RARE EARTH

Soil scientists are tracking down rare and endangered soils in a quest to document—and preserve—"pedodiversity"

By **Michael Tennesen**

In a verdant woodland on the Calhoun Experimental Forest in South Carolina, soil scientist Daniel Richter peers into a gash in the ground. It's a kind of earthen operating room, where researchers have sliced open the soil to examine its subterranean profile. In the layers of sand and clay, Richter sees telltale signs of past ecological trauma. Nearly all the thick, yellow-brown topsoil that once capped this layered soil, named the Cecil, has been eroded away. "It's decapitated," says Richter, a professor at Duke University in Durham, North Carolina. "We are looking at a natural soilscape that 150 years of cotton, corn, wheat, and tobacco farming have all but destroyed."

The Calhoun isn't the only place where the Cecil's head has gone missing. The soil covers some 40,000 square kilometers of the southeastern United States and is a regional icon, with North Carolina naming it the official state soil. But in many places, Richter says, intact Cecil is now "endangered, and may be nearly extinct."

Endangered dirt? Not that long ago, few researchers would have talked up the idea. But in recent years, efforts to identify the world's rare and endangered soils have been gaining momentum. Aided by increasingly powerful geographic information systems and Earth-observing sensors, researchers have begun mapping "pedodiversity"—the distribution and extent of different soils. This past summer, for example, Chinese researchers released the first-ever pedodiversity survey of that huge nation, identifying nearly 90 endangered soils—as well as at least two dozen that have already gone extinct. Similar surveys suggest unique dirt is also in danger in the United States, Europe, and Russia, the victim of agriculture and development.

Soil extinction carries potentially weighty implications, researchers say. Healthy, diverse soils are not only key to food production, but they also sustain a diversity of species and ecosystems—and can serve as helpful guides to restoring ravaged soilscapes. "We bury our people in it, walk on it, and yet too easily forget it," says soil scientist James Bockheim of the University of Wisconsin, Madison, a co-editor of *Pedodiversity*, the first major scholarly book on

PHOTO: USDA FOREST SERVICE

In a South Carolina forest, soil scientist Daniel Richter dissects a soil profile that, by the 1950s (*opposite page*), had been severely damaged by more than a century of farming.

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the topic, published last year. "Why not protect soils as we do plants and animals?"

Some researchers are urging governments to do just that, by creating reserves for rare and endangered soils that bar destructive agricultural practices and development. Before a rare soil can be protected, however, it has to be identified and mapped, an effort still hampered by sparse data, competing classification schemes, and technical debates over concepts and methods. Some help could come from new technologies that have the potential to cut survey costs by more than 80%. But creating trustworthy maps "still takes an element of groundtruthing," says soil researcher Alex McBratney of the University of Sydney in Australia. "Which means getting out there with a shovel."

HUMANS HAVE BEEN CHARACTERIZING and mapping soils for at least 3000 years. The ancient Egyptians identified at least two types, which helped determine land prices. In feudal China, officials recognized at least nine classes based on color, texture, and moisture content. Today, nations have adopted an array of classification schemes based on numerous soil characteristics, including its geological and climatic setting, parent rock, age, texture, moisture content, color, and chemical signature. The U.S. government's system recognizes some 20,000 soil series, typically named after places. Like life forms, they are classified in a hierarchy: a dozen orders comprising thousands of smaller groups and families. The order Gelisol, for instance, includes polar soils typified by permafrost, while Histosols are sodden soils found in wetlands.

88
Number of endangered soil types in China

24
Number of extinct soil types in China

The Cecil is an Ultisol, which are typically leached, acid forest soils found in humid areas. It was first mapped in 1899 at a site in Cecil County, Maryland, and usually has granular, yellowish topsoil up to 20 cm thick, underlain by sticky red clays flecked with mica, a shiny mineral.

In the late 1980s and early 1990s, as the concept of biodiversity was becoming a buzzword in biological circles, soil scientists began to discuss how they, too, could measure and protect diversity. By then, the problem of soil loss from erosion, farming, and development was well-understood. But just how many soils were rare or confined to small areas wasn't clear. In 1992, McBratney argued for efforts to fill that gap in a paper that is believed to mark the first use of the word "pedodiversity" (although another soil scientist, Juan José Ibáñez of Spain's National Research Council in Madrid, the other co-editor of *Pedodiversity*, was writing extensively in Spanish about similar concepts at the time).

Tallying pedodiversity turns out to be a complicated endeavor. Like biologists measuring biodiversity, soil scientists confront conceptual and technical dilemmas, such as when to lump or split soil "species," and how best to calculate single numbers, or index scores, that reflect an area's diversity and allow easier comparisons between regions. Soil nomenclature can be confusing, too. Different nations often use different names for the same soils, for instance, or the same name for different soils. In Russia, some

Ground assault. California made the San Joaquin soil the state's official dirt in 1997, but stopped short of protecting it from farmers who break up its hard subsoil with explosives (*top*, in 1916) and machines in order to plant crops.

soils still carry folk names originally coined by peasants.

STILL, soil researchers have begun to reveal the magnitude of the threat to rare soils. In 2003, a team led by Ronald Amundson of the University of California (UC), Berkeley, published a pair of milestone studies documenting pedodiversity in the United States. Analyzing government data that detailed the distribution of some 13,000 soil series, the researchers identified more than 4500 "rare" soils that each covered fewer than 1000 hectares, often the product of unique geological and ecological histories. They also found 508 "endangered" soils—ones disturbed by farming, urbanization, or other human activities across at least half their historic range. An additional 31 soils were essentially "extinct," they reported in *Ecosystems*—disturbed across more than 90% of their historic range. In six heavily farmed midwestern states, more than half of each state's known soil species were at risk.

California was another hot spot, with 104 of its 1755 soil series rated as endangered. Ironically, Amundson notes, one of those threatened soils is the San Joaquin—named California's official soil in 1997. The San Joaquin is famous for a tough, impermeable layer of silica-rich subsoil that creates seasonal ponds called vernal pools, a key habitat for an array of rare plants and animals. But the soil also sits in the middle of prime agricultural land, and farmers have routinely used explosives and machinery to rip out the hardpan. And when lawmakers gave the San Joaquin state soil honors, they also insisted that the soil get no special legal protection.

While Amundson's team took a national perspective, other U.S. researchers are zooming in on smaller regions, in part to study how often rare soils coincide with rare plant communities and ecosystems. Last year, Bockheim and Sarah Schliemann of the Metropolitan State University of Denver took a close look at an ecological transition zone that cuts diagonally across Wisconsin, where southern prairies meet northern forests. Although this transition zone covered just 13% of Wisconsin, it held 40% of the state's unique, "endemic" soils, the researchers reported in *Catena*. That's likely a result of the region's history of intense glaciation and a confluence of climatic factors. But the rare soils had little statistical association with some 100 en-

demic plants, they found, which tended be more affected by topography than soil type.

The study also revealed that half of the 159 endemic soils covered relatively small areas, fewer than 4900 hectares. That puts them at greater risk of being lost to plows or pavement, Bockheim says, adding that "I don't know if you could ever restore them."

OTHER NATIONS ARE ALSO MOVING to find rare soils. In 2009, Russian soil scientists published a mammoth Red Data Book of Russian Soils, and this past August another team published the new study of China's pedodiversity. One goal, says coauthor Peng Gong of UC Berkeley, who also worked on the 2003 U.S. survey, was to examine how massive land use change, including rapid urbanization and farm abandonment, is affecting China's soils.

Completing the survey required a mammoth treasure hunt, with researchers scouring hundreds of regional offices to unearth more than 8900 soil surveys, which were combined with a larger national survey. The end result, published in *The Scientific World Journal*, is relatively broad-brush, Gong says: The mapping scale is coarser than the U.S. study, for instance, and there is little or no information on some regions.

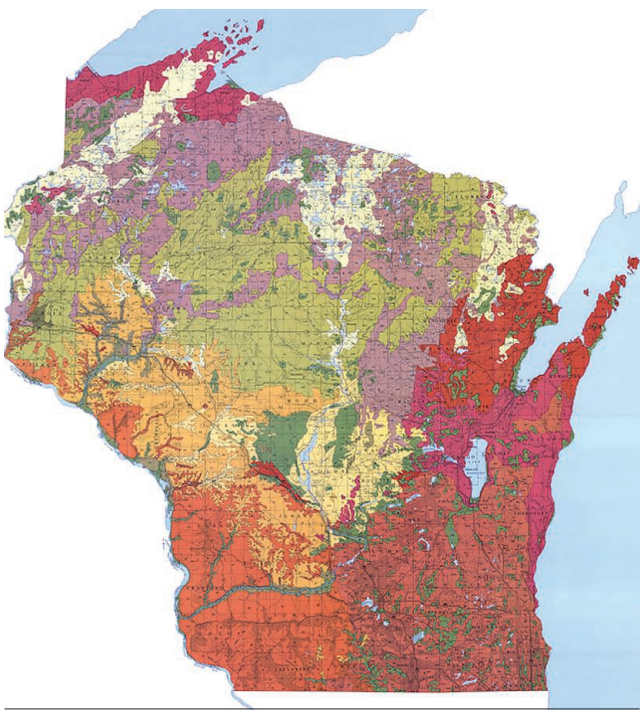
Still, the results are revealing. Most of China's soils are limited to just five or fewer provinces, and 332 are rated rare or unique. There are also at least 231 kinds of "new" soils essentially created by humans, the product of centuries of plowing, sifting, and fertilizing; they have replaced natural soils over 12% of China's land area. And farming continues to threaten more soils: Eighty-eight "endangered" soils and 17 "extinct" soils are mostly found in intensely cultivated northern regions. In contrast, urbanization threatens just six soils, the researchers estimate.

The China study also took a new step, analyzing how many endangered soils already enjoy some level of protection, such as being within a park. The answer was worrying, the researchers say: Just 11% of endangered soil series, and 16% of the area they cover, are protected. Safeguarding soils "should be a high priority in the creation of future nature reserves," the authors urge.

SOIL RESERVES may be a ways off, but some nations are already taking tentative steps. In Russia, soil scientists helped persuade the government in 2001 to adopt a soil protection policy, but subsequent action has been limited. More recently, environmental agencies in the United Kingdom have issued formal guidance on taking soil diversity into account when planning reserves, but farm groups have generally resisted rules that might restrict agriculture. In the European Union, Ibáñez and other researchers have pushed officials to formally integrate pedodiversity into conservation policies and have even proposed a network of "PanEuropean Soil Reserves." So far, however, "these issues do not seem to interest anyone," Ibáñez says.

Wisconsin's dirty secret

America's Dairyland is home to at least 119 "endemic" soils found only in the state, according to a 2013 study that linked soil diversity to past glaciation and other factors. Map shows major soil groups.



MAP: WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

One obstacle is the relatively high cost of the soil surveys needed to guide conservation decisions. In the United States, traditional large-scale soil surveys cost about $10 per hectare in 2010, according to one estimate. But prices could come down as new technologies come into use, including air- and space-based sensors that can detect soil chemical signatures and physical characteristics, and computer models that can use climate, geological, and other data to help predict soil types. Some teams have been able to drive the cost down to just $0.20 or $0.30 per hectare. Still, reliable surveys will still require boots on the ground—and spades in the earth.

Many researchers argue that the cost of soil mapping is meager, however, compared with the value of the "ecological services" that dirt provides, such as storing carbon or filtering water. That idea could get a boost next year, as the United Nations launches its International Year of Soils. It will culminate in December 2015 with the release of a major report on the status of soils worldwide.

IN THE MEANTIME, SOUTH CAROLINA'S Cecil suggests the costs of inaction, Richter says. In the early 1900s, when soil mappers first began surveying the lands around the U.S. Forest Service's Calhoun research station, the damage from erosion was so severe that they initially labeled the territory as just "rough gullied land." Over the next few decades, however, improved farming and management practices restored a semblance of health as pine forests and wildlife returned.

But "if you lift up the green blanket and look at the soil underneath," you can see the damage done, Richter says. The absence of topsoil has exposed clays that choke local rivers with bright orange sediment after heavy rains. Also missing: much of the Cecil's stored carbon, which escaped into the atmosphere as a result of the mistreatment, reported Megan Mobley of the University of Wyoming in Laramie and colleagues including Richter this past September in *Global Change Biology*. The damaged soils also aren't absorbing much new carbon from the atmosphere, they found. That's bad news for climate scientists hoping the region's soils might help curb global warming.

The tale of the lost carbon suggests one more parallel between pedodiversity and biodiversity: fail to protect either, and it is gone for good. The Cecil's decapitation and slow regeneration, Richter says, provides a reminder that past damage can leave soils "compromised for centuries." ■

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With reporting by David Malakoff.