PNAS NEWS FEATURE

# Fire in the desert

Fueled by invasive grasses and climate change, desert fires are growing larger and more dangerous.

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**Native ecosystems are losing the race against invasives, with potentially dangerous consequences for desert cities like Tucson. The city's outskirts are shown here in the midst of the 2020 Bighorn Fire, which came alarmingly close to foothill homes. Image credit: Unsplash/Frankie Lopez.**

On a punishingly hot day this June in Scottsdale, AZ, construction crews cutting rebar with a grinder accidentally set the desert ablaze. What began with the shower of sparks from metal-on-metal quickly ignited the dry scrub around a development site and grew into a 2,000-acre brush fire. Called the Diamond Fire, it would rage overnight and force the evacuation of more than 1,100 people.

The northeasterly wind pushed the flames into the nearby McDowell Sonoran Preserve, a protected desert habitat and popular hiking spot. Once a postcard of native Sonoran plant species, the preserve had been covered in towering saguaro cacti and green-barked Palo Verde trees. Now, grasses crowd the landscape, offering not only ready fuel for any spark that comes along, but an increasing threat to native species.

The Sonoran isn't the only desert losing its emblematic species to worsening wildfires that are fueled by invasive grass. In the Mojave, invasive red brome, *Schismus,* and other grasses are feeding fires that threaten endangered Joshua trees and tortoises (1, 2). And in the Great Basin, a cold desert where winters are marked by heavy snow instead of monsoons, another invasive grass species, *Bromus tectorum*, or cheatgrass, is driving massive wildfires in summer and displacing the native sagebrush habitat (3). The more that fierce fires sweep through the desert, the more each landscape's ecology changes as the flames clear more open land for more grasses to move in. It's a dangerous feedback loop, says ecologist Helen Rowe at Northern Arizona University in Flagstaff. "The dynamic isn't



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**The 2,000-acre Diamond Fire charred and killed native plants, including this barrel cactus on the McDowell Sonoran Preserve. Image credit: Mary Fastiggi (McDowell Sonoran Conservancy, Scottsdale, AZ).**

that [the desert] went from no fire to fire, but that it went from smaller, low-to-moderate fires, to having this more abundant fuel load that leads to these larger fires we've been seeing," she says, adding that this means "more severe patches where the saguaros and other cactus die."

## Mass Invasion

Starting in the 1960s, invasive grasses began spreading throughout the Southwest. Today, hip-high fountain grass as well as knee-high buffelgrass and red brome blanket the McDowell Sonoran Preserve, crowding the cacti and desert trees.

Fed by dry grasses, the Diamond Fire burned larger and hotter than the occasional fires that swept through a few decades ago. Arizona's thick, green saguaros and Palo Verde trees routinely survived small fires in the past, Rowe says. Back then, the only evidence that flames had come through would be charcoal marks on fallen logs or blackened tufts of small native grasses, which didn't fuel fires as effectively as invasives.

Rowe, who is also an ecologist at the field institute of the McDowell Sonoran Conservancy, studies restoration ecology and invasive species management. She hiked the burned area of the preserve three months after the Diamond Fire this September and found the entire understory gone. Perennial shrubs were totally incinerated. The saguaros all stood black and dead. Half the Palo Verde trees had cooked to a crisp.

## Through Rivers of Gold

The idea that invading grasses might change the very nature of the desert first sprouted in ecology in the mid-1980s. It began with botanist Carla D'Antonio leaning over a burned creosote bush near the Mojave truck stop town of Barstow, CA. "That's so strange," she recalls thinking. "Why is there fire out here?"

At the time, D'Antonio was a graduate student at the University of California, Santa Barbara. She'd driven out to her advisor's field sites to assess the competitive dynamics between creosote and woolly bursage, two California native plants. Out across the desert, D'Antonio noticed a small, burned patch of scrub. She hiked over to it while looking around for a possible cause of the fire. Charred thickets of invasive red brome and cheatgrass poked up all around the site. "Bingo," she thought.

The prevailing ecological wisdom at the time was that desert ecosystems didn't change much in general, and certainly didn't burn often. Yet, here was evidence of fire. D'Antonio pored over the botany literature through the rest of her graduate and postdoc work and wrote to land managers throughout the western rangelands, looking for any documented history of recurring fires in the desert. "People had mentioned it, but finding data was very hard," she says. That's when she began to suspect that invasive plants might be changing the dynamics of the desert itself.

By 1992, D'Antonio would publish her literature review—the first comprehensive look at the effects of grass invasions across many ecosystems, including deserts (4). Alien grasses, she found, had invaded most every continent. And in places where grasses occurred, naturally or not, fire often followed. As part of that review, D'Antonio and Stanford University ecologist Peter Vitousek proposed an idea known as the grass–fire cycle: Invading grasses bring more frequent, larger, and, in some cases, hotter-burning fires, which, in turn, kill native plants that are not fire-adapted. The grasses can recover quickly after a burn, so they outcompete native vegetation.

The first invaders probably arrived in the Great Basin, Mojave, and Sonoran in the late 1800s, D'Antonio found. Some species arrived accidentally, perhaps tracked in on travelers' boots or stuck into sheep's fur. "The cowboys who ran those sheep had huge flocks of them, and they moved them over large distances in the desert," D'Antonio says. Seeds stuck to the animals or dispersed on the wind, so grasses spread fast. But grazing sheep nibbled and trampled the plants, so invaders didn't build up into fire fuel. It wasn't until the 1930s that the invasive grasses exploded when ranchers shifted to cattle, which have a more limited grazing range. Landowners and the US government intentionally planted buffelgrass as forage for the cattle. Gradually, the landscape has been shifting into grassland ever since.

## Embers Falling

Buffelgrass certainly seems to be spurring such a grass–fire cycle in the Sonoran Desert, says plant ecologist Chris McDonald, at the University of California Cooperative Extension in San Bernardino. He's led work in southern Arizona, showing that invasive buffelgrass fires burn so hot that native desert plants don't survive and are, in turn, replaced by more buffelgrass.

**In 2020, the Mojave Desert Dome Fire burned 43,273 acres and killed as many as 1.3 million Joshua trees. The fire was able to jump roads, pushed by winds and heavy dry fuels. Image credit: JT Sohr (National Park Service, Essex, CA).**

To do that work, McDonald approached wildland firefighter crews to help, setting a series of experimental burns on field plots near Tucson (5). Buffelgrass grew thick across the plots, leaving no bare ground between native plant species. McDonald laid ceramic tiles across the plots, marked with a series of chalky, waxy materials that melt at various threshold temperatures, revealing just how hot the fires burned. He found that experimental burns at midday could reach temperatures as high as 900 °C, hot enough to melt aluminum. McDonald also planted metal posts with a standard height of about 5 feet across the plots. He photographed the flame front as it approached the posts and then used the photos to estimate flame heights. The tongues of flame leapt about 15 feet into the air over the desert, he found. Most native vegetation burns significantly cooler, McDonald says, and the flames would only burn small patches, surrounded by bare ground.

The combination of higher temperatures and longer flame tongues is a recipe for ferocious brush fires, he says. Fueled by winds, embers blowing in stiflingly hot air could, for example, jump over roads and ignite grass on the other side of the highway, or hop between vegetation clumps to crawl across the desert. This is how vast acres of land can burn in a single fire, only to sprout grasses on the burn scar the following spring.

In Utah's Great Basin, experimental burning also shows how cheatgrass invades native sagebrush habitat (6). Community ecologist Sam St. Clair led experiments in 2012, burning 30-by-30-meter plots of native vegetation. St. Clair installed rodent fencing around some of the plots, to exclude the kangaroo rats, deer mice, and Great Basin pocket mice that skitter across the Utah desert at night and are voracious nocturnal seed predators. St. Clair, who is based at nearby Brigham Young University, drove out to the site periodically over the next four years to see what grew back after the experimental burns.

He found that once fires (and especially repeat burns) cleared the land, the incoming cheatgrass seeds were so numerous that they eventually overwhelmed the rodents' ability to tamp down the plant; over time the rodents left—perhaps because fewer native plants mean less cover and make the small mammals easier targets for predators (7). Then, the sagebrush meadows convert to rolling fields of cheatgrass, making tinder for the next burn.

## Storms of Flame

"Grass is integral to these fires in most cases," says Todd Esque, a desert ecologist with the US Geological Survey, based in Boulder City, NV. "You can't see a fire and not make

**Invasive red brome grass fed the massive 2020 Bush Fire near Phoenix, charring everything in the fire's wake. Image credit: Molly McCormick (Southwest Fire Science Consortium, Flagstaff, AZ).**

that connection." In his 30 years in the Sonoran and the Mojave, Esque has found brush fires to be increasingly deadly for iconic species. That portends problems for treasured ecosystems, including those in national parks.

In 1999, for example, a major fire sparked in California's Joshua Tree National Park. Eighty percent of the Joshua trees in the fire's path died immediately or succumbed within five years of burning, Esque found through annual surveys of the burned zones (8). "We were quite concerned, as was the park," he says, because Joshua tree populations recover very slowly. A single tree can take 100 years to mature, and in the meantime, faster-growing invaders can take over. Indeed, those burn sites are cheatgrass and red brome meadows today.

Luckily, the 1999 fire only affected limited zones of the park, Esque says, and many unburned areas remain. But there is growing concern that climate change will bring even warmer and drier conditions to the entire range of Joshua trees and put the park and the Mojave more generally at risk for massive fires. California legally protected the trees in 2023, requiring a permit to fell or relocate them, among other provisions. Research by Esque and others hints at similar concerns for Mojave desert tortoises, saguaro cactus in the Sonoran Desert, and sagebrush in the Great Basin (1–3, 9). "If you have successive fires, then you're going to cause the desert to be more depauperate of plant species important to all the wildlife," Esque says. "There were serious discussions… is Joshua Tree National Park going to become cheatgrass national park?"

## Near Miss for Tucson

Despoiled public lands aren't even the half of it. More and more, grass fires are creeping up to suburban doorsteps, too.

In the summer of 2020, Ben Wilder, a desert ecologist based in Tucson, watched some 120,000 acres burn from his driveway. He remembers walking out to the curb, holding a pair of binoculars at 2:00 AM on the morning of June 5, as the Bighorn Fire crawled over the summit of the Santa Catalina Mountains and rolled down the wooded foothills toward homes. A week later, in the Tonto National Forest, outside of Phoenix, the Bush Fire would consume another 193,000 acres.

"Jarring" is how Wilder describes the size and scale of Arizona's recent wildfires. And, he says, there are "a lot of questions we don't have answers to."

One of those questions: Did buffelgrass worsen the Bighorn Fire? To find out, Wilder led a 2021 case study, in which he used remote sensing data to compare the footprint of the Bighorn Fire to the locations of buffelgrass meadows around the Catalinas in 2020 (10). What he found had

terrifying implications for the city of Tucson. The grass had very nearly set off a chain reaction, which likely would have destroyed lives and property. "The Bighorn Fire," Wilder says, "was a near miss."

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On a topographic map, Wilder and his colleagues drew the borders of the Bighorn Fire. It had consumed pine and oak woodlands and chaparral from the peak of the Catalinas down to about 1,200 meters elevation. There, the flames came to a fuel break they couldn't cross, where dense mesquite and shrubbery gave way to sparser cacti and other native desert plants.

That fuel break saved Tucson, Wilder says. No homes were destroyed, and no one died. But when he mapped the extent of the buffelgrass, Wilder found that it's been climbing the mountainside. If the grass had spread just a few hundred feet higher in elevation, or if the wind had been blowing differently, the Bighorn Fire might have lit the grass and spread into the foothill communities. "It was not the worst-case scenario," Wilder says, "because the buffelgrass has not yet coalesced at that upper elevation."

Unfortunately, the worst-case scenario did come to the tropical island of Maui, HI, this past August. Invasive buffelgrass blankets the mountainsides, especially on the seasonally dry, windswept west side of the island, spreading as a weed on defunct sugar plantations and former pasture lands (11). When fire sparked in the hills above Lahaina, strong winds fanned the flames through dry buffelgrass and down into town. The dry grass and high winds, combined with aging infrastructure—for example, old power poles, homes, and hotels not built to modern fire codes—were a recipe for a runaway fire, D'Antonio says. It would become the deadliest fire in Hawaii state history, killing 100 people (12).

Indeed, the grass–fire cycle isn't limited to deserts. It can affect any ecosystem where invading grasses, dry fuels, dry temperatures, and a spark combine, says Emily Fusco, an ecologist at the University of Massachusetts, Amherst. Just how widespread is the problem? Most studies of the grass–fire cycle, Fusco says, have been limited in scale—for example, examining one grass in one park or ecosystem. In 2019, Fusco led the first large-scale analysis of the impact of invasive grasses on fire dynamics across the country. She used invasive species occurrence data to map the range of all 12 known invasive grass species across the United States and then overlaid that map with a second dataset, showing the locations, frequency, and size of wildfires since the 1980s (13).

Fusco found that areas invaded by eight grass species consistently burned more frequently than uninvaded regions. In deserts, she found that the presence of four grasses significantly correlated with more fire: buffelgrass, common Mediterranean grass (*Schismus barbatus*), cheatgrass, and medusa grass.

It's unclear what this mass invasion ultimately portends for deserts. They are already becoming grasslands and, in some cases, shifting into much patchier systems, says Mary Lata, a Forest Service fire ecologist with the Tonto National Forest, which includes 876,004 acres of Sonoran Desert, outside Phoenix, AZ.

Lata spearheaded a special full-day session at the Tenth International Fire Ecology and Management Congress, held this past December in Monterey, CA, bringing together researchers, land managers, and other stakeholders. One hope was to identify what best-management practices should look like for grass. "Do we burn it? Spray it? Do we try and get rid of these grasses?" Lata asks. "We need to figure out the responsible thing to do, and we don't have enough information."

## Waiting on the Watershed

Deserts have a grass problem—that much is clear. What to do about the invaders is murkier, Lata says, in part due to the challenge of scale. National parks with thousands of managed acres can't send a ranger out with a Weedwacker and expect to make a dent the way a homeowner might. Right now, places like the McDowell Sonoran Preserve are actively uprooting grasses in priority areas, especially along roadsides, where hot cars parked on the shoulder can set dry plants to smolder. Efforts to thin out and remove dead understory debris at trailheads are also ongoing, but the grass invasion is too far gone to prevent every fire. When sparks do fly, managers are finding ways to respond and restore in the wake of a burn.

Back near Scottsdale, Helen Rowe is doing just that by experimenting with restoration at the McDowell preserve after the Diamond Fire. She's choosing sites to plant three-year-old saguaros, which are still only about as long as a thumb, in a variety of different burned microhabitats on the landscape. Some of the cacti will be out in the open. Others will be placed under dead, charred Palo Verde trees. And still other saguaros will be planted under burned-but-resprouting, living Palo Verdes. Baby saguaros are known to survive well under trees, so-called "nurse plants," which offer shade and slow evaporation for anything growing under them. Rowe also has a few control plots where she'll plant baby saguaros in unburned parts of the park. She'll assess the cacti's growth and survival in a few months, to see which plantings perform best. "It's not a trivial thing, getting saguaros back on the landscape," Rowe says. "It can take a saguaro 40 years to grow an arm. They're slow growers, which is why people are so worried."

Preventing fires in the first place makes a lot more sense than waiting around for cacti to grow, Rowe says. She's also working with Scottsdale Community College and the Tonto National Forest to create sods that mimic the desert's naturally hard biocrust. Often called the desert's living skin, biocrust is composed of lichens, mosses, algae, and cyanobacteria growing on top of the soil. Intact biocrusts can prevent invasive seeds from penetrating the soil and germinating, but sheep and cattle hooves destroyed the biocrust long ago in many areas.

In a back lot at Scottsdale Community College last year, Rowe laid down a layer of fabric, topped by a layer of sand,

and then a layer of natural biocrust salvaged from a development site. She watered the crusts and watched the mosses, lichens, algae, and bacteria expand from 20% cover to 80% cover by the end of March. In December, Rowe cut up the sods into 3-meter squares and laid them in burned areas around the Tonto National Forest. The idea, she explains, is to see how well these sods establish in place, crusting over burned soils, and how well the biocrusts can keep out invasive grasses, creating small fire breaks in the landscape. Rowe doesn't have published results yet, but presented her work in December at the Monterey meeting.

There are ongoing initiatives—for example, in Phoenix and Tucson—to actively remove invasive grass species. Herbicides deployed from airplanes, or by volunteers wearing sprayer backpacks, and manual weeding to pull up grass by the roots are a few approaches to kill invasives and maintain fire breaks—like the one that saved Tucson in 2020. At least one initiative is even toying with using controlled burning as a treatment, Rowe says. The problem with using fire is the grass–fire cycle itself: Invasive grasses grow back so quickly that wildfire often just clears away the last of the native plants, giving invaders a blank slate to resprout and take over.

Long-term, Rowe hopes to bring scientists, land managers, and fire managers together to discuss approaches, model scenarios, and trade ideas. There's been concern about the grass problem for a while, but researchers and managers have only started to realize the threat it poses to cities like Tucson and Lahaina in the last few years. Invasive grasses are stoking a climate-driven wildfire threat across the entire West. "It's daunting," Rowe says. "It's unlikely we'll be able to get full control over these grasses." Managers will have to pick and choose priority areas where the grass–fire cycle presents the biggest danger and then make hard choices, she says, "about how we spend our resources."


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