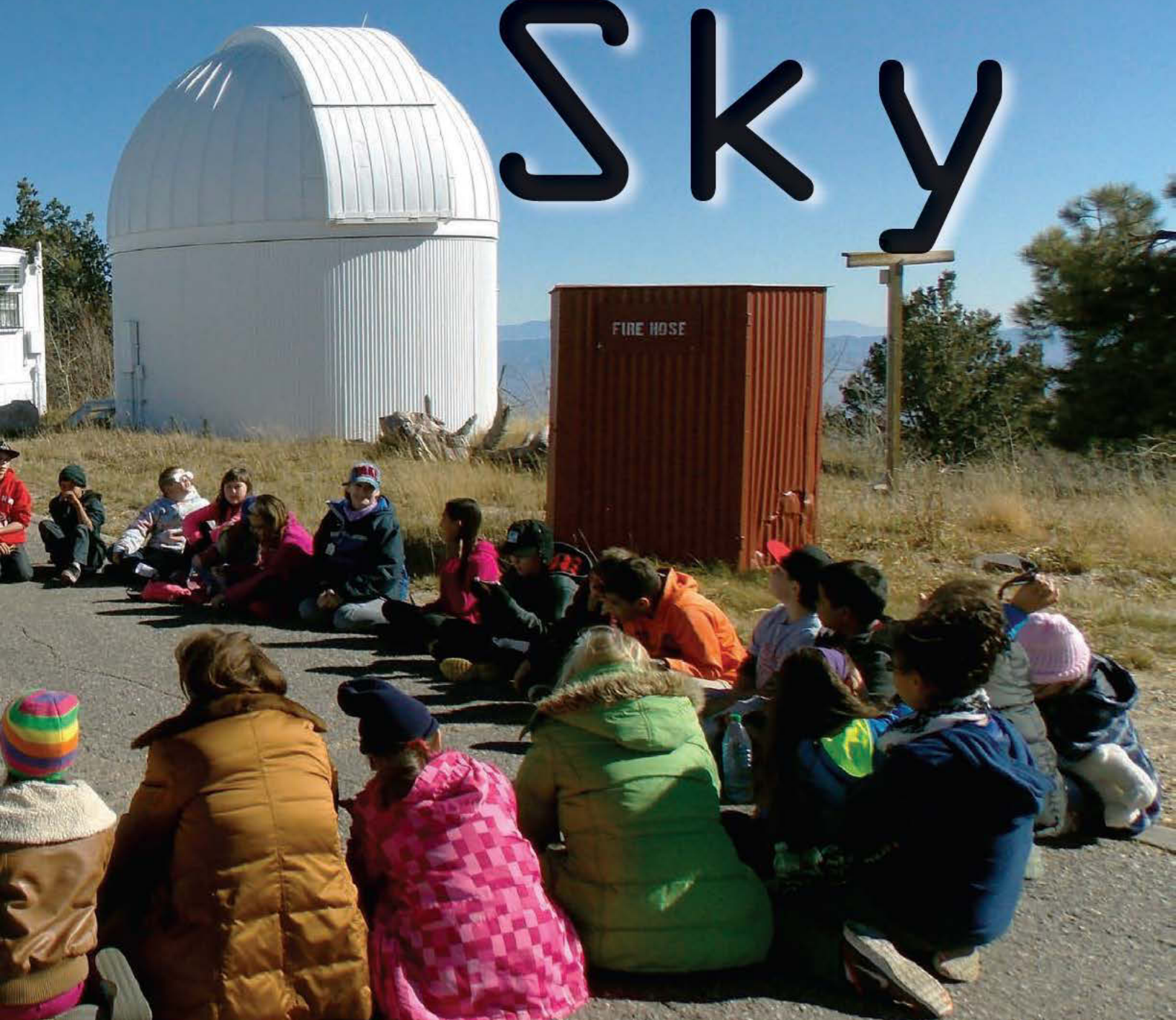
Reach

Sky School connects Tucson students
with science on Mount Lemmon



for the

Sky



Fifth graders from the Academy of Tucson share the favorite thing they learned during their stay at the University of Arizona Sky School at the Mt. Lemmon SkyCenter.

Story and photographs by Alison Dorf

If our solar system were the size of a penny, the Milky Way galaxy that contains it would be roughly the size of the United States.

Upon hearing this comparison, the children's eyes widen. Sitting in a circle, fifth graders from the Academy of Tucson listen intently as Alan Strauss, director of the Mt. Lemmon SkyCenter, tells them about our solar system and the lifespan of the sun and stars.

As he talks, he passes around small pieces of meteorites. The children take turns examining these chunks of debris from outer space that remained intact after hitting the Earth.

After the lesson, the children are off to bed, ending yet another science-filled day at the University of Arizona Sky School. This new program connects students to science through an immersive residential experience at the Mt. Lemmon SkyCenter in the Santa Catalina Mountains north of Tucson.

Now in its second year, the Sky School has brought hundreds of schoolchildren to the mountain to experience a wide spectrum of subjects from astronomy and geoscience to biology and ecology. Programs range from a two-day, one-night stay for grade-schoolers to a four-day, three-night program for high school students. All the programs are led by UA scientists and graduate fellows.

The Sky School programs have become so popular that they are booked through June 2014. "Demand has outpaced our plan for growth," Strauss said.

In early November, 34 fifth graders from the Academy of Tucson spent two days and one night immersed in science from the bottom of Mount Lemmon to its 9,130-foot summit. The youngsters connected with their teachers and peers in a new environment outside the classroom.

"It's great to just watch the students having fun," said Celeste Perrotta, a fifth grade teacher at the Academy of Tucson. She said she enjoyed talking to the children as people, not just teacher to student. "I just get to know them better, and they get to know each other better.

UP THE MOUNTAIN

The students arrived at Babad Do'ag Overlook, the first stop of their Mount Lemmon adventure, around 9 a.m. There they were met by Strauss and Pacifica Sommers, a doctoral candidate in UA's Department of Ecology and Evolutionary Biology. Sommers, a senior instructional specialist and lead graduate fellow, helps organize the trips and mentors the other graduate fellows in the Sky School program.

Sommers distributed a stack of field guides for the children to record their notes and observations. She then split the youngsters into groups led by the other graduate fellows.

After an introduction and short lesson, the children piled into several cars and vans. On the way up to the Sky-Center, they stopped several times to learn about Mount Lemmon's temperature variations, climate, humidity and plant life.

The students are encouraged to speculate and ask questions, said Janet Dougherty, a fifth grade teacher at the Academy of Tucson. "It's just such a great environment for them to get out of the classroom and to put into practice some of the things we do within the constraints of four walls."

Before each visit, teachers let the Sky School know what they are teaching and what they are interested in learning about, said Rebecca Lipson, a senior instructional specialist for the Sky School and a middle school teacher at Miles Exploratory Learning Center in Tucson. "There's just so much up here to learn about," Lipson said. "Our focus is to get kids doing science."

A MUTUAL BENEFIT

The Sky School benefits the students as well as the UA graduate fellows and science teachers who lead the program. "Our graduate student scientists are learning from the kids about how to communicate science and be fun teachers," Strauss said, "and [they are] seeing the value of inspiring these students."

For Sommers, the program has taught her how to explain her research more clearly. "Every trip, I encounter new pieces of knowledge that I didn't realize a fifth grader didn't have, and I learn new ways to explain things," she said.

Learning in a real environment reinforces what students are studying in the classroom. "Even if these kids never go on to be scientists," Lipson said, "hopefully it gives them an experience that they can take with them to understand why science is important in their lives and why this mountain is such an amazing place."

Sommers led the pilot program last year, shortly after receiving a NASA Space Grant Fellowship for science outreach and education.

The Sky School now includes nine scientists and graduate fellows, along with other staff members.

High school students conduct independent research. They



TOP: Academy of Tucson fifth graders take a 3-mile hike near the Mt. Lemmon SkyCenter. Almost two thirds of the mountain burned during the 2003 Aspen Fire.
ABOVE: The fifth graders take a break during their hike. The Sky School has brought hundreds of schoolchildren to the mountain to experience a spectrum of subjects from astronomy and geoscience to biology and ecology.
LEFT: Chase Canant, 11, draws a picture of a flower during an activity at the Sky School.

A group of students and a graduate student are gathered in a forest of tall, thin trees. The students are dressed in outdoor gear like jackets and scarves. One student in the foreground is wearing a colorful, patterned hoodie. The scene is outdoors with sunlight filtering through the trees.

For More Information

The University of Arizona Sky School program was developed in collaboration with local school districts to meet Arizona State and Next Generation Science Standards. All programs include daytime field instruction in small groups on Mount Lemmon. UA graduate student scientists lead hands-on research projects and stargazing through large telescopes.

Fees include all instruction, meals and dormitory lodging. The current price is \$250 per person for the four-day, three-night program. Schools that qualify for Title I status receive a discounted rate of \$225 per person. The cost of the two-day, one-night program is \$100 per person (\$80 for Title I schools). All fees apply to adult chaperones as well as students.

Visit the Sky School website: <https://skyschool.arizona.edu/Questions?> Contact Alan Strauss at (520) 626-8122 or uaskyschool@gmail.com



Moira Hough, a University of Arizona graduate student studying natural resources and a fellow at the Sky School, leads students from the Academy of Tucson through 10 minutes of silence to hear the sounds of the forest.

work on a multiday inquiry project guided by graduate fellows. The students come up with question, hypotheses and experiments, then present their findings in a symposium at the end of the trip.

Before attending the Sky School, many students had never been to Mount Lemmon, Strauss said. He hopes the program will serve as a legacy for the SkyCenter.

THE SOUNDS OF SILENCE

After arriving at the SkyCenter, the students spent the next few hours engaged in various activities, from an energetic predator-prey game to graphing data collected earlier in the day.

But the learning had only just begun.

After the activities ended, the students embarked on a three-mile hike near the SkyCenter.

For 10-year-old Nadia Hachenberg, the hike was her favorite part of the day. "I liked hiking because I liked the smell of all the trees, and I liked the coldness," she said.

Once the group reached a clearing, Moira Hough, a UA graduate student who is studying natural resources, asked for 10 minutes of silence to listen to the sounds of the forest.

Afterward, the students discussed the different sounds they heard, from birds chirping to branches crackling in the distance.

"If I go out into the woods and I really want to hear some birds or see some wildlife, I'd better be quiet," Hough told the students. "Wasn't that cool when you heard the wind go through the trees?"

A STARRY NIGHT

After dinner, the students split into groups for their next activity: stargazing. They took turns heading to the top of the mountain, where they piled into a large room to look through the 20-inch John Jamieson Telescope.

In just a few hours, the temperature had dropped from T-shirt weather to frigid cold. Donning hats, mittens and heavy coats, the children nestled together and sat on the floor, using red flashlights to see. The red light is better than white light for night vision. Even a small amount of light from car headlights or an open window can leak into the telescope and interfere with stargazing.

Once their eyes had adjusted, the students gasped in amazement at the blanket of stars sparkling in the night sky, with Venus shining brightly just above the horizon.

Sommers led the viewing session. She showed various sky objects, such as Vega, the fifth brightest star in the night sky; the Pacman Nebula; and the Andromeda Galaxy.

"It was really cool because down in Tucson we can't really see the stars that well, because of all the light and stuff," said 10-year-old Becca Lux.

Around 10 p.m. the students headed to their dorm rooms. There were no sounds outside but the soft wind blowing through the trees. No lights but the brightness of the stars.

A version of this story appeared in the Green Valley News on Jan. 19, 2014.



STAR POWER

Billions of stars toward the center of the Milky Way galaxy form a band of light that can be seen at night in the dark skies above Southern Arizona's mountains.

PHOTOGRAPH BY D. ERIK GOODMAN





Rebalancing Nature

Reintroducing Desert Bighorn Sheep to the Catalinas

Story and photographs by Cathy Rosenberg

The helicopter lands easily on the concrete slab. Hurriedly, the team onboard carries the desert bighorn sheep to a stretcher. Blindfolded and entangled in a capture net, the sheep is moved to a nearby staging area.

Many hands restrain the animal as the twisted net is quickly removed. The ram struggles, and then relents as he is poked, prodded and processed in preparation for transport to his new home in the Santa Catalina Mountains near Tucson.

“Overheating is the greatest concern during the capture,”

says Anne Justice-Allen, a wildlife health specialist for the Arizona Game and Fish Department. Overheating can cause capture myopathy, a stress-related complication from problems such as overexertion that sometimes occur during capture. The condition damages muscles and can lead to heart failure.

After a temperature reading, cool water is poured over the animal. The sheep is given oxygen and an intravenous drip to help keep him from overheating during his evaluation.

Along with a team of assistants, Justice-Allen draws blood,

ABOVE: A desert bighorn ram dashes toward an uncertain future in the Santa Catalina Mountains, north of Tucson. The Arizona Game and Fish Department released 31 desert bighorn sheep in November 2013 as part of a project to reestablish a viable population.

A version of this story appeared in the Tucson Weekly on Jan. 9, 2014.

takes nasal and oral swabs to check for respiratory diseases such as pneumonia, and snips a small piece of skin from the sheep's ear for DNA testing. Then a biologist attaches a satellite GPS radio collar to the ram's neck.

The GPS system will show Arizona Game and Fish biologists where the sheep is located after his release. If satellite reception is good, the system will upload at 7 a.m. each day and indicate four of the ram's locations from the past 24 hours.

Twenty-one adult ewes, three yearling ewes, five adult rams and two yearling rams were captured in the Trigo Mountains near Yuma, Ariz., and the Plomosa Mountains near Quartzite, Ariz. Shortly after sunrise on the two days of capture, helicopters headed out into the mountains in search of sheep.

Arizona Game and Fish contracts the copters. Their pilots come from Grand Canyon Papillon Helicopters, the company that flies helicopter tours of the Grand Canyon.

A nonlethal net gun is shot from one copter as it hovers over the sheep. The net entangles the animals, which are then scooped up by the crew and brought back to the staging area.

The operation took place on a weekend in November 2013. The following Monday morning the sheep were released in Catalina State Park as the first phase of the Catalina Bighorn Restoration Project.

The reintroduction leaves many questions unanswered. No one knows if the sheep will become a self-sustaining population. The bighorns might fall victim to the same fate that caused their disappearance from the Pusch Ridge Wilderness Area of the Catalinas in the late 1990s. Sheep had thrived in that range through most of the 20th century.

"No one is really certain why the original herd disappeared," said Mike Quigley, the Arizona representative for the Wilderness Society. "It was likely due to a combination of factors."

The sheep declined as the number of people living in the region grew. That correlation suggests that human encroachment might have contributed to the sheep's demise.



Wildlife specialists from the Arizona Game and Fish Department evaluate a bighorn's health and equip it with a GPS monitoring collar. The sheep will be tracked as they vie for a foothold in mountains where bighorns roamed until the late 1990s.

Other theories include the effects of fire suppression on bighorn habitat, predation by mountain lions and disease passed to the native sheep by their domestic cousins. In the last two decades, much speculation has occurred about why the sheep disappeared, but no definitive answer has been confirmed.

HISTORICAL PRESENCE

Desert bighorn sheep have roamed the American Southwest for tens of thousands of years—from what is now Mexico into Arizona and Nevada, through southern New Mexico and western Texas.

In the 1800s large populations lived in nearly all the mountainous regions of Arizona. As settlers moved in, the number of bighorns declined. Diseases transmitted by domestic sheep brought from Europe infected and killed the native sheep. The bighorns didn't have enough evolutionary time to adapt to these new diseases.

Unregulated hunting and loss of traditional water sources might also have contributed to the bighorns' decline. Bighorn meat was commonly sold in Arizona markets in the late 1800s.

As early as 1887, bighorns gained

protection in the Arizona Territory. This protected status, however, did not result in an increased abundance of sheep. The factors contributing to their decline continued to affect their overall numbers.

Two national wildlife refuges—Kofa and Cabeza Prieta—were established in 1939, providing 1.5 million acres in southwestern Arizona for the bighorn sheep as well as other wildlife. About 900 bighorns still live in these two refuges. By the early 1990s, however, their range elsewhere in the state had been reduced to the Grand Canyon and a few other remote areas.

Today the desert bighorn sheep again occupy many of their historical sites in Arizona because of translocation projects implemented by Arizona Game and Fish. More than 5,000 sheep now live throughout the state.

The bighorn sheep disappeared from the Catalinas in the late 1990s, when construction and development brought in large numbers of new residents. The roadways expanded, with some 55,500 cars now passing along Oracle Road daily at the Ina Road intersection, according to the Arizona Department of Transportation.

One theory is that the mere presence

of people precipitated the bighorns' decline. "The sheep are notoriously sensitive to humans, especially during lambing season," said Randy Serraglio, the Southwest conservation advocate for the Center for Biological Diversity. "Hikers can cause sheep to scatter and get separated from their young."

Humans can also prevent sheep from moving freely from one part of their habitat to another in search of food and water. Ewes can miscarry when frightened by humans, Serraglio said.

In response to the declining population, the U.S. Forest Service instituted hiking and trail restrictions in the historical lambing areas in 1996. Those restrictions are still in place.

Hikers are instructed to stay on hiking trails. No off-trail hiking or bushwhacking is allowed from January through April, when the ewes give birth and nurture their newborn lambs. Dogs are also banned from lambing sites because they traumatize sheep. Research has shown that bighorns have higher heart rates when dogs accompany hikers than when hikers are alone.

"Encroachment of the urban area may have also cut off connectivity corridors that the sheep used to get from the Catalinas to other mountain ranges around the Tucson Basin," Serraglio said.

PLAYING WITH FIRE

Along with human encroachment, fire suppression and predation are thought to be responsible for the disappearance of the sheep. Historically, the mountain ranges in Arizona burned on a regular basis. Natural fires, usually set by lightning strikes, "maintain the forests by keeping the undergrowth in balance with the rest of the ecosystem," Serraglio said. "There was no one around to put the fires out."

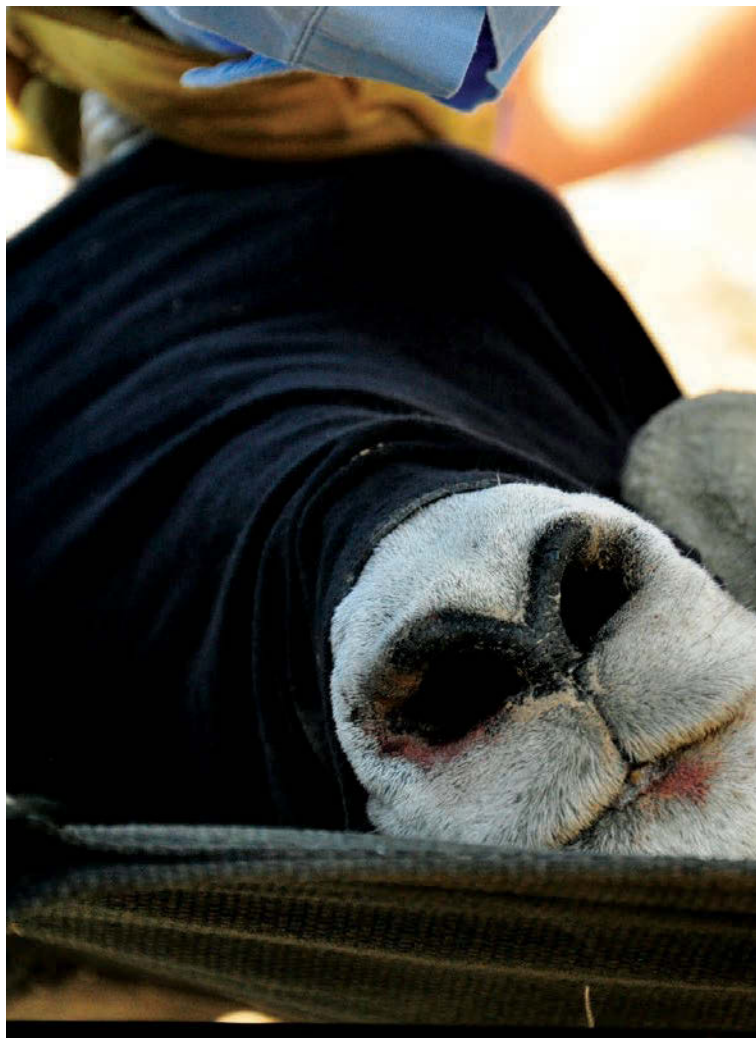
In recent decades, however, the U.S. Forest Service has routinely extinguished forest fires. Because of fire suppression, the undergrowth grew thicker. "The change in forest structure may have crowded out the sheep's preferred forage," Quigley said.

The dense vegetation also created hiding places for mountain lions, Quigley said. The sheep could not see the lions and were more likely to fall victim to attacks.

Conditions needed to change if the species was going to be restored to the region. "There has always been a desire to put sheep back into the Catalinas," said Joe Sacco, a field supervisor for Arizona Game and Fish.

After two large fires in the Pusch Ridge Wilderness Area — the Bullock Fire in 2002 and the Aspen Fire in 2003 — the habitat again became suitable for bighorn sheep. The fires reduced the opportunity for mountain lions to prey on sheep and also increased the grasses, forbs and shrubs like jojoba and fairy duster that sheep eat, Serraglio said.

The U.S. Forest Service is exploring a new policy to allow some of the natural fires in sheep country to burn — as long as they do not threaten human life or property. Prescribed burns will not only help maintain better conditions for sheep but will also re-establish a healthy ecosystem naturally driven by fire.



A captured bighorn is processed at a staging area in the Imperial National Wildlife Refuge, north of Yuma, Ariz. The captured animals are blindfolded, then given oxygen and an intravenous drip to offset the effects of stress.

FORMING A COALITION

Typically, Arizona Game and Fish uses an accumulation of biological data to manage wildlife. The agency sometimes consults with conservation organizations and holds public hearings to solicit community input.

With the bighorn translocation, however, the agency wanted to implement creative solutions to some of the existing issues, particularly management of fire and predation by mountain lions. "We knew this project was going to be controversial and wanted broad support from the community," Sacco said.

The Catalina Bighorn Advisory Committee was formed to bring to the table many diverse voices interested in public lands and a healthy wildlife population. Representatives from the Wilderness Society, Arizona Wilderness Coalition, Center for Biological Diversity, Sky Island Alliance and Arizona Bighorn Sheep Society joined the committee. The members work closely with Arizona Game and Fish and the U.S. Forest Service in making decisions about translocating the bighorns to the Catalina Mountains.

Participating on the advisory committee created an opportunity for the conservation community to work hand in



LEFT: A bighorn is carried to a staging area in the Imperial National Wildlife Refuge for a health check. CENTER: A helicopter takes captured bighorns to a staging area before their relocation to the Catalinas. RIGHT: A satellite transmitter on a collar will relay a sheep's location even in deep canyons.

hand with Arizona Game and Fish. In the past, Sacco said, the agency did not always have a good working relationship with some environmental groups.

The Wilderness Society was interested in restoring a population of desert bighorn sheep “to where they rightfully belonged, within the context of a larger restoration project for the mountain range as a whole,” Quigley said.

Forming a committee could be a good model not only for the success of the bighorn project but also for wildlife restoration in the rest of the state. The high level at which the coalition influences decision-making in the restoration project is unprecedented in any wildlife management undertakings in Arizona, Quigley said.

If the advisory committee could agree on the bighorn translocation, then maybe this type of committee could again be used in other environmental restoration initiatives. “At the Center for Biological Diversity we believe every species is important,” Serraglio said, “especially in a time when species are winking out faster than they have in millions and millions of years.”

A big part of the discussion focused on protecting the sheep by managing the mountain lions. Since the initial population of reintroduced sheep was small, just 31 animals, lions hunting bighorns could disrupt the success of the project, Sacco said.

To build a viable population of sheep, mountain lions that preyed on the reintroduced bighorns would have to be removed. Some mountain lions even specialize in preying solely on sheep.

Biologists and wildlife managers at Arizona Game and Fish believe that a healthy, robust population of mountain lions lives in the Catalina Mountains. Track counts and scat analysis, plus the large number of lions taken by hunters in recent years, support this theory. White-tailed deer and javelina, the lion's primary prey, also thrive in the range, indicating that the predator population is probably large too.

“The best way to determine if a healthy number of lions exists in a region is through hunt harvest information,” said Ben Brochu, a wildlife manager for Arizona Game and Fish. Hunting mountain lions is legal in the state, and Arizona Game and Fish issues yearly tags to interested hunters.

Every hunter who kills a mountain lion is required to present that animal to Arizona Game and Fish within ten days. A

DNA sample is taken and a premolar extracted to provide an index to the population structure of lions within a given area.

The premolars collected in recent years indicate that both young and older lions have been harvested. If the population was overexploited or in trouble, then the teeth would represent mostly young animals, Brochu said.

A research study conducted in the Catalina Mountains from 2005 to 2008 collected genetic samples of mountain lions to analyze their viability. The results showed a low probability of inbreeding, Brochu said.

Mountain lions are very difficult to survey because they are secretive. Lions avoid human contact and are rarely seen. This behavior leads people to a false assumption that mountain lions are rare or even endangered.

In addition, the lions have large home ranges. Those found in the Catalinas are part of a metapopulation that roams the Catalina, Rincon, Tortolita and Galiuro ranges. Because of this enormous area, “There is no such thing as a limited or fixed mountain lion population in the Catalinas,” Brochu said.

Mountain lions reproduce more quickly than their prey. The females have litters of one to six kittens every year and a half. About 66 percent survive.

Bighorn sheep, however, are more susceptible to drops in population because of their low reproduction rate. “Ewes usually only have one lamb a year, with about a 20 to 25 percent success rate,” Sacco said. Lambs fall off cliffs, die from disease and are lost to mountain lions and other predators such as golden eagles.

The ultimate goal is for sheep and lions to coexist in a natural balance. But until the sheep population is stable, the advisory committee supports a short-term predator management protocol for mountain lions. If a mountain lion preys on bighorn sheep, a hunter will be sent in to attempt to kill the lion. Usually a mountain lion will remain in the vicinity of its kill for several days. If five days go by and the lion is not found, it won't be removed. A mountain lion with kittens will be spared.

Arizona Game and Fish has put in place a moratorium on sport harvest of mountain lions using dogs in the Bighorn Sheep Management Area within the Pusch Ridge Wilderness. With information collected from the bighorns' GPS collars, Arizona Game and Fish will conduct a long-term research study comparing where the sheep settle with the

effect those site selections have on predation.

In order to include the opinions of the Tucson community, three public hearings were held before the sheep were released. Some of the most frequent questions were about hiking restrictions and killing mountain lions.

OTHER INITIATIVES

Translocating bighorn sheep is not a new practice. Arizona Game and Fish has been reestablishing new populations since 1957. "We've taken small subgroups from established populations and moved them to locations where sheep have lived historically and the habitat is sufficient to maintain them," Sacco said.

Sometimes these projects are not successful at first. "It takes time for the sheep to find water and get used to new habitat," Sacco said. The first historical population of bighorn sheep reestablished in Arizona was in Aravaipa Canyon, where the sheep took 18 years to reestablish.

In most translocation projects the sheep initially respond with similar behavior. The newly introduced sheep in the Catalinas were no different. "At first the sheep scattered and then hunkered down, which is what we have seen with other restoration efforts," Brochu said.

The animals remained in one area for several days. "It took time for the sheep to relax and begin to explore their new surroundings," Brochu said.

After the sheep calmed down, they started moving around more and found

FOR STATUS UPDATES

Visit the advisory committee site catalinabighornrestoration.org

suitable terrain higher up on peaks and cliffs with an open field of view.

The Arizona Desert Bighorn Sheep Society has been working with Arizona Game and Fish to reestablish desert bighorns for more than 40 years, said Brian Dolan, past president of the Arizona Desert Bighorn Sheep Society and a member of the Catalina Bighorn Advisory Committee.

One of the first translocation projects the two organizations worked on together was in Aravaipa Canyon. "The new, reintroduced population is doing quite well," Dolan said.

Overall, the translocation projects in Arizona have been about 70 percent successful.

THE RELEASE

The trailer loaded with desert bighorn sheep sat at a distance from the group of spectators at Catalina State Park. Before the release a representative from the Tohono O'odham Nation spoke privately to the sheep. He said they were ready to go into their new home.

When the gates opened, there were a few moments of silence, followed by banging as most of the sheep bolted. Others, probably unsure of what was happening, had to be pulled out by their horns. One sheep jumped out of the trailer, stopped, looked around at

the crowd of people and then skedad-dled, following the other sheep into the mountains.

The GPS monitoring collars help Arizona Game and Fish keep track of the sheep. A few days after the release, many of the sheep had shifted to two canyons farther east, an area used in the past for lambing. One ram had roamed higher into the mountains.

Another ram had not moved much since the release. A few days later that ram died, most likely from capture myopathy, which can persist for two to four weeks after release.

By the second weekend, two ewes had been killed by mountain lions. As established by the management plan set up for the project, a houndsman and a wildlife manager were sent into the area where the sheep were killed. Separately, the men found and shot the two mountain lions responsible for killing the two sheep, whose remains were found in both of the lions' stomachs.

A third ewe was killed by a mountain lion and found on Dec. 9, bringing the total mortalities up to four. The mountain lion responsible for the recent death was not removed because snow and ice prevented the hunter's dogs from picking up a scent.

The rest of the sheep have begun moving into habitat where mountain lions are less likely to prey on them.

The plans for reestablishing a viable herd remain in place. Arizona Game and Fish intends to capture about 30 sheep in 2014 and another 30 in 2015 for release into the Catalinas.



Two relocated bighorn sheep set off into the mountains after their release in Catalina State Park. The sheep face many challenges. Disease and predation by mountain lions can wipe out a small herd in just a few weeks.

Beyond Infinity

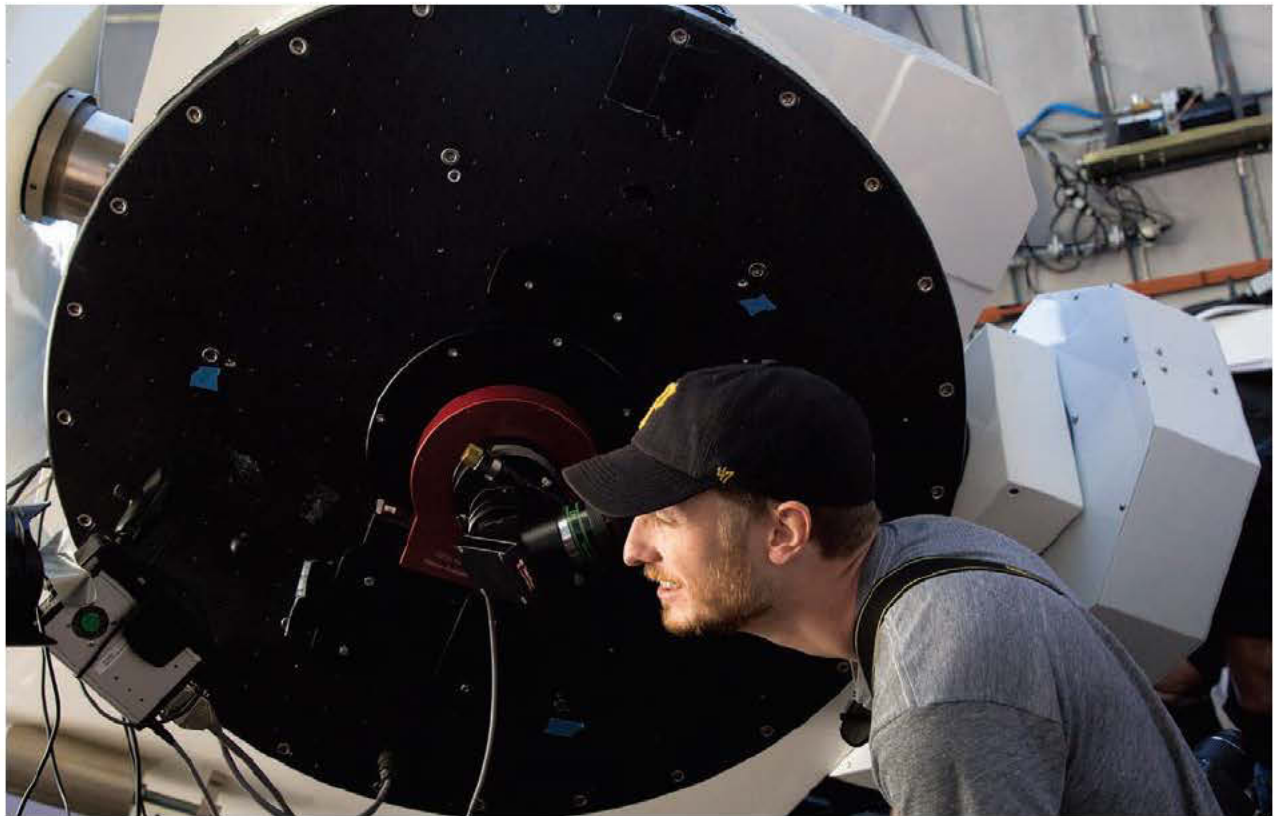


PHOTOGRAPH BY COREY RAMIREZ-POINDEXTER

ABOVE: An airplane streaks across the sky past the geodesic dome atop Mount Lemmon, which was originally developed by the U.S. Air Force as a radar tracking facility. ABOVE RIGHT: Technicolor sunsets are photographers' favorites during the SkyCenter's popular SkyNights program.

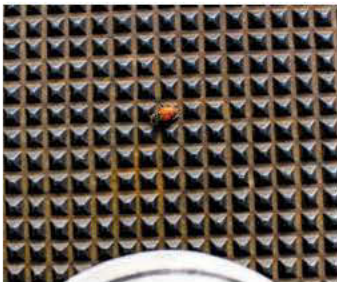


PHOTOGRAPH BY SYDNE LEMIEUX



PHOTOGRAPH BY NOELLE HARO-GOMEZ

Jason Davis, a University of Arizona graduate student, looks through the 32-inch Schulman Telescope at the Mt. Lemmon SkyCenter.



PHOTOGRAPH BY TANNER CLINCH



PHOTOGRAPH BY NOELLE HARO-GOMEZ



PHOTOGRAPH BY SUSAN E. SWANBERG

LEFT: As summer shifts toward winter, ladybugs invade an observatory, looking for a roost. MIDDLE AND RIGHT: Herpetologist Cecil Schwalbe shows UA graduate student Maya Kapoor a greater short-horned lizard, which is one of two lizards in Arizona that gives birth to live young.

A Rendezvous with the Stars



PHOTOGRAPH BY JASON DAVIS

The Earth's rotation can be seen in this time-lapse photograph of star trails captured from the summit of Mount Lemmon.

The View from the Top of Mount Lemmon

By Michaela Kane

THE RIDE UP

I was yawning in a futile attempt to get my ears to pop as we rounded yet another curve. The white van was making its way up Mount Lemmon, carrying a group of science journalism students to the University of Arizona's SkyCenter for an evening of stargazing. As we wound our way up the mountain, the view changed with each life zone we passed through, making it seem as if we had traveled farther than a few miles north of Tucson.

The Catalina Highway twists up Mount Lemmon, at 9,175 feet the highest peak in the Santa Catalina Mountains. The Catalinas are one of the sky islands. These mountains poke up like islands from the surrounding desert and grasslands.

Life zones change with elevation. In an hour we drove from the desert up through grasslands, chaparral and woodlands into coniferous forests—much like the changes in vegetation you'd see if you drove from Arizona to Canada.

At our first stop, Molino Basin Campground, we observed oaks scattered on the south-facing slopes and denser oak woodlands on the north side. Cecil Schwalbe, an ecologist emeritus with the U.S. Geological Survey, explained how climate change affects the oaks. "As temperatures rise and rainfall drops," he said, "the trees must move uphill over time in order to thrive."

We wandered around, our cameras taking in the shapes of the mountains and the array of plants and trees.

As we continued up the mountain,



PHOTOGRAPH BY AKRAM KATEREGGA

The Catalina Highway twists up Mount Lemmon, taking drivers from desert to coniferous forest in about an hour.

huge pillars of stone came into view. "They were shaped by the wind," Schwalbe said.

At the overlook above the San Pedro River Valley, huge pine trees gave the impression that we were near Flagstaff rather than Tucson.

Journalism senior Danielle Herington spotted a greater short-horned lizard. Schwalbe said it's one of the two horned lizards in Arizona that gives birth to live young. Cameras snapped as the reptile became an instant celebrity.

Our final stop on the life zone tour was the Mt. Lemmon Ski Valley, the southernmost ski area in the continental United State. The small ski lift stood idle, surrounded by white-trunked aspens just beginning to turn gold with autumn's approach.

The sign for the Mt. Lemmon SkyCenter announced that we were close to our destination.

"I love this," said geoscience senior Sydnie LeMieux. "I think it's great that we really get a hands-on experience with the science."

ATOP THE MOUNTAIN

"Ask questions. Interrupt me."

Keith Schlottman, a program leader at the Mt. Lemmon SkyCenter, told us not to worry about cutting him off mid-sentence as he introduced us to the white-domed telescopes atop the mountain. One is operated remotely by astronomers in South Korea. Two others are occupied by the Catalina Sky Survey, which searches for asteroids and comets. An old radar building once housed airmen scanning for bombers and missiles during the Cold War.

Our mission was to look at stars and other celestial objects through the Schulman telescope. Its 32-inch mirror makes it the largest telescope available for public viewing in Arizona.

Weighing about 5,000 pounds and standing 12 feet high, the telescope filled the center of the SkyCenter. Schlottman explained the history of the telescope while another program leader, Eric Shuman, typed commands on a computer.

Suddenly the dome and telescope began to move, making me feel as if I were spinning without moving my feet.

One by one, we pressed our faces to the telescope's eyepiece, looking into space at the star Vega and then Venus, Mercury and Saturn.

"You learn about the planets when you're a kid," said Maya Kapoor, a graduate student in creative writing.



PHOTOGRAPH BY PETIMAT DUDURKAEVA

Shadows cast on a white building at sunset are blue, not black, because of the scattering of light from the sky. Watching the sunset is part of the SkyNights program at the Mt. Lemmon SkyCenter.

Our final stop on the life zone tour was the Mt. Lemmon Ski Valley, the southernmost ski area in the continental United States.

"But actually seeing them is pretty neat."

SUNSETS AND SHADOWS

Partway through a light meal in the nearby Learning Center, we raced out of the warm building to take pictures of the setting sun. But first, Shuman directed our attention to the shadows we cast on a white building behind us. They were blue rather than black. Shuman said the shadows appeared blue against the white backdrop because of the scattering of light from the sky.

As the sun sank below the horizon, we calibrated our binoculars for a better view of the disappearing star, hoping to catch a glimpse of the green flash.

A few of us saw the fleeting optical phenomenon.

SHUTTERS AND STARS

Our visit culminated with a return to the SkyCenter. The only light we had to

guide us back to the telescopes came from the small flashlights we were given. The red beams scattered across the ground as we set up tripods or ventured back inside the observatory.

Some of us tried our hand at taking pictures of the Milky Way and other stars in the black sky. Guided by journalism graduate student Jason Davis, we pointed our cameras toward the sky and adjusted the speed and time for long exposures.

For the next hour, we clicked cameras or went into the observatory, taking in the plethora of stars. Schlottman and Shulman played quiet music while finding various celestial objects in the telescope for us to admire.

After two hours of stargazing, we piled back in the van and headed down the mountain. The ride back to Tucson was much quieter than the journey up.

I yawned one more time as we returned to campus, finally getting my ears to pop.

Earth's Carbon Budget in Soils

By Kathleen Compton

Rebecca Lybrand uses a large funnel to pour a pale yellow fluid with the consistency of warm honey from a beaker into a graduated cylinder. Lybrand is measuring the density of SPT, a nontoxic fluid she uses in her soils experiments to separate different types of carbon.

For her experiments to work, Lybrand must let water evaporate out of the SPT until it is a density of 1.65. Today, she reads only 1.4. Water, by comparison, has a density of 1.

Lybrand is a doctoral candidate in the University of Arizona's Soil, Water and Environmental Science Department and a member of the Jemez-Catalina Critical Zone Observatory (CZO). This consortium of scientists is funded by the National Science Foundation to study the critical zone in the Santa Catalina Mountains north of Tucson and the Jemez River Basin in the Valles Caldera National Preserve in New Mexico.

"Earth's critical zone spans from the top of the canopy all the way down to the actively cycled groundwater," says Julia Perdrial, an assistant professor at the University of Vermont who was a postdoctoral researcher for the Jemez-Catalina CZO. In the critical zone, rock, water, air, sunlight and soils interact. "You can think about it as the zone of life," Perdrial says.

Lybrand, Perdrial and other members of the Jemez-Catalina CZO study how carbon is trapped in the soils of the Catalinas. When in the atmosphere, carbon is mostly present as carbon dioxide, a greenhouse gas. Forests, like those found at high elevations in the Catali-



PHOTOGRAPH BY MARY RINKER

As the climate warms, desert cactuses like this prickly pear are starting to grow at higher elevations in the Santa Catalina Mountains just north of Tucson.

nas, take carbon from the atmosphere and store it in their soils. With climate projections indicating a hotter and dryer southwestern United States, high-elevation forests are likely to shrink in size.

Globally, forests stockpile carbon. "These are the sites storing the most carbon for the longest amount of time," Lybrand says. "We don't know as soil scientists what's going to happen if there is a change in the dominant vegetation cover. Is the carbon cycling going to change?"

Lybrand and other CZO scientists are working to document the current soil processes by studying the three type of carbon in soils—free, occluded, and mineral—and how that carbon move etween atmosphere, soil and water.

CARBON IN THE SOIL

Before they can study complex soil processes, soil scientists have to know the types and amount of carbon in the soil. Like a recipe, the type of soil and how much carbon it contains depend on the ingredients. Altering the ingredients,



PHOTOGRAPH BY KATHLEEN COMPTON

Soil samples from the Santa Catalina Mountains await analysis. Researchers will separate three types of carbon from each sample to study how the type and amount of carbon changes between the desert scrub at low elevations and the mixed conifer forests at higher elevations.

such as the rock type or amount of rainfall, changes the recipe and results in different soils, different life forms and a different distribution of carbon. The soils of the desert scrubland in the Catalina foothills and the mixed conifer forest on top of Mount Lemmon are environmental products of different recipes.

Lybrand digs soil pits all across the Catalina Mountains to classify the different types of soils and collect soil

samples from different environments. Her samples range from the desert scrub at low elevations near Biosphere 2 to the mixed conifer forest near Marshall Gulch at the top of the Catalinas.

Back in the lab, Lybrand mixes her soil samples into the dense SPT liquid and conducts a density separation experiment. Free carbon floats to the top. Mostly pine needles and leaf litter, free carbon is the crunching sound under your feet on an autumn day. Free carbon earns its name because it cycles quickly. Microbes can eat it and break it down, and it is easily flushed out of the soil system by streams.

Next, Lybrand breaks up the soil aggregates, or soil grains that are stuck together, by vibrating her soil samples. This method, called sonication, releases the carbon trapped in the aggregates. “Since this carbon is stored within the aggregates, microbes can’t get to it to break it down, so it’s a very stable source of carbon.”

This carbon is called the occluded fraction. Much of it is in the form of charcoal, the trapped remains of past forest fires.

The last carbon fraction, called the mineral fraction, comes from the minerals in the rock on which the soil sits, as well as from windblown dust.

Lybrand’s study highlights the differences between desert and forest soils. “In the desert sites, there’s not very much carbon there at all, and it cycles very quickly,” she says. “But the mixed conifer site was really nice. We have slower cycling carbon, a higher amount of the occluded fraction, especially in terms of the charcoal, and the carbon was older.”

In the forest environments, soils contain more carbon and store it for a long time. “This is really emphasizing the importance of our forests,” Lybrand says. Her findings demonstrate that forest environments are better than desert environments at taking carbon out of the air and trapping it in the soils. In a way, forests are an efficient carbon sequestration system.

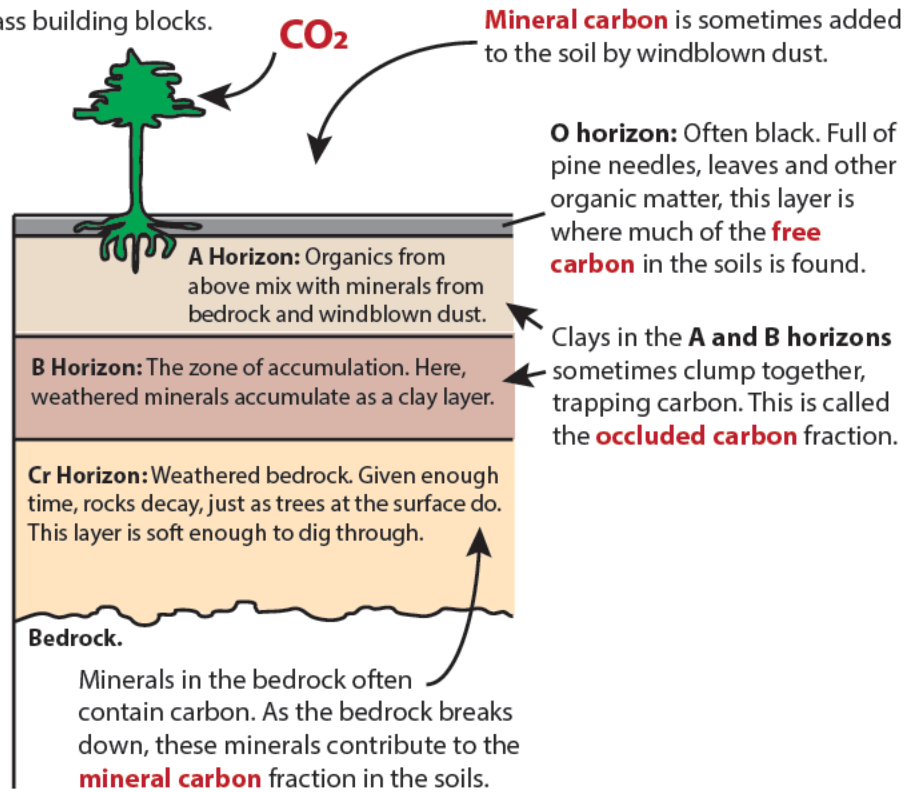
HOW CARBON MOVES

From year to year, the amount of carbon on Earth remains the same, so the amount going into the soil and the amount coming out has to balance over time. “The question is where

The Anatomy of Soil: Where is the carbon?

Soils are much more than just dirt. Soils comprise distinct layers, or horizons, which can reveal information about climate, vegetation and carbon storage.

Trees take up **CO₂** from the atmosphere and convert it to forms of **carbon** that become biomass building blocks.



SOURCES

Rebecca Lybrand, doctoral candidate: Soil, Water and Environmental Sciences, University of Arizona

Julia Perdrial, assistant professor: Department of Geology, University of Vermont

Caitlin Orem, doctoral candidate: Department of Geosciences, University of Arizona

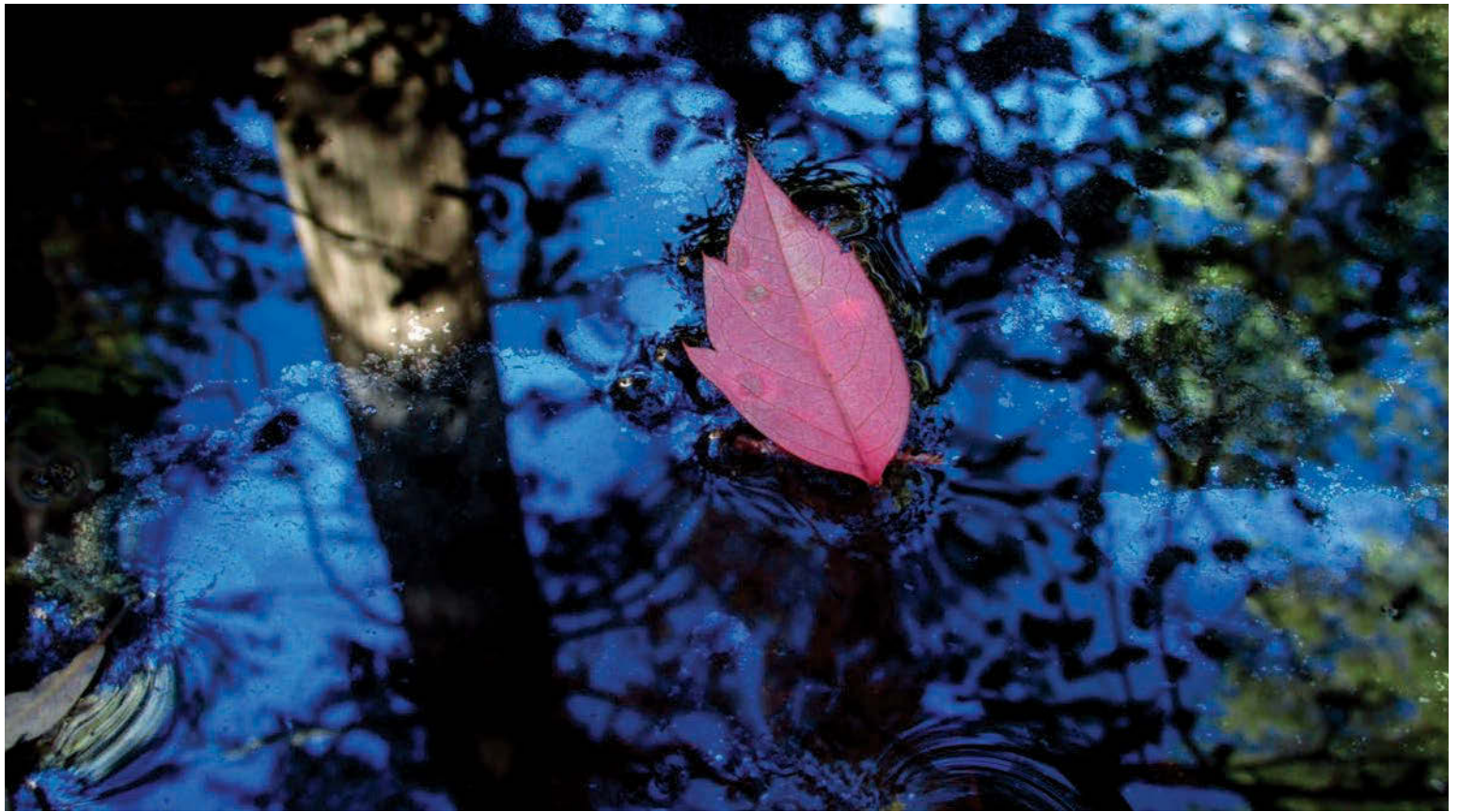
© 2013 Kathleen Compton

it is right now and where it moves,” Perdrial says. Like carbon accountants, Perdrial and Lybrand measure where carbon goes and how fast it’s escaping from soils or being saved.

For the Earth, the soils are the savings account for carbon. “Soils are amazing because they actually store more carbon on a global scale than the atmosphere,” Lybrand says.

There is about 800 gigatons of carbon in the atmosphere, but soils store about 2,300 gigatons — nearly three times as much as the atmosphere. “So the soils play an important role in this entire carbon story,” Perdrial says. “If all that carbon that’s right now in the soils goes into the atmosphere, it would be a catastrophe.”

In the atmosphere, carbon exists as carbon dioxide, a greenhouse gas that is contributing to global climate change. During photosynthesis, forests take carbon dioxide from the



PHOTOGRAPHS BY MARY RINKER

ABOVE: Streams and ground water help flush carbon out of forest soils. OPPOSITE: In the Southwest, forests are few and far between, typically confined to the top of mountain ranges. Scientists expect climate change to shrink these environments, such as the coniferous forest at the top of the Catalinas.

atmosphere and store it as biomass. When they decay, part of this carbon is stored in the soil, either as free carbon or incorporated into soil aggregates as occluded carbon.

Scientists with the Jemez-Catalina CZO have been working to measure the carbon budget—how much carbon is taken up by plants via photosynthesis and stored in the soil and as biomass. Huge amounts of carbon are coming into the forest soil systems. “It’s gigantic,” Perdrial says. Between 3,000 and 4,000 kilograms of carbon per hectare is taken up by photosynthesis and stored in biomass and soils every year.

Since there is so much carbon coming into the system, “we expected that a lot was coming out through the streams and ground water,” Perdrial says. “But there is almost nothing leaving these systems.” At most, only 50 kilograms of carbon per hectare leaves the system via water transport every year. “For us, this was really interesting,” she says.

So where does the carbon go? Even though there are large amounts of carbon in the soil, there’s nowhere near as much as would be expected based on the accounting of photosynthesis in and transport out by streams. “The hypothesis is that we lose carbon from these systems through wildfires,” Perdrial says.

Big fires release large amounts of carbon back into the atmosphere and into streams. Like a carbon shopping spree, forest fires flush carbon out of the soil savings account.

FORESTS UNDER THREAT

What’s going to happen to these important savings accounts in the future?

As the Earth’s climate changes, the Southwest is likely to become even drier. Drought-like conditions and a history of fire suppression have led to larger, more severe fires that kill the forests and slow down or stop the photosynthesis uptake of carbon. “The entire Southwest is hammered with wildfires with increasing severity and abundance,” Perdrial says.

And it’s not just the increasing number and severity of fires that is threatening the forests. A drier climate means “desert environments are becoming competitive at slightly higher elevations,” Lybrand says.

In places like the Southwest, where forests are already small and at the top of the mountain ranges, scientists expect to see those environments shrink in size. Desert ecosystems are less efficient in capturing carbon from the atmosphere, so the effect of shrinking forests is a shrinking savings account for carbon.

As large, severe fires become more common and forest ecosystems shrink, there will, at the very least, be less carbon absorbed by plants and stored in the soils. But what will happen to the carbon already in the soils is still an unknown. “Right now, I’m documenting what’s happening in this environment,” Lybrand says. She hopes her findings will provide a baseline for future comparison studies.

Many aspects of climate change and carbon cycling are still not known, but one thing is clear: In addition to thinking about carbon in the atmosphere, scientists also have to consider the soils.



