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Effects of Hydrocarbon Extraction on Landscapes of the Appalachian Basin

Shale-gas and other hydrocarbon development can result in substantial landscape disturbance that can affect ecosystem structure and function, socioeconomic activities, and the health and distribution of critical plant and animal species. Natural gas exploration, development, and delivery have also resulted in changes in land use and increased population density, putting stress on infrastructure and having the potential to affect the human environment.

Background

An important and sometimes overlooked aspect of contemporary natural gas exploration, development, and delivery activities is the geographic profile and spatial footprint that these activities have on the land surface. The function of many ecosystems and the goods and services they provide, in large part, are the result of their natural spatial arrangement on the landscape. Shale-gas development can create alterations to the pattern of land use and land cover (LULC), and represents a specific form of land use and land cover change that can substantially impact critical aspects of the spatial pattern, form, and function of landscape interactions, including many biological responses.

The need for energy resources has created numerous economic opportunities for hydrocarbon extraction in the Appalachian basin. The development of alternative energy natural gas resources from deep-shale drilling techniques, along with conventional natural gas extraction methods, has created a flurry of wells, roads, pipelines, and related infrastructure across many parts of the region. An unintended and sometimes overlooked consequence of these activities is their effect on the structure and function of the landscape and ecosystems (fig. 1). The collective effect of over 100,000 hydrocarbon extraction permits for oil, coal bed methane, Marcellus and Utica Shale natural gas wells, and other types of hydrocarbon gases and their associated infrastructure has saturated much of the landscape and disturbed the natural environment in the Appalachian basin (fig. 2). The disturbance created by the sheer magnitude of the development of these collective wells and infrastructure directly affects how the landscape and ecosystems function and how they provide ecological goods and services.

Suggested Science Strategies

To address these issues, the U.S. Geological Survey (USGS) is assessing the landscape changes associated with hydrocarbon exploration and development in the Appalachian basin. The USGS is creating detailed maps of the extraction surface disturbances by digitizing features from high spatial resolution aerial images (that is, the National Agriculture Imagery Program) and entering them into a geographic information system. These features are then combined with other LULC data to create landscape metrics that help scientists analyze the effects of natural gas exploration and development on natural resources, habitats, and ecosystem functions and goods and services (fig. 3).

The mapping of these anthropogenic features and the analysis of landscape metrics will allow scientists to evaluate the effect of natural gas and other hydrocarbon exploration and development activities on forests and other ecological resources so that informed decisions can be made about the development of these energy resources and their effect on the environment.

Early Products and Decision-Support Strategies

The first step in this scientific investigation is the documentation of the level of disturbance that can be attributed to natural gas exploration and development activities and the explicit footprint on the landscape, which is now completed. This information is important to many subsequent studies, such as effects of hydrocarbon exploration and development on: (1) fish, (2) local and migratory fauna, (3) runoff and soil erosion, (4) cultivation of invasive species, (5) biodiversity, (6) surface-water and groundwater quality, (7) conservation in individual watersheds, and (8) regional conservation programs, such as the Chesapeake Bay Watershed Agreement. A series of reports documenting the change in landscape metrics are available at http://pubs.usgs.gov, and then searching for "Landscape consequences of natural gas extraction." The disturbance data are available for 2004–2010 online at https://www.sciencebase.gov/catalog/folder/551333cee4b02e76d75c0982.

Future Research

Remote sensing is a time- and cost-efficient method of mapping natural spatial arrangement on the landscape, and it is critical to the standard landscape assessment techniques used to analyze shale-gas-related disturbances to the land surface, which can alter the spatial pattern, form, and function of ecosystems and landscape interactions. Remote sensing also provides a bird's-eye view of the landscape that permits the observation and mapping of the landscape features, and it is the most

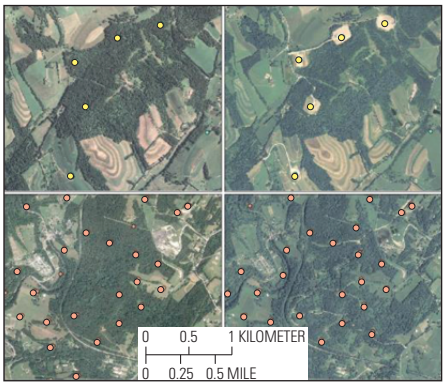

Figure 1. Forested landscape examples from Washington County, Pennsylvania (fig. 3), showing the spatial effects of roads, well pads, and pipelines related to unconventional gas (top image pair), and conventional gas (bottom image pair) development.

Key Science Questions:

1. What is the level of overall disturbance attributed to natural gas development, and how has this changed the land cover over time?
2. How is natural gas development affecting the condition of forests and other ecosystems, including structural characteristics, scale, distribution, and trajectory of succession?
3. What are the cumulative impacts of natural gas development, such as changes in temperature, albedo, carbon sequestration, long-term land use, and other effects?

time- and cost-efficient means of evaluating the impact of gas development on the function of the landscape and ecosystems. Remote sensing-based analysis could also play an important role in other natural gas-related issues, such as (1) environmental impact assessments; (2) detecting fugitive methane releases; (3) locating abandoned wells; (4) environmental restoration efforts; (5) environmental monitoring through time-series analysis; (6) detecting watershed boundaries and finding suitable waste-water treatment locations; (7) monitoring post-gas operation, ecological-succession impacts; (8) detecting opportunistic invasive species colonization due to disturbance; (9) monitoring environmental impact mitigation efforts; (10) guiding field investigators to the most fragmented habitats for assessment of the hydrological and biological resources and impacts of habitat loss (for example, fragmentation); and (11) detecting areas prone to natural hazards that could be exacerbated by disturbances (for example, mudslides).

Benefits

The mapping and digital capture of the spatial patterns of disturbance in the Appalachian basin is a necessary first step in the long-term evaluation of this landscape activity and its effects on natural resources and ecosystem functions, goods, and services. The development of deep underground hydrocarbon resources, such as the Marcellus Shale, has led to significant amounts of energy production, but it is also altering the landscape at an unprecedented rate. This research will help policy-makers to make informed decisions about future hydrocarbon extraction development.

Reference Cited

Slonecker, E.T., Milheim, L.E., Roig-Silva, C.M., Malizia, A.R., Marr, D.A., and Fisher, G.B., 2012, Landscape consequences of natural gas extraction in Bradford and Washington Counties, Pennsylvania, 2004–2010: U.S. Geological Survey Open-File Report 2012–1154, 36 p., at http://pubs.usgs.gov/of/2012/1154.

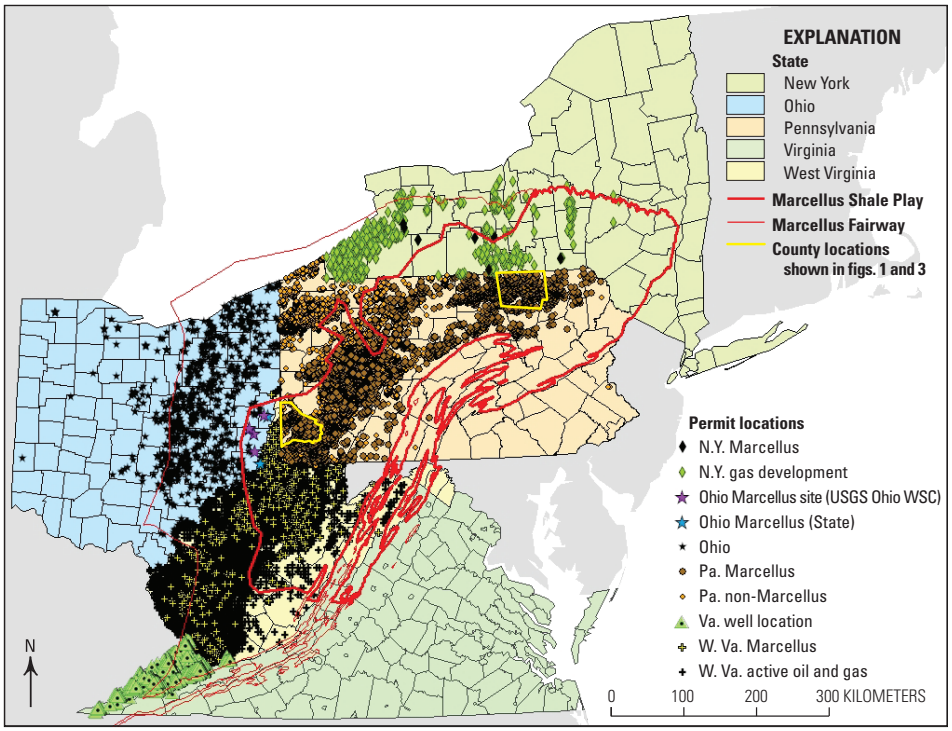

Figure 2. Hydrocarbon permits in the Appalachian Region, 2004–2010. Permits for Marcellus and Utica Shale, coal-bed methane, and oil wells in this area total over 100,000.

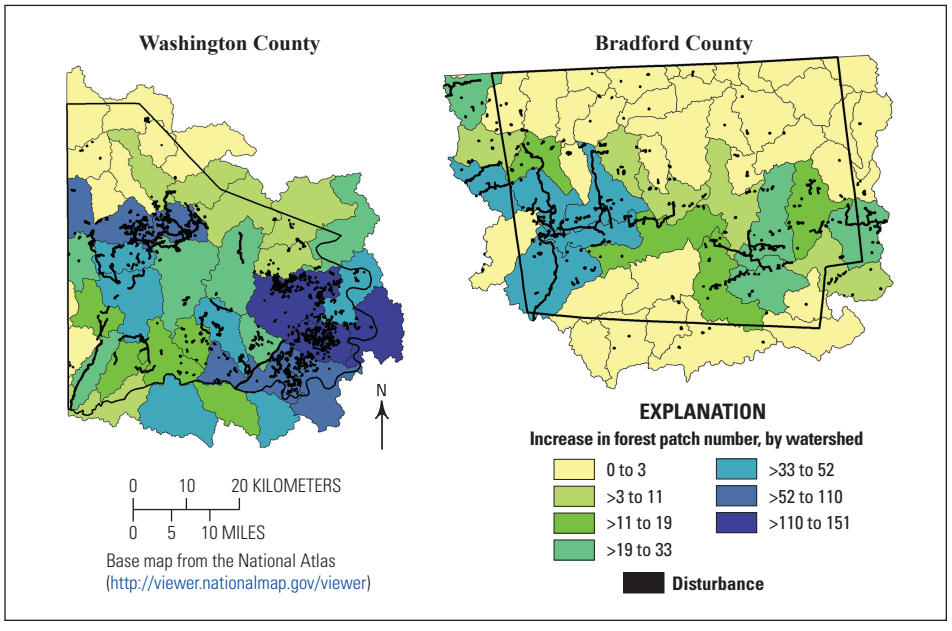

Figure 3. Change in number of forest patches from 2001–2010 showing increasing fragmentation in Bradford and Washington Counties, Pennsylvania (Slonecker and others, 2012).

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ISSN 2327-6932 (online)
http://dx.doi.org/10.3133/fs20153064