Fracking's Footprint

Scientists Study Impact of Shale Gas Development on Pennsylvania's Forests

by Madeline Fisher

Southeastern Pennsylvania is known for its lush, pastoral landscapes and prosperous farming communities. But the economy in the state's north and west has historically depended—as in most of Appalachia—on resource extraction and its inevitable cycles of boom and bust. Nearly all of Pennsylvania was clear-cut in the late 1800s and early 1900s, making it for a time the nation's largest producer of lumber. Below-ground coal mining started even earlier, but the impacts really became apparent when surface strip-mining began in the 20th century. Oil and gas production have also flourished here; since 1859 more than 325,000 oil and gas wells have been drilled in the state.

Now the latest boom is on. Thousands of feet below the surface are the Marcellus and Utica shales and their largely untapped reserves of natural gas. For decades, geologists have known about the fuel stored in deep rock formations such as the Marcellus, which runs beneath Pennsylvania, New York, West Virginia, and other Appalachian states. But extracting it wasn't economical until the advent of hydraulic fracturing, or fracking, a controversial technique in which millions of gallons of pressurized water, sand, and chemicals are injected deep into the earth to fracture the shale and release the trapped gas.

Since 2004, nearly 3,000 shale gas wells have been drilled in Pennsylvania, which is still just a tiny fraction of the state's number of conventional oil and gas wells. But because shale gas is so deep and extracting it means handling massive amounts of water, much more infrastructure is involved than in conventional drilling—creating a much bigger footprint as a result, says SSSA member Patrick Drohan, a Pennsylvania State University assistant soil science professor. "I could see right away when I saw my first Marcellus gas pad that this would be something that would change Pennsylvania's landscape unlike anything the state has seen in well over 50 years."

He adds that shale gas drilling likely won't be as intense and damaging as strip-mining, nor will vast areas of land be affected, as during the lumbering era. Still, there is cause for concern. Spatial analyses by Drohan and his Penn State colleagues indicate the heaviest gas development is occurring in the Susquehanna River Basin—the source of more than half the freshwater flowing into the embattled Chesapeake Bay. And nearly 25% of wells have gone into Pennsylvania's last remaining tracts of unbroken, "core" forest, which is among the last intact forest in the entire Northeast, as well.

This is why the team has embarked on an ambitious, interdisciplinary research project, which aims first to characterize the Pennsylvanian landscapes in which drilling is occurring: where the activity is concentrated, what the topography and soils are like, and whether the land cover is agriculture or forest. They hope their data can then inform the siting of future wells, pipelines, and roads so that this infrastructure causes the least disturbance in the short term and eases the way toward bringing back forests and farmland later on.

Gas well in Pennsylvania. *Photo by Anthony Buda/ Penn State Marcellus Electronic Field Guide.*

Forest Fragmentation

Pad access road in Pennsylvania. *Photo by Patrick Drohan/Penn State Marcellus Electronic Field Guide.*

Compressor station in Pennsylvania. *Photo by Margaret Brittingham/Penn State Marcellus Electronic Field Guide.*

The research doesn't just have implications for Pennsylvania. While the Marcellus formation is grabbing headlines in the United States right now, shale gas exploration is happening throughout the world. In Britain, Poland, and elsewhere in Europe, it's being touted as a way to ease high natural gas prices and foster energy independence. Shale gas production is widespread in Canada. And now the enormous store of natural gas in the 7,000- to 9,000-ft-deep Utica shale, which extends from Quebec to Kentucky, is being heralded as the next frontier in U.S. drilling.

As shale gas development has surged, however, studies of the possible environmental consequences have lagged behind. Scientists have known for decades, for example, that deep, high-pressure fluid injection can trigger earthquakes. But the field lay dormant for years until a series of quakes caused by deep disposal of fracking wastewater in Ohio and Arkansas helped prompt a revival. On other issues, virtually no studies have been done at all, and this includes the effects on eastern U.S. forests, says U.S. Forest Service (USFS) soil scientist Mary Beth Adams, who studied the impacts of fracking wastewater on forestland in West Virginia a few years ago (see sidebar on page 8).

"One of the things we learned from our experience was just how little research has been published in the scientific literature about the effects of natural gas development on forest resources," says Adams, an SSSA Fellow and SSSA and ASA member. "So there are a myriad of opportunities and information gaps. We could learn a lot more."

One of the unknowns is the potential for shale gas development to create openings and edges in previously intact forest, or what's called forest fragmentation. To support the drilling of a 5,000-ft-deep well and the hydraulic fracturing process that follows, engineers must build a raised, gravel pad of 3 to 5 ac in size and a stormwater system to handle the resulting runoff. New roads to the drill pad are needed as are compressor stations for pumping the gas and pipelines to carry it away. And because most of the pressurized water comes back up once hydraulic fracturing is finished, flow-back water storage ponds and treatment facilities must be constructed, as well.

To understand how this infrastructure is affecting Pennsylvania's landscape, Drohan and his Penn State colleagues, Margaret Brittingham and Joseph Bishop, used GIS and other

Flow-back pond in Pennsylvania. *Photo by Anthony Buda/Penn State Marcellus Electronic Field Guide.*

spatial techniques to characterize the locations of existing gas pads and future, permitted ones. To their surprise, they found slightly more than 50% of pads were located in farmland (with the rest in forest), suggesting the impacts on forestlands might be less than they hypothesized.

However, their study—published this spring in *Environmental Management*—also revealed that most existing pads in forest cover were situated in large, unbroken tracts. Moreover, an analysis of permitted pads showed that gas development in Pennsylvania forests could increase by more than 80% in the future, leading potentially to the loss of 1,700 ac of core forest when all existing and permitted pads are counted. "That's a very small part of the state," Drohan says. "But it's a very significant part of the state's forest."

What makes fragmentation so troubling is how it fundamentally changes the forest ecosystem, says Brittingham, a professor of wildlife resources and a wildlife extension specialist. After they were clear-cut during the lumbering era, she explains, northern and western Pennsylvania's forests grew back to become some of the last refuges in the Northeast for birds that depend on the forest interior. This is especially true of neo-tropical migrants, such as warblers, thrushes, and tanagers, which over-winter in Central and South America and then fly north in the summer to breed. Roughly 20% of the world's population of scarlet tanagers, for example, breed in Pennsylvania.

But as gas development fragments core forest, Brittingham predicts these birds will be replaced by chickadees, woodpeckers, and other generalist species that thrive in smaller woodlots. In fact, monitoring by her student has shown new species are already using the openings and edges near gas pads—including a shorebird frequenting a flow-back water pond. And the same is true of plants, mammals, and amphibians. "Basically, any species that can do well around people or across a range of habitats will tend to benefit" from the changes, she says. "And ones that are very specialized on a certain type of habitat and are sensitive to disturbance—you lose those."

Just as important is the loss of the ecological roles they play. Neotropical migrants, for instance, "are the insect-eating machines of the forest," Brittingham says, keeping down mosquitoes and forest pests. Similarly, Penn State weed ecologist David Mortensen has been examining whether new roads built for Marcellus drilling will foster the spread of invasive plants, which tend to snuff out native forest species—and the ecosystem services they provide.

Shifting Patterns of Infiltration and Runoff

Yet another concern is how gas development will affect the forest's ability to retain nutrients, hold soils, and prevent erosion of sediments into downstream waterways, particularly since so much activity is concentrated in the Susquehanna River basin. Not only does the Susquehanna contain the most pads of any of Pennsylvania's major river basins (60% of existing pads and 54% of permitted ones), but more than 25% of them are in core forest. Roughly 145 miles of new roads could also be built in the basin—one to two orders of magnitude greater than in any other. What this all means is shale gas development poses a substantial new risk to the water quality of Chesapeake Bay, which land managers and research-

ers have already been struggling for decades to improve.

How much of a risk, though, depends on where, when, and how gas development proceeds, which is where the second body of research by Drohan and Brittingham comes in. Many drilling companies are based out-of-state and therefore aren't used to dealing with the hilly terrain, rocky soils, and cold and wet conditions of Pennsylvania. "It's not Texas," Drohan says. "There are a lot of challenges they did not expect." To help the industry better anticipate and meet those challenges, he and Brittingham have now characterized the topography and soils in current and future drilling areas.

One important finding from this work is how gas pads can cause shifts

Fracking Fluid Overdose Leads to Dying Vegetation in West Virginia

When a company obtained a permit to dispose of hydraulic fracturing wastewater on the U.S. Forest Service's Fernow Experimental Forest in 2008, staff at the West Virginia site helped decide where to apply the fluids and over how large an area. But they had no plans to study the process or its effects—until the disposal began and forest vegetation began dying back.

"It was very, very dramatic," says Mary Beth Adams, a soil scientist with the Forest Service's Northern Research Station. "That's when we decided that we needed to monitor this area and find a way to quantify the damage and the recovery."

At the time, surface disposal of hydraulic fracturing wastewater was allowed in West Virginia, and the company met all legal requirements for applying the fluids on the Fernow, where it had drilled a conventional natural gas well and used hydraulic fracturing to release the fuel. But in an effort to affect as little forestland as possible, the driller agreed to apply the wastewater over just a quarter-acre of land—a choice that in retrospect likely led to an overdose.

During the two- and a half-day disposal process, the leaves of shrubs and other understory plants on the quarter-acre site began to shrivel and turn brown. About 10 days later, leaves also began falling off trees, says Adams, who published the findings in the *Journal of Environmental Quality* last year. Two years after the fluids were applied, 56% of the trees had died, with

Forest pipeline construction.
Photo by iStockphoto/AlexAnin.

in patterns of infiltration and runoff across the landscape, or what Drohan calls "hydrologic capture." When an impervious, gravel pad is built atop soils that used to hold or convey water, sometimes the water simply moves underneath the pad without eroding it, in which case engineers let things be, Drohan says. But in other situations, the pad interrupts the water's natural flow path; in fact, stormwater systems are often built that direct runoff from the pad in a specific direction.

When this happens, downslope areas that used to receive water can dry out, while others become wetter than normal. Modeling work by Drohan shows that much depends on where the pad is located—on the side of a slope, for instance, versus on top.

American beech suffering the highest mortality and sugar maple the least.

Monitoring of surface soils also revealed concentrations of sodium and chloride in the application area some 50-times higher than in nearby, untreated plots of soil, and Adams suspects these high salt concentrations are what killed the trees and other plants. Fortunately, sodium and chloride leach easily from the soil with rain, and salt concentrations have since been returning to normal. Continued monitoring of the area also indicates some recovery of trees.

Adams cautions that the work was a case study of a single event, rather than a controlled, replicated experiment, "so we've tried to be careful about the inferences we make from it." Still, she adds, "the results are pretty strong." Plus she and her colleagues were astonished by how little they found in the scientific literature about the impacts of hydraulic fracturing on eastern U.S. forests or practices and standards for preventing the kind of overdose they observed.

Amid all that's not known at this point, the experience has left them certain of one thing: Much more science is needed. "In some ways," says Northern Research Station research forester Susan Stout, "this case study of what happened on the Fernow has prompted us to take a hard look at the research needs and identify a research program."

Damage to trees in the Fernow Experimental Forest can be seen in the foreground with non-treated forest in background. Photo taken 17 May 2009. *Courtesy of the U.S. Forest Service.*

"Some pads will have very little effect on flow rerouting," Drohan says, "and some have a pretty substantial impact."

What worries him and Brittingham is that certain gas pads may cut off or reroute water that normally feeds downslope wetlands, like vernal pools. Because these forest wetlands tend to be ephemeral—holding water in the spring and fall, and drying out in summer—people often don't notice them and many remain unmapped. But breeding amphibians make heavy use of them, suggesting they're "a big group that would get hit" if these wetlands began drying up, Brittingham says. "And, of course, the Appalachian Mountains are the heart of amphibian diversity in the United States." Her group is now collecting baseline data on the amphibian populations near gas pads, as well as how their movement might be restricted by new barriers such as pipelines and roads.

Gas pads (**left**), in certain cases, may cut off or reroute water that normally feeds downslope forest wetlands, which are heavily used by breeding amphibians (**right**). *Left photo by Patrick Drohan/Penn State Marcellus Electronic Field Guide. Right photo by Joseph C. Mitchell/ U.S. Park Service.*

Drohan, meanwhile, is focused on areas that may get wetter with gas development. Although his and Brittingham's study found that three-quarters of pads are located on soils with few drainage problems, 20% are situated on potentially wet soils. Some 60% also occur on slopes at risk for at least some surface water runoff and erosion, with 10% sitting on steep, high-risk slopes. Add to this the likelihood of severe storms in summer, and there's real potential for heavy erosion and nutrient runoff if best practices for managing stormwater aren't followed, Drohan says.

What's more, he adds, soil scientists know from agricultural research that working wet soils can cause a decade or more of soil compaction problems—and a major obstacle to restoring vegetation later on. Along similar lines, the USFS is starting to consider how shale gas development may affect the soils underneath roads and pads. Forest managers have decades of experience with roads both

Marcellus shale close up.
Photo courtesy of Wikipedia.

for timber production and conventional gas development, says Susan Stout, a research forester with the USFS Northern Research Station.

"But the sheer amount of water involved in Marcellus well development and the possible hardening of roads to transport it may cause us to revisit many of the previous assumptions about what happens to forest roads and well sites over the intermediate to longer term," she says.

Working Towards a Regional, Landscape Approach

Given all the unknowns, can't agencies like the USFS put a halt to shale gas drilling on their lands until more research is done? The answer, at least in the Northeast, is "no," Stout says. "There is a long tradition here of separate ownership of the surface and sub-surface." In other words, when a company owns the rights to gas reserves underground, owners of surface land must allow drilling to proceed, although they can negotiate for certain requirements. In Pennsylvania, for example, the Department of Conservation and Natural Resources (DCNR) is trying to get drillers to share pipeline corridors on state lands, rather than letting each cut its own pipeline path through the forest. Drohan also recently received a grant from the DCNR to model where the wettest soils occur on state forests, so the agency can work with industry to protect the most vulnerable areas.

State lands aren't the biggest issue, however. "The problem is the private lands," Drohan says. "That's the thing we're most worried about." Indeed, 90% of Pennsylvania shale gas drilling is happening on privately owned properties today, according to his analysis with Brittingham and Bishop—suggesting that landscape-scale coordination of drilling activities will be hard to achieve.

Still, Penn State is doing what it can. Penn State Extension has created a Marcellus shale gas website (http://extension.psu.edu/naturalgas) to educate citizens, landowners, businesses, and municipalities, as well as a "Marcellus Shale Electronic Field Guide" with information on controlling invasive plants, restoring vegetation, creating wildlife habitat, and other land management topics. The university's School of Forest Resources and the USFS Northern Research Station also co-sponsored a forum in early April that brought together academia, government agencies, industry, and environmental organizations to discuss the impacts and challenges of extracting shale gas in forested landscapes.

The dialog has been mostly positive so far, Drohan says, and many people are grasping the need for a regional, landscape approach to siting drilling infrastructure. At the same time, choices about where to put gas pads necessarily depend mainly on "what's 6,000 ft below the ground," he adds. "In some cases, companies may have some wiggle room. In other cases they may not." And that's why he and Brittingham know in the end that compromise must rule.

"[These decisions] are never going to be based all on biology," Brittingham says. "But," she adds, "it would be nice to have biology be a part of it."

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