PERSPECTIVES FROM THE FIELD

Oil and Gas Impacts on Forest Ecosystems: Findings Gleaned from the 2012 Goddard Forum at Penn State University

Patrick J. Drohan, James C. Finley, Paul Roth, Thomas M. Schuler, Susan L. Stout, Margaret C. Brittingham, Nels C. Johnson

Energy production presents numerous challenges to both industry and land managers across the globe. The recent development of unconventional (shale gas) plays around the world [US Energy Information Administration (USEIA), 2011] has brought attention to the potential for rapid change in affected landscapes and associated ecosystem services. While shale-gas development specifically has been the focus of recent research on how landscapes are changing (Drohan et al., 2012; Entrekin et al., 2011; Johnson, 2010), continued scientific investigation can lessen the resulting ecosystem disturbance across all energy infrastructure.

In April 2012, the Pennsylvania State University hosted the 2012 Goddard Forum *Oil and Gas Development Impacts on Forested Ecosystems—Research and Management Challenges*. The Penn State Goddard Chair, Dr. James Grace, opened this event with a poignant statement, with which most in attendance would agree, "Shale-gas development potentially poses the biggest permanent impact on Pennsylvania forests in the last 100 years; however there is opportunity to manage this important energy resource while carrying out our stewardship responsibility for forest resources." Here we present a succinct summary of research results and management strategies drawn from presentations by individuals representing scientists, managers, conservation organizations, and industry working with oil and gas development. Our hope is that this information will serve to advance research and knowledge regarding landscapes affected by energy development in order to minimize the effects of resource extraction on ecosystems.

The Footprint of Energy Development

While not as extensive as the approximately 102,000 ha of abandoned surface mines in Pennsylvania [Pennsylvania Department of Environmental Protection (PA DEP), 2012] shale gas has the potential to leave an extensive spatial footprint across the state. The PA Department of Conservation and Natural Resources (DCNR) represents the largest public landholding, with approximately 1 million ha and nearly 300,000 ha of leased deep-gas development rights; the PA Game Commission has the next most leased lands. While there is concern about the impacts of development on public lands, development on private lands is greater by a factor of about 9:1 (Brittingham, Drohan, and Bishop, 2012[1]).

Prior to drilling shale-gas wells, the ground is cleared and leveled, then reinforced with a dense stone layer up to 18 inches thick that may cover on average a 2.2-ha area (Drohan and Brittingham, 2012). This is necessary to support the very heavy equipment required for drilling and hydrofracturing the wells. Up to 12 wells have been located on a single pad in PA; the average as of February 2012 was 3 wells per pad (Brittingham, Drohan, and Bishop, 2012).

The Nature Conservancy (TNC) in PA estimates that approximately 12 ha are disturbed for every shale-gas well pad built, and total build-out of the Marcellus play could result in 6,000–15,000 pads, with on average 4–10 wells per pad (Johnson et al., 2012). Thus, shale-gas extraction has the potential to disturb 180,000 ha, which would be an area similar in extant to the state's abandoned surface mines. Comparisons of shale-gas pad development over the last 18 months to TNC projections of total potential shale-gas pad build-out show that 65% of actual pads are within 1 km of a TNC projected shale-gas pad location.

The pattern of shale-gas development has a unique spatial footprint unlike many other surface disturbances, and resembles a web unfolding across the landscape (Drohan, 2012); so far, the pattern has had an unequal but spatially extensive effect on landscapes. PA has seen 45%–62% of its pads on agricultural land and 38%–54% in forest land (Drohan et al., 2012). While the use of existing infrastructure, especially roads, has been high so far, with most pads near existing roads (Brittingham, Drohan, and Bishop, 2012), pipeline and road development appears to be a greater factor in altering landscapes. While mean number of wells per pad is currently about 2–3, industry representatives suggest more wells per pad will become the norm, minimizing the number of pads needed but also potentially lengthening the time frame when the full spatial extent of a pad is needed.

To date, 24% of pads in PA were built in what was previously core forest habitat; that is, more than 100 m from preexisting edge. Preliminary research involving both deep and shallow well development suggests that some bird species with high site fidelity have relocated because of development, while denser development has led to homogenization and increase in gap and edge generalists in bird communities (Brittingham, Drohan, and Bishop, 2012; Thomas, 2012; Wood, 2012).

There is evidence of hydrologic capture associated with shale-gas roads and pad development (Drohan, 2012; Harrison, Edwards, and Williard, 2012; Ziegler, 2012) resulting in some areas becoming wetter and some drier. Such changes may negatively affect hydric soils, wetlands, amphibian habitat, and infrastructure. A substantial

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proportion of pads are sited on soils with high to very high runoff potential and moderate slopes, which along with their infrastructure could pose substantial risk for erosion and sedimentation problems. Implementation of best management practices (aka recommended practices) is critical to minimizing potential long-term ecosystem degradation. Where shale-gas is being developed in southwestern PA, known landslide-prone soils and topography may increase management challenges during some phases of the well-pad life cycle (Drohan, 2012).

The environmental effects of shale-gas development may be most felt in PA's Susquehanna River Basin, which contributes 26 billion gallons of water per day to the Chesapeake Bay. The Susquehanna River Basin Commission (SRBC) projects 30 million gallons a day of consumptive use associated with full development of just the Marcellus play. By comparison, one nuclear power plant uses about the same amount of water per day, and three nuclear power plants are in the SRBC (Richenderfer, 2012). Thus, while the water needs for shale-gas development are significant, alternative sources of domestic energy also require significant water resources. To date, the SRBC notes that the average withdrawal per well for hydrofracturing has been 4.4 million gallons.

Siting Flexibility

How shale-gas infrastructure is placed on the landscape depends on surface characteristics and the underlying lithology (Harper, 2012). The landscape perspective of surface-resource managers (the Bureau of Forestry, for example) is defined by stream networks, forest-patch size and integrity, and existing road networks (Keefer, 2012). The landscape perspective of gas developers is defined by the depth, thickness, integrity, and flatness of various shale layers. The underlying lithology and its structure are defined originally by seismic surveys that lead to a location development plan for well pads, which may be changed after plan submittal with further information from test-well microseismic results within a development tract or by early well yields.

A key question is whether and how to synergize these two perspectives. Changing economics and technology affect what the shale-gas industry can do to work with those affected by their decisions. These factors include (a) gas pricing, (b) drilling technology, and (c) water supply and management technology. For example, drilling technology is rapidly resulting in much longer horizontal wells than in other parts of the United States (2,438-m horizontal wells in PA versus 610-m wells in Arkansas). This, in turn, may result in fewer pads built in PA because more wells can originate on a pad and exploit more of the formation by the horizontal drilling process.

Other examples include evolving recycling technology for flowback water used in hydrofracturing, and the development of water pipelines to serve well development, which has reduced water-hauling truck traffic near pipelines by several orders of magnitude (separate presentations by Bennett, Kuntz, and Kepler, 2012). Lastly, some companies are developing shared infrastructure for water supply or gas delivery, which is minimizing the overall landscape footprint had these companies not worked cooperatively (Bennett, Kuntz, and Kepler, 2012).

Adaptive Management: Integrating New Solutions as We Learn

There are ample opportunities to use what we already know regarding best management practices to minimize erosion and sedimentation issues originating from road siting, well-pad and pipeline right-of-way construction, and reconstruction over and above regulatory minima. The Central Appalachian's wetter climate conditions compared to other regions of the nation suggest a need for industry training in support of erosion and sediment control practices. Specific discussion should focus on site-specific mapping of soils and stricter soil protection when work conditions are disadvantageous, such as not working soils when they are too wet in order to help avoid compaction, erosion, and sedimentation (Drohan, 2012).

Flexibility on the part of industry and regulatory agencies may help expedite adoption of new tools to protect landscapes while improving infrastructure development time and costs. For example, the SRBC is currently developing a new low-flow regulatory framework for all water users in order to help ensure the waters of the commonwealth are available for all (Richenderfer, 2012). This framework ensures that any flow change caused by water withdrawal does not unfavorably affect water resources during low flows (SRBC, 2012). New ideas were suggested to explore habitat trade-offs and habitat banking to maximize habitat protection (Benner, 2012). Findings from habitat research may be adaptively applicable across species and ecosystems as development unfolds (Larkin, Stoleson, and Gover, 2012). While some aspects of surface disturbance from shale-gas development may be temporary but severe (such as sediment production and loads associated with development of pipelines, water-retention ponds, and well pads), others have the potential for long-term ecosystem disruption (e.g., interior forest fragmentation, invasive species associated with development, chronic sediment delivery associated with steep slope development) across extensive areas of the state and many types of land owner.

Impacts on Other Industries

As with any economic boom, there are winners and losers. The forest industry in PA reports significant economic hardship caused by changes in Act 13 [Pennsylvania General Assembly (PGA), 2012], which has increased regulation and overall business costs such as road bonding, competition for labor, and regulatory compliance. There have also been some new business opportunities and increased demand for selected goods and services (e.g., chips for roads) (Lyskava, 2012). There has also been speculation to changes in the economics surrounding private-land forest and farm management associated with new revenue opportunities created by gas leasing and royalty payments; however, evidence of these potential trends is currently anecdotal.

Research Results Only Beginning to Accumulate

About 130 participants attended the conference, where a common topic of discus-

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sion was that research focused on shale-gas development in forested systems was just beginning to accumulate. The conference presented a comprehensive picture of research currently under way while also identifying research needs. A common call through several presentations was the need for a paired-watersheds or patch-analyses approach to evaluating different densities of development (Harris, 2012; Larkin, Stoleson, and Gover, 2012; Mead et al., 2012; Roth, 2012; Thomas, 2012; Wood, 2012). Some presentations suggested a possible threshold level of development intensity below which shale-gas development effects on ecosystems were comparable to other sources of variation in environmental conditions. Harris (2012) showed large effects on water quality due to conventional (shallow, nonshale) gas operations but found no negative response in macroinvertebrate community composition. Thomas's (2012) research design, focusing on varying conventional gas-disturbance densities, suggests a threshold response leading to the homogenization of forest interior bird communities associated with intensive development. Wood (2012) found little short-term effect on Louisiana waterthrush populations near shale-gas operations, possibly because many alternative unaffected stream reaches were in the immediate vicinity. Mead et al. (2012) conducted a shale-gas pilot study in which a water-quality threshold was found in relationship to the density of well pads within a given watershed. However, there were also caveats for the preliminary results presented, a recognized need for suitable replication of many of the studies, and that long-term results are currently rare. Some recommendations for future work include the need to understand not only the effects of conventional and unconventional (shale gas) development, but the interactions among the two. More research is needed on the effects of noise and light pollution and air quality (Pekney, 2012) within forested airsheds; the temporal variability to partial or full site reclamation; and the cumulative effects on forest habitat and water systems.

Management Responses

The PA DCNR Bureau of Forestry has adopted a strategy of avoid, minimize, mitigate, monitor as a way of realizing their surface stewardship objectives while leasing subsurface resources. The Bureau of Forestry manages the 2.2-million-acre state forest system for a suite of management values. Currently, 273,162 ha are available for natural gas development and 155,804 ha are under lease; on 117,359 of these ha, the subsurface rights are separately and privately owned (Keefer, 2012). The bureau's management philosophy follows their Guidelines for Oil/Gas Activities on State Forest Lands (Faulkenberry, 2012). An important component of this approach is prelease planning, which designates areas off-limits based on special considerations in accordance with an ecosystem management approach. The Bureau of Forestry works interactively with 18 different operators, from gas-tract development proposals to final development plans. This approach seeks to avoid or minimize negative surface impacts (Keefer, 2012).

Nongovernmental organizations (NGOs) are working with industry to successfully minimize disturbance during shale-gas extraction. For example, the PA chapter of TNC is working with the University of Tennessee and some gas companies to develop a decision-support tool—*Decision by Design*—that will provide industry with surface-value conservation factors to consider in their development plans (Bearer et al., 2012). In addition, TNC is conducting a comprehensive review of applicable best management practices for oil/gas development from other regions of the country and covering related industries. This analysis will assess the scientific rigor and applicability of both terrestrial and aquatic best management practices for environmental conditions found within the Marcellus drilling extent.

Industry, as well, is working to be more proactive in the drilling process. Spokespersons for Anadarko Petroleum Corporation, Range Resources, and Seneca Resources addressed work by the Marcellus Shale Coalition (2012), an industry group within the play, that is developing *recommended practices* (RPs), which have focused primarily on drilling practices but also siting of infrastructure.

An overarching theme among all was that natural gas development should strive to incorporate and evaluate subsurface (geological) and surface (terrestrial, aquatic) considerations to avoid or minimize impacts on surface resources to the greatest extent possible. In addition, all surface owners should endeavor to communicate surface concerns to gas developers to avoid or minimize conflicts with land management and gas development. Benefits to both surface and subsurface owners can stem from good communications.

Protection of Sensitive Environmental Resources

The rapid, extensive development seen across PA has concerned many who study and manage the state's flora and fauna. For example, Natural Heritage Areas experiencing oil and gas development have been closely watched because they contain one or more plant or animal species of concern at state or federal levels, exemplary natural communities, or exceptional native diversity (Yeany, Tracey, and Zimmerman, 2012). In PA, the permitting process (for oil and gas extraction) emphasizes project-level impacts on erosion and sedimentation and on threatened and endangered species: examples of species of concern are timber rattlesnakes (*Crotalus horridus*), Allegheny woodrats (*Neotoma magister*), and green salamanders (*Aneides aneus*). One tool used to assess potential conflicts between species and oil and gas extraction is the state-NGO coordinated PA Natural Diversity Inventory (PNDI), which lists specific locations of tracked species and plans of land disturbance projects (across all industries). The PNDI process has helped facilitate a direct benefit of species tracking across oil and gas extraction regions since inventories required by the permitting process for the natural gas industry have increased the pool of PNDI species distribution data (Benner, 2012). However, because small-project reviews are easier, and able to be conducted on line, some large projects are submitted piecemeal and, as such, preclude the opportunity to evaluate the broader potential landscape-level cumulative effects of many projects in a relatively small geographic area. This issue of concern suggests a need for better coordination and consistency of the PNDI review process within and between agencies. Current analyses suggest that as many as 148 of PA's 253 identified Natural Heritage Area Core Habitats could be affected by Marcellus development (Yeany, Tracey, and Zimmerman, 2012). However, to date, 98.5% of the shale-gas wells drilled in PA have not affected these areas.

Reclamation

Shale-gas development has the benefit of drilling multiple wells from one pad, but currently not all proposed wells on one pad are typically developed during the same time frame. As such, reclamation of the pad is not desired until the larger pad area is no longer needed for drilling equipment. Pads may have operational lives of decades instead of months or years, and this could significantly delay reclamation efforts. There are considerable differences between the benefits of potential reclamation strategies in forested and nonforested environments (Larkin, Stoleson, and Gover, 2012); while many pads are not yet at the point of reclamation, other infrastructure may be (Drohan, 2012). Many lessons on how to reclaim shale-gas infrastructure can be gleaned from reclamation practices used for coal strip mines (Skousen, 2012). Perhaps most promising are the approaches favored by the Appalachian Regional Reforestation Initiative (ARRI) and opportunities to address a recognized deficiency in PA for early successional forest habitat; given the diversity of infrastructure and complicated soil and landscape patterns, however, reclamation may be best achieved on a case-by-case basis (Drohan, 2012). Reclamation practices could synergistically address some key conservation needs, including providing habitat for some important species of concern, such as the golden-winged warbler (Larkin, Stoleson, and Gover, 2012), but must also minimize the spread of invasive species (Drohan, 2012). Presentations and discussion revealed that surface interests and the gas industry have very different temporal perspectives on this question.

Monitoring

A successful monitoring program will address current management challenges and provide relevant data and analyses to inform an adaptive management approach for continually improving management practices. A suite of management challenges from shale-gas development in the context of forested systems arise, such as surface disturbance, forest fragmentation, habitat loss and species impacts, introduction and spread of invasive plants, loss of wild character, recreational conflicts, spills and pollution incidents, and water-use and disposal issues (Keefer, 2012). The PA DCNR Bureau of Forestry has developed an organization-wide interdisciplinary team whose objective is to integrate data from multiple program areas across state forest districts engaged in managing surface impacts of shale-gas development (Roth, 2012).

The Bureau of Forestry's monitoring program has three objectives: (a) to generate an annual, comprehensive assessment of shale-gas activities on state forest land; (b) to analyze conditions of shale-gas activities through a paired landscape analysis approach aimed at establishing baseline/reference conditions of nondeveloped versus developed areas in representative units of analysis; and (c) to coordinate and facilitate external partner collaboration. Through a process of internal and external facilitated exercises, the agency has identified 15 focus values for the monitoring program: water, plants, animals, invasive species, soil, recreation, infrastructure, local communities, air, revenue, incidents, land use, forest health, timber products, and energy.

The SRBC approach to monitoring focuses on water-quantity and water-quality issues (Richenderfer, 2012). It is important to note that the SRBC does not regulate water quality, but is very involved in monitoring water quality within the basin. As such, it will address water-quantity and water-quality issues through evaluation of surface-water withdrawals, aquatic resource surveys, implementation of a new low-flow protection policy, and its remote water-quality monitoring network, which provides real-time continuous monitoring data on conductance, temperature, pH, dissolved oxygen, turbidity, and water depth. This information is available on line at http://mdw.srbc.net/remotewaterquality/.

Conclusion

The 2012 Goddard Forum achieved its goal of bringing together scientists, managers, conservation organizations, and industry representatives who are working with oil and gas development to share research results and management strategies as they affect forest resources. After two days of compelling presentations and thought-provoking discussion, meeting participants left the conference with a more comprehensive perspective on the management challenges and research needs for evaluating the effects and impacts of shale-gas development on PA forested ecosystems. The prospects of a significant new source of energy are bright, but the risks of environmental degradation while developing the resource should not be discounted. Site and landscape-level issues can be best minimized if industry, regulatory agencies, scientists, and land managers are fully aware of the issues and work cooperatively. This meeting represented a significant effort in that regard but much remains to be done.

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Note

1. Many of the citations found in this article are from presentations made at the 2012 Goddard Forum *Oil and Gas Impacts on Forest Ecosystems—Research and Management Challenges* held at the Penn Stater Conference Center, April 9–10, 2012.

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Address correspondence to: Patrick J. Drohan, Department of Ecosystem Science and Management, Pennsylvania State University, University Park, PA 16802; (phone) 814-863-4246; (fax) 814-863-7043; (e-mail) patdrohan@psu.edu.

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