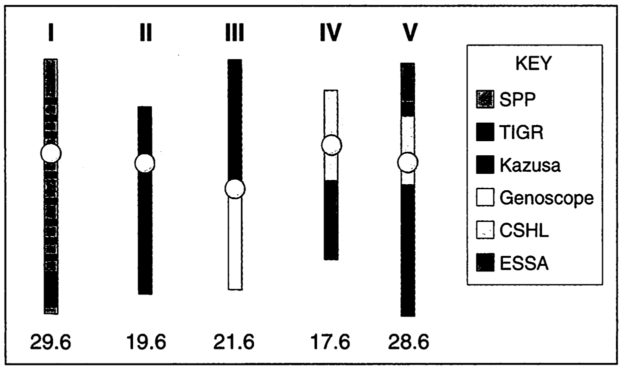
other organisms," she notes.

Already, biologists are concentrating on the 8000 or so newly discovered genes that have no known function or matches in other genomes. North Carolina's Dangl, for example, has identified 10 genes that seem to be activated by infection or insect attack—genes that had eluded discovery by his and a dozen other labs for the past 15 years. Now, thanks to ongoing efforts by Ecker and others to create a mutant strain of *Arabidopsis* for each gene, it may soon be possible to work out the function of each of those genes.

A few biologists are also trying to trace the evolution of plant biochemical pathways by looking for the genes involved. By scanning the existing genomic data, for instance, Anthony Bleecker of the University of Wisconsin, Madison, and his colleagues discovered that an *Arabidopsis* ethylene receptor gene is very similar to one in the cyanobacterium *Synechocystis*, a simple photosynthesizing microbe. Because this microbe is thought to be close kin to the microbe that was incorporated into ancient plant cells and became the chloroplast, the similarity suggests that the *Arabidopsis* gene migrated from the chloroplast genome into the *Arabidopsis* genome and subsequently evolved a new role in controlling plant development. "It gives us an idea about how plants got to be so different [from animals]," Meyerowitz explains. "All the sudden we have insight into how things came to be."



Who did what. Colors indicate how the sequencing teams—Stanford/University of Pennsylvania/USDA–University of California, Berkeley (SPP); The Institute for Genomic Research (TIGR); Kazusa DNA Research Institute in Chiba, Japan; Genoscope in Evry, France; Cold Spring Harbor Laboratory/Washington University (CSHL); and the European Union Consortium (ESSA)—divided up the sequencing of *Arabidopsis*'s five chromosomes and 117 megabases.

Not bad for a plant that few biologists had heard of a decade ago. Given these and other insights, plant biologists are clamoring for the sequence—but finishing it by the end of the year, when a paper is due at *Nature* and a party is planned at Cold Spring Harbor Lab, is going to be a stretch. "We're close, but we're not done," concedes Michael Bevan, a plant biochemist at the John Innes Centre in Norwich, U.K. Meanwhile, in Japan, the United States, and Europe, computers and sequencing machines are running full tilt, polishing off the last pieces and filling in gaps (see graph at left). At the same time, two of the labs are feverishly scanning the entire genome, predicting and classifying genes. It's a frantic pace, involving scores of people—quite a contrast to the life the Somervilles were enjoying when they first envisioned this plant's future 23 years ago in Paris.

—**ELIZABETH PENNISI**

ECOSYSTEM RECOVERY

Ghost Towns Tell Tales of Ecological Boom and Bust

Scarred desert ecosystems are recovering at the sites of some abandoned boomtowns, but are slow to heal at others. Soil age appears to be the key difference

The greatest mining scandal in U.S. history struck Greenwater, California, in 1906. A miner discovered copper in Death Valley's Black Mountains—and within months, this boomtown exploded with saloons, shacks, and 2000 treasure hunters. "Greenwater is destined to be the richest mineral-producing city on the whole globe," declared one flyer.

By 1908, the town was empty.

Greenwater turned out to be more bust than boom. Only flecks of low-grade copper graced the mountains, while swindlers made a fortune selling shares in nonexistent mines. But today, Greenwater is finally paying off—with ecological data. Robert Webb, a hydrologist with the U.S. Geological Survey (USGS) in Tucson, Arizona, is studying eight Mojave Desert ghost towns, including Greenwater, to see how their long-abandoned soils have recovered from the pounding they took during the mining boom. Sprawling creosote, burrobush, and desert sage are reclaiming these boomtown sites, turning them into outdoor labs for desert recovery—and challenging popular ecology theory along the way.

For at least 25 years, ecologists have described the parched desert landscape as "easily scarred and slowly healed." Conventional wisdom once held that disturbed desert soils never fully recover. Without question, the landmarks are stark—in parts of the central Mojave, for instance, tank tracks left from World War II training exercises still gouge parts of the desert floor. But, popular wisdom aside, Webb and other scientists are also witnessing desert recovery.

In Webb's study, disturbed soils at some ghost town sites have rebounded, defiantly blooming in less than a century—while others sport much sparser plant populations. By comparing the towns' geology and history, Webb is uncovering features, such as soil age, that determine rates of plant recovery. The emerging data could help the managers of the Mojave's six military bases and four national park areas make ecologically sound management decisions. "All landscape is not created equal," Webb says. "If you have to route a road, if you have to run tanks over it, let's use our scientific sense about how to do it."

Resource managers say insight from the Mojave is badly needed. "There's a lot of pressure on park managers to make quick decisions, and we're starving to find immediate answers to problems," says vegetation specialist Jane Rodgers of Joshua Tree National Park, which spans parts of the Mojave and Colorado deserts. "If we're looking at where to put a new campground, for instance, this information could be really useful." The ghost towns also offer a rare look at desert recovery in action, adds Joseph

Fragile beauty. Death Valley is fragile in parts, resilient in others.

CREDIT: (TOP) ADAPTED FROM TIGR, WITH INPUT FROM J. ECKER; C. AURNESS/CORBIS

Ecologists Spar Over Population Counts Of Threatened Desert Tortoise

With a size that rivals Scotland, you'd think the Mojave Desert had space for everyone. But this arid neighborhood packs a lot of personalities—with six military bases, four national park areas, sprawling suburbanites, and off-road riders, there's considerable jostling for elbow room. One unassuming neighbor, in particular, has been the focus of many real estate fights: the desert tortoise. And the shell-slinging is starting again.

In 1990, the Mojave tortoise was listed as a "threatened" species under the U.S. Endangered Species Act, a designation that has put it in the way of church leaders, military managers, and utility officials. All have had plans delayed—or blocked—in developing desert areas that might interfere with the animal or its habitat. Now, a controversial study in the October issue of *Conservation Biology* claims the tortoise's threatened status is based on inaccurate population counts. In the 1991–96 study, ecologist Jerome Freilich, now at the Nature Conservancy in Lander, Wyoming, and volunteers did weekly spring surveys of captured and marked tortoises in a 2.6-kilometer-square plot inside the Mojave's Joshua Tree National Park. Using a mathematical model to estimate tortoise populations, they found hugely varying tortoise numbers—between 43 and 97 animals—in different years, depending on rainfall. But the average estimate came out to 67 adult tortoises at the site—three times more than reported in a 1978 survey of the same spot.

Time to hide. Was the Mojave tortoise undercounted because it hides during drought years?

Tortoises, Freilich explains, hide in underground burrows during drought years. And that may have biased the studies used by the U.S. Fish and Wildlife Service (FWS) to list the tortoise, because they were conducted during a severe drought in the 1980s. "In some of their data points, there were hardly any tortoises," Freilich says. "Were they truly gone, or were they just waiting for that nice rain in 1991? And did Fish and Wildlife go the extra distance to check this data?"

Faster than a fleeting desert sunset, Freilich's study is drawing hostile fire. "Drought is part of the desert," responds Kristin Berry, an ecologist with the U.S. Geological Survey who did some of the primary studies Freilich casts doubt on. "Some sampling is done in wet years, some in dry, and the differences are taken into account." She adds that Freilich's paper contains "major flaws." Among them: Freilich incorrectly described the 1978 survey at the Joshua site as a standard 60-day survey; in fact, says Berry, the survey was done on just 25 days, scattered from spring to fall.

Freilich stops short of saying the tortoise's "threatened" status is wrong. Instead, he argues that a newer survey method, called distance sampling, should be used to verify the animal's numbers in the Mojave. With this technique, researchers map tortoises to given points and then estimate populations based on the animals' distribution. But Berry cautions that distance sampling is costly and may work well only in areas with high tortoise numbers.

The tortoise flap doesn't surprise FWS biologist Ray Bransfield. "If you're in the tortoise community, there's a lot of sniping about this or that person's data," says Bransfield. "Sometimes it's hard to be in the same room with these researchers." At least the tortoises are agreeable, he adds: "These animals have a lot of charisma." **–K.B.**

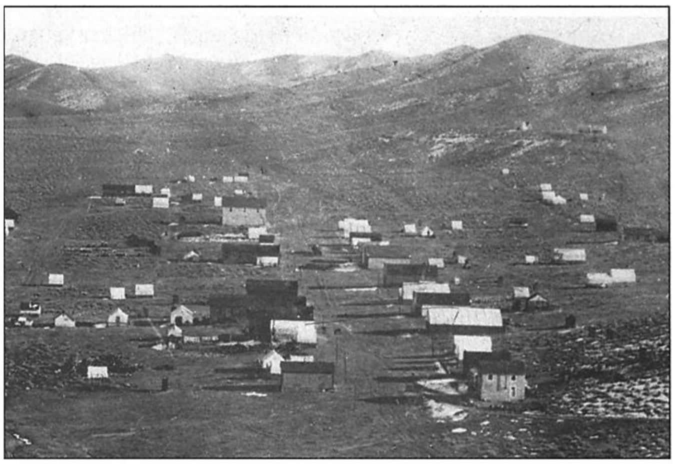
McAuliffe, research director at the Desert Botanical Garden in Phoenix, Arizona. In more forgiving locations, abandoned towns have often been grazed by cattle or transformed by developers. Not so these sites in Death Valley, which sit empty and baking in the harsh sun. "This is one unique set of records," McAuliffe says.

Ghostly images

The smallest of four North American deserts, the Mojave is a mercurial place. A mix of shadowy mountains and flat basins, the desert sits mostly in California, although its borders creep into Nevada and Arizona. Low valleys in the Mojave are very dry, as surrounding mountains block the moist Pacific air. The mountains of Death Valley, for instance, exist on just cups of rain, about 200 millimeters a year. But this is no wasteland. Creosote bushes cloak much of the rocky valley in evergreen, and in spring, native primrose, daisies, and sagebrush can splash color everywhere.

There's another prominent feature on the landscape: people. The early mining boom set a frenetic pace for desert settlement, and it hasn't slowed yet. Today, the Mojave hosts military bases such as Twentynine Palms, China Lake, and Fort Irwin, where troops simulate desert warfare. Wilderness areas include Death Valley National Park and the Mojave National Preserve, among others. And in between, gas pipelines, off-road vehicles, and homeowners stake their claims on the land. "This caldron of the desert is full of values and conflicts," remarks geographer Leonard Gaydos of NASA's Ames Research Center in Moffett Field, California.

As the Mojave has grown more crowded, conservation has become a hot-button issue. "At one time, these military installations were in the middle of nowhere," notes Ruth Sparks, a resource manager at Fort Irwin. "Now there are people living right next door, and they want to know how we're going to protect the environment." The National Park Service, too, has come under pressure to preserve ecosystems inside park boundaries (*Science*, 7 April, p. 34). In the Mojave, the question



Recovering from an insult. Skidoo scarred the land during its boom years from 1906 to 1917, but vegetation is rebounding on its young soil.

CREDITS: (TOP TO BOTTOM) J. FREILICH/THE NATURE CONSERVANCY; USGS is how. What, exactly, scars the desert landscape? And just how long do plant populations need to recover from a new road or a rolling tank?

Webb of USGS has long wondered the same thing. In the 1970s, while studying off-road vehicle tracks in the Mojave, he decided to hunt for evidence of desert comebacks at old Mojave sites that had been heavily used and then abandoned. He found a 1961 paper in *Science* by Philip Wells (8 September 1961, p. 670), who had mapped the plants poking out of the ground in a former boomtown, Wahmonie, Nevada. Wells reported that a markedly new crop of pioneer plants, from bunch grass to weedy shrubs, dominated the Nevada site just decades after the boomtown's bustle had faded away. Inspired, Webb searched for other ghost town sites to study.

He didn't have to look far. On the west side of Death Valley, the Panamint Range hosted a successful boomtown, Skidoo, from 1906 to 1917. At lower elevations on the east side, the Black Mountains housed Greenwater and other towns. Little trace of the towns remained by the 1970s, but old plat maps and town photos revealed their layout and vegetation during the boom years, 7 decades earlier. Webb surveyed the plants and studied the soil on the town sites.

Sure enough, the disturbed sites looked starkly different than before the mining boom. A new crop of colonizers—fast-breeding, short-lived plants, like cheesebush—had begun moving in. The greenery was patchy, and long-lived plants like creosote, which had dominated the predisturbance landscape, were sparse. But what really interested Webb were differences between the sites. The Skidoo sites showed the stirrings of plant succession, with short-lived invaders giving way to a mix of species, including their longer lived peers. By comparison, the Greenwater site had barely begun recovering. Some 70 years after the town had collapsed, only the first colonizing plants peeked aboveground. Maybe Skidoo was coming back. Maybe Greenwater was damaged for good. But why?

Soil strategy

After 2 decades—and three return trips to the ghost towns—Webb has found some answers. Today, Skidoo has recovered almost completely. Spiny hop-sage shrub dominates the site, with ephedra and other predisturbance shrubs recolonizing their old haunt. From the air, Webb says, you'd never know a boomtown once sat at Skidoo. Greenwater hasn't fared so well. The total amount of green cover at the site is approaching that of its preboomtown days, but the mix of species is very different—almost completely short-lived, early invaders like cheesebush and Cooper's goldenbush. The changes in vegetation still mark a clear outline of the old Greenwater town site.

All these differences, Webb says, come down to one basic factor: soil age. Greenwater's soil is at least 100,000 years old, according to calculations of soil formation rates in the region. By contrast, Skidoo's soil is less than 4000 years old, Webb says. Skidoo was built on a debris flow—a sludgy avalanche of sediment that had raced down the rainy mountainside and then settled in the dry canyon below. When the boomtown hit, this relatively fresh soil had little structure and an early cast of colonizing plants. "Young surfaces have vegetation in an early successional stage," explains Webb. "And it's much quicker to get back to that stage than to the types of vegetation on older surfaces."

Based on the abandoned boomtowns, Webb estimates that after moderate disturbance, young Mojave soils can grow a new layer of perennial cover in an average of 80 years—but the original mix of plant species can take several millennia to return, if they return at all. That may seem slow, but it's comparable to recovery timing in other ecosystems, like old-growth forests leveled by logging, Webb says.

No wasteland. Creosote bushes and spring flowers splash color in Death Valley, belying its reputation as a lifeless desert.

CREDIT: USGS

The relatively quick recolonization of young desert soils makes sense to ecologist Jayne Belnap of USGS in Moab, Utah. "In the desert, the geomorphic age of soil means a whole lot," Belnap says. For one, she notes, young desert soils have a coarse, gravelly texture that soaks up and holds water better than aged soils, which have grown fine or become clogged with clay. McAuliffe—who has found a similar recolonization of young soils at a military range in the Sonoran Desert—adds that the driest soils pack silt and clay beneath a stony top. "When tanks roll over these desert pavements, the scars essentially last forever," McAuliffe says.

Such vastly different soils suggest that the desert is not one simple, delicate landscape. "The desert is a patchwork of soils, and recovery may largely revolve around the geomorphic age of the surface below you," Webb says. For resource managers in the Mojave, he adds, the conclusion is simple: If you have to disturb the desert, go for young soil sites.

That strategy will come in handy, predicts Jennifer Haley, a resource manager at Lake Mead National Recreation Area. "We often have to choose which areas to develop," Haley says, "and this information could help us make better choices." And the effects of bad decisions linger, she adds. Fifty years ago, while building the Hoover Dam, crews carved a two-track road at Lake Mead. "Even now, we only have one or two plants at the site," Haley says. "They just don't come back." Still, turning such basic soil science into decisions about desert use is tough, cautions Dawn Lawson, a Navy natural resources specialist who works on Mojave military bases. "Can you develop a training scenario that meets military standards, incorporates federal regulations, and takes into account the age of the soil?" Lawson asks. "It's possible—but not always easy."

Now, with the Mojave ghost stories in hand, scientists hope to study other desert soils to see whether the plant recovery trends hold up. "We've got to make the leap from site-specific findings to the broader landscape, with models, to make the information more practical," says Belnap. Jeff Herrick, a soil scientist at the U.S. Department of Agriculture's Jornada Experimental Range in Las Cruces, New Mexico, adds that it's important to find out whether the most fragile, or "easily scarred," landscapes are also the slowest to heal. Resistance to damage and resilience afterward are different challenges for a patch of soil.

Researchers also need to define "recovery" carefully, Herrick adds. There's a big difference between an emerging cover of green and the return of something close to the original mix of plant species. Webb agrees. As more people move into the desert, he says, a better understanding of desert ecosystems is urgently needed. The ghosts of the past may have a lot to teach us.

–KATHRYN BROWN

Kathryn Brown is a writer in Alexandria, Virginia.