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December 27, 2016

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Public Comments Processing
Attn: FWS-R5-ES-2016-0135
Division of Policy, Performance, and Management Programs
U.S. Fish and Wildlife Service
5275 Leesburg Pike, ABHC-PPM
Falls Church, VA 22041-3803.

Re: NEPA Scoping Comments for Proposed Incidental Take Permit and Habitat Conservation Plan; Docket No. FWS-R5-ES-2016-0135

Delaware Riverkeeper Network submits these comments on NEPA Scoping Comments for Proposed Incidental Take Permit and Habitat Conservation Plan; Docket No. FWS-R5-ES-2016-0135. The U.S. Fish and Wildlife Service (FWS) noticed in the Federal Register its "…intent to prepare a draft environmental impact statement (EIS) for proposed issuance of an incidental take permit (ITP) under section 10(a)(1)(B) of the Endangered Species Act (ESA) for the draft Oil & Gas Coalition Multi-State Habitat Conservation Plan (O&G HCP). The O&G HCP is being developed to streamline environmental permitting and compliance with the ESA for nine companies in conjunction with their respective midstream and upstream oil and gas exploration, production, and maintenance activities in Ohio, Pennsylvania, and West Virginia over a 50-year period."[1] The bat species that would be covered by the ITP are: the endangered Indiana bat (*Myotis sodalis*), the threatened northern long-eared bat (*Myotis septentrionalis*), the little brown bat (*Myotis lucifugus*), the eastern small-footed bat (*Myotis leibii*), and the tri-colored bat (*Perimyotis subflavus*).

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[1] **Federal Register** / Vol. 81, No. 227 / Friday, November 25, 2016 / Notices, Department of the Interior, Fish and Wildlife Service, pages 85250-54

Delaware Riverkeeper Network urges the FWS to deny the application. The current and projected decline of these five bat populations places these species in peril due to disease such as white nose syndrome, harmful human and environmental interventions such as development, traffic, feral cat predation, wind turbines[2], and climate change, and habitat degradation and loss. The additional harm from oil and gas activity under the ITP could result in the inability of these bats to survive and recover in the wild from the "…midstream and upstream oil and gas exploration, production, and maintenance…"[3] activities' adverse effects, in violation of the Endangered Species Act and FWS regulations. Additionally, the uncertainty of the future condition of these species, the uncertain future of oil and gas development, the uncertainty of other impacts such as human interference, and unreliable oversight and monitoring efforts by companies and agencies, compound to undermine the reliability and accuracy of any modeling that projects future conditions, making it impossible to prepare and carry out an effective Habitat Conservation Plan (HCP).

If FWS moves ahead with this application to prepare an EIS, Delaware Riverkeeper Network provides the following comments to be considered in the drafting of an EIS.

Build Out of oil and gas development and the individual and cumulative impacts

Delaware Riverkeeper Network considers the analysis that will model the build out of gas and oil development in Pennsylvania, West Virginia and Ohio to be of paramount importance in evaluating the impacts that this development will have on these species and their habitat. In a report issued by CNA "Potential Environmental Impacts of Full-development of the Marcellus

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[2] Bats of several migratory tree-dwelling species are being killed in unprecedented numbers at wind turbines. By 2020 an estimated 33,000 to 111,000 bats will be killed annually by wind turbines in the Mid-Atlantic Highlands alone (T. H. Kunz *et al*., *Front. Ecol. Environ* 5, 315 (2007) from Boyles, J., "Economic Importance of Bats in Agriculture", www.sciencemag.org SCIENCE VOL 332 1 APRIL 2011. Arnett E. B., W. K. Brown, W. P. Erickson, J. K. Fiedler, B. L. Hamilton, T. H. Henry, A. Jain, G. D. Johnson, J. Kerns, R. R. Koford, C. P. Nicholson, T. J. O'Connell, M. D. Piorkowski, and R. D. Tankersley, Jr. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management, 72:61–78 from Hein, C. D. 2012. "Potential Impacts of Shale Gas Development on Bat Populations in The Northeastern United States", unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas.

[3] **Federal Register** / Vol. 81, No. 227 / Friday, November 25, 2016 / Notices, Department of the Interior, Fish and Wildlife Service, pages 85250-54

Shale in Pennsylvania"[4], funded by Delaware Riverkeeper Network, a geospatial analysis methodology was used to identify build out locations and a select number of environmental impacts. The maps that resulted show several categories of impacts including land use changes, forest fragmentation, air emissions, water withdrawals, and wastewater generation.

These findings excerpted from this report should be used as guideposts for an analysis of some of the build out impacts in the Commonwealth of Pennsylvania in the Marcellus Interior Shale formation:

- **Well development** – 47,600 additional wells could be developed on 5,950 well pads over the next 30 years in Pennsylvania.
- **Land use change** – Natural gas infrastructure (well pads, gathering pipelines, and access roads) to support projected well development would result in about 94,000 acres of land disturbance. Over half (about 51,000 acres) of the land disturbance would impact agricultural land, while about 28,000 acres would constitute the clearing of forest cover.
- **Forest change –** Of the 28,000 acres of forest that would be cleared, 12,700 acres were core forest areas (over 100 meters from the nearest forest edge). Additionally, over 88,000 acres of core forest would be fragmented by road and pipeline development and converted to edge forest. Thus, over 100,000 acres of core forest would be lost due to the combined effect of clearing and fragmentation.
- **Air emissions –** The additional well development would result in greater emissions of NOx, VOCs, and CH4 from activities related to well preproduction and production, and compressor stations for moving gas through gathering lines. When the play nears full development (i.e., ongoing emissions from producing wells reach their peak), the annual average air emissions could reach 37,000 tons per year for NOx, 22,500 tons per year for VOCs, and 388,000 tons per year for methane. Air emissions not only emit to the air but also deposit on vegetation and water, posing a risk of additional contaminant pathways for wildlife such as bats. CH4 (methane) is a powerful greenhouse gas, 86 times more powerful in trapping heat than carbon over a 20 year time frame.
- **Water use, withdrawal, and consumptive use –** The projected natural gas development in the Marcellus in Pennsylvania would require 242 billion gallons of water in total, in order

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[4] Hansen, L., Habicht, S., and Faeth, P., CNA, "Potential Environmental Impacts of Full-development of the Marcellus Shale in Pennsylvania", September 2016.

to mix frac fluid for the hydraulic fracturing process. Averaged over 30 years, this is a water use rate of 34 cubic feet per second or 22 million gallons per day. Roughly 200 billion gallons of fresh surface water would be withdrawn to support this development, and 167 billion gallons would be used consumptively and would not re-join the hydrologic cycle after hydraulic fracturing injection.

- **Wastewater generated –** 84 billion gallons of wastewater would be generated from projected natural gas development in Pennsylvania. Wastewater includes drilling fluid waste, plus flowback and produced water/brine recovered from the shale after frac fluid injection and during gas production.[5]

Adverse impacts of gas and oil development on bats

Over nine thousand unconventional Marcellus Shale wells have been drilled in Pennsylvania[6]. PADEP has issued over 16,000 drilling permits. Since the boom began, about 10 years ago but not in earnest until 2008, over 5,000 violations of oil and gas permits by drillers have been issued by PADEP through 2015. [7] [8]

Various aspects of unconventional shale gas development adversely affect bat populations, including water withdrawals, water contamination and toxic exposures, habitat loss and degradation including the loss of biodiversity in the natural environment, and greenhouse gas emissions. These direct and indirect impacts to imperiled bats and their hibernating, breeding, foraging, and roosting habitats compound the threats posed by white nose syndrome (WNS) and other impacts such as wind turbines, human disturbance, development and other land use changes.[9] More information is in the attached report: Potential Impacts of Shale Gas Development on Bat Populations in The Northeastern United States, Hein, C. D. 2012. In

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[5] *Ibid*. p. iv-v.

[6] DEP counts wells according to conventional and unconventional. These definitions are in the state regulations and are based on depth of formation and drilled horizontally within the formation—Marcellus wells are unconventional wells. The definition of unconventional well is found at 25 Pa. Code, Ch. 78.1.

[7] Total Unconventional Wells as of Mar. 27, 2015", 04.24.2015, provided by The FracTracker Alliance on FracTracker.org.

[8] http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Wells_Drilled_By_County.

[9] Hein, C. D. 2012. "Potential Impacts of Shale Gas Development on Bat Populations in The Northeastern United States", unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas.

addition, bats naturally have low reproductive rates and respond slowly to rapid population declines.[10] For instance, the Indiana bat only gives birth to one young per year.[11]

In terms of water contamination and toxic exposures, oil and gas development's use of toxic and hazardous substances in hydraulic fracturing fluids used to stimulate gas and oil well production involves the transport, storage, mixing and injection of highly toxic compounds. 1,076 chemicals are known to be used in hydraulic fracturing fluids, according to the U.S. Environmental Protection Agency (EPA). These include acids, alcohols, aromatic hydrocarbons, bases, hydrocarbon mixtures, polysaccharides, and surfactants such as lead, ethylene glycol, benzene, toluene, and xylene compounds.[12]

Hydraulic fracturing produces waste that contains many of the hazardous and toxic constituents that are injected and also deep geology pollutants that are disturbed, distributed and ejected to the surface by hydraulic fracturing, exposing the environment and those who live in it to the increased risk of disease and adverse health effects from exposure to the toxins. Contaminants "…can include, but are not limited to: salts (chlorides, bromides, and sulfides of calcium, magnesium, and sodium); metals (including barium, manganese, iron, and strontium); oil, grease, and dissolved organics (including benzene and toluene); naturally occurring radioactive materials (NORM); and production chemicals from hydraulic fracturing…Exposure to these contaminants at high levels may pose risks to human health and the environment".[13] The depth of the shale formation influences the salt and mineral content of the produced water; generally, the deeper the formation, the higher the salt and minerals.

Produced water from Marcellus Shale can have salt and mineral levels 20 times higher than coalbed methane wells, for instance.[14] High salt levels (represented as Total Dissolved Solids or

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[10] Barclay, R. M. R. and L. D. Harder. 2003. Life histories of bats: life in the slow lane. *In* T.H. Kunz and M.B. Fenton (eds), Bat ecology. University of Chicago Press; Chicago, IL from Hein, C. D. 2012. "Potential Impacts of Shale Gas Development on Bat Populations in The Northeastern United States", unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas, and p.13.

[11] http://www.pgc.pa.gov/Wildlife/EndangeredandThreatened/Documents/Indiana%20Bat.pdf

[12] Environmental Protection Agency (EPA). 2015. Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources – External Review Draft. June 2015. Available at: www.epa.gov/hfstudy; Hein 2012, p. 2.

[13] US General Accountability Office, ***Information on the Quantity, Quality, and Management of Water Produced During Oil and Gas Production***, GAO-12-56, January 2012.

[14] *Ibid.*

TDS), typical of Marcellus Shale gas wastewater, are toxic to the natural environment and can carry significant adverse impacts, including impairment and death of aquatic life. In 2010, DEP stated that "…many of the rivers and streams of Pennsylvania have a very limited ability to assimilate additional TDS, sulfates and chlorides because of elevated levels from historic practices".[15] Mercury, likewise, is a toxin found in gas drilling wastewater[16] that has severe health impacts.[17] EPA has set a safe drinking water limit of 2 ppb, reflecting that tiny amounts of mercury can contaminate water supplies and will have direct health effects.

The radioactive isotopes that are brought to the surface from the ancient shales that are being fractured for gas and oil are produced in the form of solids (rock cuttings), liquids (drilling fluids, flowback water and brine), and gas (radon).[18]

According to the Resnikoff Review[19] of PA Department of Environmental Protection's (PADEP) NORM Study[20]:

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[15] PADEP "Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges", April 11, 2009.

[16] New York State Department of Environmental Conservation, ***Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and other Low-Permeability Gas Reservoirs***, September 2011, Table 5.9.

[17] **Mercury CAS #: 7439-97-6, How can mercury affect my health?** The nervous system is very sensitive to all forms of mercury. Methylmercury and metallic mercury vapors are more harmful than other forms, because more mercury in these forms reaches the brain. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause effects including lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation. **How likely is mercury to cause cancer?** There are inadequate human cancer data available for all forms of mercury. Mercuric chloride has caused increases in several types of tumors in rats and mice, and methylmercury has caused kidney tumors in male mice. The EPA has determined that mercuric chloride and methylmercury are possible human carcinogens. **How does mercury affect children?** Very young children are more sensitive to mercury than adults. Mercury in the mother's body passes to the fetus and may accumulate there. It can also pass to a nursing infant through breast milk. However, the benefits of breast feeding may be greater than the possible adverse effects of mercury in breast milk. Mercury's harmful effects that may be passed from the mother to the fetus include brain damage, mental retardation, incoordination, blindness, seizures, and inability to speak. Children poisoned by mercury may develop problems of their nervous and digestive systems, and kidney damage. http://www.atsdr.cdc.gov/tfacts46.pdf

[18] Marvin Resnikoff, Ph.D., Radioactive Waste Management Associates, "Review of Pennsylvania Department of Environmental Protection Technologically Enhanced Naturally Occurring Radioactivity Materials (TENORM) Study Report", December 2015.

[19] Resnikoff, M., Radioactive Waste Management Associates, "Review of Pennsylvania Department of Environmental Protection Technologically Enhanced Naturally Occurring Radioactivity Materials (TENORM) Study Report", December 2015, p.1.

> “It has been known since the 1960’s that the Marcellus shale formation is radioactive[21]. Drilling logs by gas companies[22] and reports by USGS[23] show that underground/subsurface radium concentrations in the Marcellus shale are up to 32 times surface background concentrations. More recent measurements by New York State DEC show radium in rock cuttings over 200 times background concentrations[24].” Resnikoff 2015 at 1.
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> “Measurements by Duke University scientists[25] that showed elevated levels of chloride and bromide, combined with the strontium, radium, oxygen, and hydrogen isotopic compositions reflect the effluents of Marcellus Shale produced waters. According to the study, the discharge of the effluent from the treatment facility increased downstream concentrations of chloride and bromide above background levels. In particular, Ra-226 concentrations in stream sediments at the point of discharge were 200 times greater than upstream and background sediments and above radioactive waste disposal threshold regulations.” Resnikoff 2015 at 12.

Compounding the problems posed by wastewater contaminants is inadequate regulation that results in disposal of waste that is not protective of the environment and those who live in it, including bats, and increases exposure to harmful substances. Currently, no set of federal regulations for waste produced during hydraulic fracturing exist except for a prohibition by EPA for the treatment of gas and oil wastewater at sewage treatment facilities. This only addresses part of the management issues and will leave some critical loopholes in place that pose environmental threats. Because of a 1988 oil and gas industry waste exemption from the Resource Conservation and Recovery Act (RCRA), oil and gas waste is not regulated as hazardous, even though it contains hazardous constituents.[26] The list of RCRA exempt wastes includes produced

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[20] PADEP, Permafix, “Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) Study Report, January 2015.

[21] Swanson, VE, “Oil Yield and Uranium Content of Black Shales,” USGS paper 356-A, 1960.

[22] Resnikoff, M, Alexandrova, E, and Travers, J. "Radioactivity in Marcellus Shale." Report Prepared for Residents of for the Preservation of Lowman and Chemung, 2010.

[23] *Ibid.*

[24] NYSDEC, Division of Environmental Remediation, August 2012, re. Allied Landfill, Niagara County.

[25] Warner, NR, et al, “Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania,” Enviro Science and Technology, Oct 2, 2013, pp. 11849.

[26] Oil and Gas operations are exempt from portions of major federal environmental laws including: Clean Air Act; Clean Water Act; Safe Drinking Water Act; Resource Conservation and Recovery Act, Comprehensive Environmental Response, Compensation and Liability Act (the Superfund Law); and Emergency Planning and Community Right-to-Know Act. Amy Mall, et. al., Natural Resources Defense Council, ***Drilling Down***, October 2001, p.iv.

water, drilling fluids and muds, drill cuttings, hydrocarbons, hydraulic fracturing fluids, pit sludges, certain gases and hydrocarbons, workover wastes and sediment from the bottom of tanks.[27]

The incidence of environmental and water pollution occurring from the use of these toxic substances has increased as development of hydraulically fracked wells has increased. In the most recent compendium of scientific papers and literature, the Concerned Health Professionals of New York and Physicians for Social Responsibility found[28]:

> "Specifically, as demonstrated by PSE's statistical analysis of the body of scientific literature available from 2009-2015—which, at the date of publication included 685 peer reviewed papers—69 percent of original research studies on water quality found potential for, or actual evidence of, water contamination; 87 percent of original research studies on air quality found elevated air pollutant emissions; and 84 percent of original research studies on human health risks found signs of harm or indication of potential harm." CHP at 4.

Medical professionals in Pennsylvania are so alarmed by the proliferation of pollution events and reported health effects from the development of shale gas in the Commonwealth that they passed Resolution 16-206 entitled "Pennsylvania Medical Society Support for a Moratorium on Fracking" at its annual meeting in October 2016. Citing increasing negative effects, the Society resolved: "That the Pennsylvania Medical Society urge and support a moratorium on new natural gas extraction using high-volume hydraulic fracturing in Pennsylvania" and "That the Pennsylvania Medical Society urge the state legislature to fund an independent health registry and commission research studies on the health effects of fracking."[29]

An October 2016 analysis from the Yale School of Public Health found carcinogens and other dangerous chemicals in fluids used in hydraulic fracturing. The study, which lead author and assistant professor Nicole Deziel said "represents the most expansive review of carcinogenicity of hydraulic fracturing-related chemicals in the published literature," examined more than 1,000

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[27] U.S. Environmental Protection Agency, "Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations," p. 10-11, http://epa.gov/osw/nonhaz/industrial/special/oil/oil-gas.pdf

[28] Concerned Health Professionals of New York and Physicians for Social Responsibility, "Compendium of Scientific, Medical, And Media Findings Demonstrating Risks And Harms Of Fracking (Unconventional Gas And Oil Extraction)", Fourth Edition, November 17, 2016.

[29] Pennsylvania Medical Society, "Support for a Moratorium on Fracking", Resolution 16-206, October 23, 2016.

chemicals that may be released into air or water as a result of fracking.[30] It found that 44 percent of the water pollutants and 60 percent of air pollutants were either confirmed or possible carcinogens of the 119 compounds for which sufficient data exists. More than 80 percent of those chemicals lacked sufficient data on cancer-causing potential, supporting a pressing need for further research, with 20 of those tied to increased risk for leukemia or lymphoma, specifically highlighting concern for childhood leukemia.[31]

The incidence of water contamination, both surface water and aquifers that express to the surface as a result of hydraulic fracturing for oil and gas, is also documented by PADEP files available on line and through file reviews. The current on-line report of private well water contamination in the state documented 284 water well contamination cases that were determined by PADEP to have been caused by oil and gas operations as of 12.13.2016[32]. These are considered a vast underestimate due to many incidents of water pollution that have resulted in non-disclosure agreements so are not in the public reporting system and many cases that have not been resolved such as the Woodlands, Butler County, PA where families have been without clean water for over 5 years, relying on donated water from the community until their case is resolved.

The fact is that water wells have been contaminated by oil and gas development in Pennsylvania despite regulations and claims of enforcement of those regulations by PADEP. Adding to the evidence of environmental pollution from oil and gas development in Pennsylvania, there have been 3,383 resolved complaints of water supply pollution incidents related to oil and gas from January 1, 2007 to December 27, 2016 according to PADEP on-line records[33]. Combined with the over 5,000 known violations documented by PADEP, also considered an underestimate due to lack of adequate government oversight in the field, the problem of pollution of water supplies and the environment by oil and gas is undeniable.

Bats may ingest water from frack ponds that may contain contaminants. These basins, located either at oil or gas well pad sites or regionally serving several well sites, hold water for the

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[30] Deziel, N. et al, Yale School of Public Health, Journal of Exposure Science and Environmental and Epidemiology, January 2016.

[31] *Ibid.*

[32] http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Determination_Letters/Regional_Determination_Letters.pdf accessed by DRN 12.27.2016

[33] http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Complaints/CTS_WS_Complaints accessed by DRN 12.27.2016

hydraulic fracturing of wells or frack wastewater. The water contained in these ponds can have dangerous levels of contaminants. According to the Hein shale gas bat report, “The percentage of chemical additives in a typical HVHF operation is <0.5% by volume but can reach as high as 2% by volume (Soeder and Kappel 2009, NYSDEC 2011). Thus, an HVHF operation using 5 million gallons of water can use 25,000 to 100,000 gallons of chemical additives.”[34] Fluids containing contaminants utilized or produced by hydraulic fracturing, as well as methane, can occur in ponds and also are released as spills, leaks, expressions to the surface from underground or in accidents, exposing the toxins to bats and insect habitat.

Bats are especially sensitive to chemicals and ingest chemicals through water intake, roosting on contaminated vegetation, and ingestion of contaminated insects. As documented by the Pennsylvania Game Commission, “Bats have a history of accumulating contaminants found in pesticides. This was particularly true when organochlorine pesticides such as DDT had a strong presence in our environment. It's unclear if the pesticides that have replaced the now banned organochlorines are being bioaccumulated by bats.” PGC at 3. The potential for bats to accumulate or have immediate impacts from the ingestion of or exposure to water, insects or other contaminated media will add to the burden these animals must face from oil and gas development.

Water withdrawals for oil and gas development impact bat habitats by effecting the volume, flow and quality of surface and groundwater. Hydraulic fracturing requires large volumes of water per high-volume well in the shale regions in Pennsylvania, Ohio and West Virginia. Estimates ranging from 2 to 7 million gallons of water are used per operation, depending on conditions of the site (NYDEC 2011, Susquehanna River Basin Commission [SRBC] 2010, US Environmental Protection Agency [USEPA] 2011). These withdrawals can adversely impact surface water relied upon by bats and the insects they eat. Concentration of contaminants can occur when aquifers are overdrawn, reducing base flow of streams, in turn affecting water quality and water-born insects. As explained in Hein’s shale gas bat study[35]:

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[34] Boyles, J., Economic Importance of Bats in Agriculture, www.sciencemag.org SCIENCE VOL 332 1 APRIL 2011, p. 3.

[35] Hein, C. D. 2012. “Potential Impacts of Shale Gas Development on Bat Populations in The Northeastern United States”, unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas.

> “In the northeastern US, shale formations (e.g., Devonian, Marcellus, and Utica) underlie a number of sensitive watersheds, such as the upper Delaware River, a designated Wild and Scenic River that supplies drinking water to >15 million people. Stakeholder concerns include the high rate of water removal from small streams at the headwaters of these watersheds (Maclin et al. 2009, Myers 2009). Withdrawals of large quantities of water at these locations can significantly affect the hydrology and hydrodynamics of surface water resources. Changes in water depth can alter the flow regime, velocity, and temperature of springs, streams and lakes, affecting *in situ* flora and fauna (Zorn et al. 2008). Additionally, removal of significant volumes of water can reduce the dilution effect and increase the concentration of contaminants in surface water (Pennsylvania State University 2010).
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> Ground water resources (e.g., aquifers) also are tapped for HF operations. Rapid withdrawal from aquifers can lower the water table levels, changing water quality by exposing naturally occurring minerals to an oxygen-rich environment, potentially causing chemical changes that alter mineral solubility and mobility, leading to salination of water and other chemical contaminations. Lower water tables also may cause upwelling of lower quality water and other substances (e.g., methane) from deeper within an aquifer and could lead to subsidence or destabilization of the local geology. (USEPA 2011)” Hein 2012 at 2.

According to a report from the National Conference of Undergraduate Research, streams are very important habitat for bats and stream quality, which affects macroinvertebrate abundance and subsequent insect biomass, affects bat foraging. Industrial activities from mining and Marcellus shale gas development in Pennsylvania depress insect abundance due to water quality harms, reducing the number of insects available as insect prey for bats. As explained in the report[36]:

> “Streams provide an important habitat for foraging among the nine species of insectivorous bats (family Vespertilionidae) found in Pennsylvania, particularly the common Myotis lucifugus (little brown bat). Many streams in Pennsylvania are negatively impacted by abandoned mine drainage (AMD), while an unknown number face further impending damage from Marcellus Shale natural gas drilling projects. The researchers attempted to determine the effects of stream quality on bat foraging. Stream benthic macroinvertebrate abundance was expected to be positively correlated with stream quality, and bat foraging was hypothesized to be greater in stream locations with higher water quality and associated high levels of insect abundance.” Payne 2011 at 1.

In terms of habitat loss, Bradford and Washington Counties, Pennsylvania, where unconventional shale gas and coal bed methane development has been occurring over recent years was studied by the U. S. Geological Survey; the results document the massive landscape changes that are

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[36] Payne, C., Biology Department, Saint Vincent College, “Bat Foraging in Riparian Zones: Responses to Stream Quality, Insect Abundance and Season”, 2011.

reshaping forest and farm lands in Pennsylvania through the construction of gas wells and impoundments as well as supporting infrastructure of roads and pipelines.[37] The report documents the overall loss of forest habitat as well as the increase in forest fragmentation that shale gas and coalbed methane development has caused over a very short time period.

In Bradford County, 0.12 percent of the county's forest was lost to gas development, contributing to a 0.32 loss of interior forest and a gain of 0.11 percent in edge forest. In Washington County, the USGS report documented a 0.42 percent forest loss, contributing to a 0.96 percent loss of interior forest and a gain of 0.38 percent in edge forest. USGS Report at 28-29. Pipeline construction and associated road construction had the greatest effect on the increase in forest fragmentation, patchiness, and forest edge. This industrialization of the landscape for unconventional fossil fuel development is a huge concern for forest-dependent bat species, as those areas of Pennsylvania that have the highest concentrations of forested lands also constitute the primary areas targeted for shale gas and coalbed methane extraction, as well as oil development.

The scope and scale of the transformational impacts of unconventional fossil fuel extraction on forested landscapes throughout the Commonwealth that support these imperiled bat species are illustrated in two reports by the Nature Conservancy. The first documents the potential cumulative habitat impacts from energy development under low, medium, and high development scenarios.[38] In forested areas, where 30 acres of forest are affected directly (8.8 acres per well pad and associated infrastructure) and indirectly (21.2 acres from new forest edge), these scenarios result in a loss of forest from Marcellus Shale development alone (i.e., not including shale gas efforts targeting other formations or coalbed methane extraction efforts) of between 15,300 acres in the low scenario to 283,300 acres in the high scenario. TNC Report 1 at 18. Nearly two-thirds of well pads are projected to be in forest areas. TNC Report 1 at 29.

The second Nature Conservancy report used the same low, medium and high development scenarios as in Report 1 to estimate the miles of gathering pipelines that will be constructed to

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[37] U.S. Geological Survey, "Landscape Consequences of Natural Gas Extraction in Bradford and Washington Counties, Pennsylvania, 2004-2010" (Open-File Report 2012-1154).

[38] Nels Johnson, et al., The Nature Conservancy. "Pennsylvania Energy Impacts Assessment: Report 1: Marcellus Shale Natural Gas and Wind", November 2010.

support Marcellus Shale gas extraction sites.[39] In forested areas the habitat loss will not just be in the immediate footprint of the pipeline, but it will impact an additional 300 feet of forest on either side of the ROW.[40] This means that for every mile of pipeline cut through a forest an additional 12 acres of forest will be harmed.

In terms of gathering lines alone (i.e., pipelines that run from each well pad to centralized transmission lines), the Nature Conservancy's second report estimates that between 10,000 and 25,000 miles of new gathering lines will be constructed. Conservatively estimating that fifty percent of all future pipelines will be built in forest areas, this report estimates that between 60,000 and 150,000 forested acres will be cleared for new gathering lines and rights-of-way over the next two decades, and that an additional 360,000 to 900,000 acres of new forest edge will be created. TNC 2 at 5. The report does not estimate the forest acres to be cleared or adversely affected by major interstate gas transmission lines, but this acreage will be significant as well, as will the acreage affected by compressor station construction and other gas-related infrastructure projects.

Habitat loss impacts are well illustrated by an examination of the preferred habitat for the Indiana bat, as documented by the Pennsylvania Game Commission (PGC).[41]

> "Indiana bat hibernation sites have stringent requirements, including noticeable airflow and the lowest non-freezing temperatures possible. Only a small percentage of available hibernacula provide these temperatures. Indiana bat sites usually also have some standing or flowing water. Primary maternity roosts are trees (often large, dead ones) with exfoliating bark and sun exposure that results in high temperatures, while males seek cooler roosts. Most roosts are within a ¾ mile of water. A multi-year PGC study of female Indiana bats from the church maternity colony found that their primary insect-foraging habitat was on gentle to moderate south-facing slopes covered by mixed oak or mixed northern hardwood forests". PGC at 2.

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[39] Nels Johnson, et al., The Nature Conservancy, "Natural Gas Pipelines: Excerpt from Report 2 of the Pennsylvania Energy Impacts Assessment" December 2011.

[40] *Ibid.,* CNA, *The Potential Environmental Impacts of Fracking in the Delaware River Basin*, 2015; Cara Lee, Brad Stratton, Rebecca Shirer, Ellen Weiss, *An Assessment of the Potential Impacts of High Volume Hydraulic Fracturing (HVHF) on Forest Resources*, The Nature Conservancy, Dec. 19, 2011.

[41] http://www.pgc.pa.gov/Wildlife/EndangeredandThreatened/Documents/Indiana%20Bat.pdf

In terms of changes to habitat caused by oil and gas development that results in loss of biodiversity, according to the Kiviat Wildlife Study, high-volume horizontal hydraulic fracturing threatens biodiversity in many ways. Especially vulnerable are species "…with small geographic ranges and a large overlap with the extensively industrializing Marcellus and Utica shale-gas region" and "… those sensitive to forest fragmentation and loss or to degradation of water quality, two notable impacts of fracking." [42] "Biodiversity at all levels, from genes to ecosystems, constitutes many important values to human society and ecosystem functions, as well as the intrinsic importance of each species.[43] Conserving biodiversity is important because each species has unique compounds, behaviors, and other information that we may be able to use to improve human health, biotechnology, and enjoyment. Biodiversity is also of great value to the function of ecosystems—and we do not know how the elimination of certain species will affect ecosystem function." Kiviat at 10.

The loss of bats and bat species has economic impacts for humans. In a report on the economic benefits of bats to agriculture, the authors point out that bats are voracious predators of nocturnal insects, including many crop and forest pests. The "…loss of bats in North America could lead to agricultural losses estimated at more than $3.7 billion/year."[44] The report documents further[45]:

> "For example, a single colony of 150 big brown bats (*Eptesicus fuscus*) in Indiana has been estimated to eat nearly 1.3 million pest insects each year, possibly contributing to the disruption of population cycles of agricultural pests (*8*). Other estimates suggest that a single little brown bat can consume 4 to 8 g of insects each night during the active season (*9*, *10*)." Boyles 2011 at 41.

Overall, the environmental impacts of oil and gas development, including the removal of forests and trees (living and dead), the diminishment of surface water availability and the contamination of available water, the disturbance of and alteration of caves and other hibernacula, and land use changes that reduce surface habitat and other environmental changes that change habitat or

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[42] Kiviat, E. and Gillen, J., "Hydraulic Fracturing Threats to Species with Restricted Geographic Ranges in the Eastern United States", ENVIRONMENTAL REVIEWS AND CASE STUDIES, 2012, p.1 doi:10.10170S1466046612000361

[43] Wilson, E.O. 1992. *The Diversity of Life*. Harvard University Press, Cambridge, MA, 424 pp.

[44] Boyles, J., Economic Importance of Bats in Agriculture, www.sciencemag.org SCIENCE VOL 332 1 APRIL 2011.

[45] *Ibid.*

reduce insect populations, all have direct impacts that can reduce bat populations and the health of species.

Additionally, it is important to recognize that ecosystems function as naturally connected systems, much like pulling on a thread unravels a fabric. The Indiana bat, for instance, partners in roosts with the little brown bat in Pennsylvania, demonstrating the interrelation of some bat species and that impacts to one species has effects on others. Impacts must be considered from this comprehensive perspective.

Greenhouse gas emissions and climate change implications

On August 1, 2016, The Council on Environmental Quality (CEQ) issued final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews. The final guidance directs federal agencies on how to consider a proposed action’s impacts on climate change—both in terms of the potential effects of *a proposed action on climate change* (by assessing the GHG emissions that would result *directly and indirectly* from the action) and in terms of the effects of *climate change on a proposed action* and its environmental impacts.

The guidance, building off of recent scientific assessments and conclusions, including the 2009 EPA finding that climate change impacts are “reasonably anticipated to endanger the public health and public welfare of present and future generations”, states that “Climate change is a fundamental environmental issue, and its effects fall squarely within NEPA’s purview.” The document acts as a guide for federal agencies to apply NEPA principles and practices to the analysis of GHG emissions and climate change.

The FWS must address how greenhouse gas emissions and resulting climate change from the development of oil and gas in the three Ohio, West Virginia, and Pennsylvania will effect these bat populations. The increased greenhouse gas emissions from the development of oil and gas using hydraulic fracturing will exacerbate global warming and climate change because the potential for warming of the atmosphere by methane is 86 times more powerful than carbon on a 20 year time frame. According to Hein's shale gas bat study[46]:

> "During combustion, natural gas emits less carbon dioxide (a greenhouse gas (GHG)) and less nitrogen oxide and sulfur oxide (two contaminants contributing to acid rain) (Entrekin et al. 2011) than coal. However, during extraction, shale gas development produces considerable amounts of methane, a major component of natural gas and a powerful GHG (Howarth et al. 2011). The amount of fugitive emissions of methane into the atmosphere during HVHF operations compared to conventional operations may contribute more to global warming than other fossil fuel development (USEPA 2010). Howarth et al. (2011) calculate that during the life cycle of an average shale gas well, 3.6–7.9% of the total production of the well is emitted to the atmosphere as methane, which is at least 30% to 50% as great as estimated for a conventional well. Methane dominates the GHG footprint for shale gas on a 20-yr time horizon, contributing 1.4–3 times more than does carbon dioxide emission, resulting in a GHG footprint for shale gas at 22%–43% greater than that for conventional gas." Hein 2012 at 6.

The impacts on bats of climate change has not received much study but the sensitivity of bats to temperature changes signals a likely potential for adverse effects, including reproductive ability. In addition, changes to precipitation and stream levels will affect availability and abundance of insects for bats. According to Hein's shale gas bat study:

> "The effects of climate change on bats have not been studied extensively. However, it is believed that insectivorous bats may be among the most affected species because seasonal temperature changes may affect hibernation, food abundance and availability, and recruitment (Jones et al. 2009). Most bat species have specific temperature regimes that are conducive for surviving over half the year in hibernation. For example, Indiana bats hibernate in caves or mines where the ambient temperature is consistently below 10° C (Hall 1962, Meyers 1964, Henshaw 1965, Humphrey 1978, Tuttle and Kennedy 2002). Tuttle and Kennedy (2002) reported that populations hibernating with temperatures between 3–7.2° C remained stable or increased, whereas populations hibernating at temperatures above or below this range were unstable or declined. With winter conditions expected to become shorter and warmer, disruptions to the mammalian overwintering energy budgets are expected (Gu et al. 2008). Milder winter conditions may force bats to enter hibernacula later than usual, presumably with inadequate fat reserves if food availability decreases in late fall (Matteson 2010). Warmer temperatures in winter also may result in unsustainable arousal frequencies (Humphries et al. 2002). Because arousals

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[46] Hein, C. D. 2012. "Potential Impacts of Shale Gas Development on Bat Populations in The Northeastern United States", unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas.

> account for up to 80% of the energy budget (Thomas 1995) of hibernating bats, any increase in frequency or duration could decrease survivorship." Hein 2012 at 11-12.

In its 12.20.2016 webinar presentation, FWS discussed the Habitat Conservation Plan (HCP) that would be required by the issuance of an Incidental Take Permit (ITP). A cornerstone of that plan, as with all habitat conservation plans, is monitoring and oversight of its implementation. Delaware Riverkeeper Network has experience monitoring the construction of gas pipelines, one of the activities that the ITP would cover. Based on this experience, we advise that adequate monitoring and adherence to environmental planning and permits cannot be expected for pipeline projects, one of the activities that would be covered by the HCP.

As the result of document reviews and field investigations during construction of three sections of pipeline in Pennsylvania -- the TGP 300 line upgrade, TGP Northeast Upgrade Project (NEUP), and Columbia 1278 pipeline -- in the Upper Delaware River Basin, the Delaware Riverkeeper Network documented:

- over 60 instances where best management practices (BMPs) were not present, inadequate or not functioning or in need of repair, maintenance or reinforcement,

- 4 instances of fueling being conducted in wetlands or near waterbodies,

- dozens of instances of poor signage and staking and mapping errors which sometimes led to impacts off of the permitted Right of Way (ROW), loss of trees outside the ROW, and inaccurate mitigation calculations,

- thermal impacts, extreme (and unreversed) soil compaction, nutrient impacts, benthic invertebrate changes from pipeline cuts, including for streams with exceptional value, high quality and or C-1 anti-degradation classifications,

- discrepancies between pipeline company monthly compliance reports and what work and activities to meet compliance and avoid pollution were actually occurring or not occurring on the ground. We also noted excessive lag time in the filing and/or public release of construction reports making for difficult follow up in the field. We documented too few pipeline inspectors and a lack of oversight person-power for these extensive linear projects that spanned many miles and where work was going on simultaneously along the routes with little independent oversight.

Based on first hand observations and monitoring of these pipelines, it is clear that:

- Interstate natural gas pipeline projects result in a multitude of environmental impacts that inflict high levels of unnecessary ecological damage – this damage is not avoided, nor properly mitigated, despite the resource reports that are drafted or the guidance provided by PADEP or other federal or state agencies;

- Violations of environmental laws are common place and an accepted part of pipeline construction – and compliance outweighs penalties and violations to the detriment of the environment and the public;

- Construction problems and potential violations are not properly responded to by the company, by the PADEP or by other state or federal agencies and mitigation does not undo the harms inflicted - as a result of both, pipelines inflict enduring and/or repetitive harms on natural resources; and

- Current or proposed guidance from the PADEP or other regulatory agencies do not prevent, avoid, or otherwise mitigate these ecological and public harms or the multitude of bad practices used by the pipeline companies.

- To the extent that analyses do not build in a consideration that not all BMPs will be appropriately deployed and all aspects of plans will not be implemented as required, approval of an ITP or HCP is arbitrary.

DRN's observations in the field demonstrate and document that construction, implementation of a HCP and the rigors of an ITP, simply cannot be counted on, no matter what the promises. Indeed, in terms of compliance with environmental permits and implementation of BMPs during gas pipeline construction in Pennsylvania, even when in full compliance with regulatory standards, unavoidable, unmitigated and irreparable harm and violations of state water quality standards and wetlands protections routinely occur. In addition, Delaware Riverkeeper Network monitoring has documented that over and above these impacts, violations of law are commonplace during pipeline construction, operation and maintenance and as a result the violations of law, including water quality standards and wetland protections, resulting harms are further exacerbated. For further details on our field observations see: Delaware Riverkeeper Network *Field Monitoring Report, Pipeline Construction & Maintenance Irreparably Harms Rivers, Wetlands and Streams.*

For these reasons, based on field experience, we do not have confidence that a HCP or an ITP will be carried out as FWS intends nor that mitigation and minimization, required under FWS regulations and the Endangered Species Act, will be successfully achieved to avoid the endangerment of the presence of these five bats in the wild. Delaware Riverkeeper Network contends that the failure of companies to carry out the goals of planning and permitting for pipeline construction describe and predict the damages that can be expected under the proposed ITP.

Conclusion and Recommendation

Delaware Riverkeeper Network urges FWS to not approve the ITP based on abundant evidence that the impacts of oil and gas development in the three states will cause harm to the five bat species, which will endanger their presence in the wild. This is prohibited under Section 9 of the ESA and is contrary to FWS regulations, disallowing these proposed actions under Section 10 of the ESA. We arrive at this conclusion because of the already imperiled condition of these species and the documented statistical evidence in Pennsylvania and the Marcellus shale region of water contamination, environmental pollution, habitat degradation, greenhouse gas emissions, and the reasonable expectation, based on field experience, that implementation and enforcement of the ITP and HCP will not successfully avoid or minimize the taking of animals in the proposed five bat species. Under NEPA, we contend that the harms that will result from the ITP will significantly affect the human environment and are not mitigatable. If the project progresses, a comprehensive environmental impact statement under NEPA is required that analyzes cumulative and secondary as well as immediate and individual impacts and alternative actions to the proposed action.

Thank you for the opportunity to comment on the NEPA Scoping Comments for the Proposed Incidental Take Permit and Habitat Conservation Plan.

Respectfully submitted,

Maya van Rossum	Tracy Carluccio
the Delaware Riverkeeper	Deputy Director

Attachment: Hein, C. D. 2012. “Potential Impacts of Shale Gas Development on Bat Populations in The Northeastern United States”, unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas.

Impacts of Shale Gas Development on Bat Populations in the Northeastern United States

Indiana bat (*Myotis sodalis*). Photo credit: Bat Conservation International.

A report submitted to

The Delaware Riverkeeper Network

Bristol, PA

by

Bat Conservation International

Austin, TX

June 2012

Report Citation

Hein, C. D. 2012. Potential impacts of shale gas development on bat populations in the northeastern United States. An unpublished report submitted to the Delaware Riverkeeper Network, Bristol, Pennsylvania by Bat Conservation International, Austin, Texas.

Photo accessed February 2012 from http://towneforcongress.com/economy/solutions-with-hydraulic-fracturing/

ACKNOWLEDGEMENTS

Thanks to Maya K. van Rossum (Delaware Riverkeeper Network) and Mollie Matteson (Center for Biological Diversity) for providing background information, and relevant reports and other documentation useful in creating this report. Special thanks to Jane Davenport and Tracy Carluccio (Delaware Riverkeeper Network), Ed Arnett (Theodore Roosevelt Conservation Partnership), Katie Gillies (Bat Conservation International) for providing insightful reviews of this report.

BACKGROUND

Natural gas development from shale is rapidly expanding across the US (Ground Water Protection Council GWPC and ALL Consulting 2009). Shale gas reservoirs, or plays, are distributed across the country (Fig 1.) and can be found at depths ranging from 152–4,115 meters (m). The most productive plays include the Barnett, Haynesville, Fayetteville, Woodford and Marcellus Shales (Zoback et al. 2010). In the northeastern US, the Devonian, Marcellus, and Utica shales extend across several states and are located within the Appalachian Basin Province (Coleman et al. 2011).

Figure 1. Location and size of shale gas reservoirs, or plays, in the United States. Source: US Energy Information Administration (USEIA) based on published data.

The process of producing natural gas from shale and other unconventional reservoirs (i.e., formations with low permeability and porosity) requires fracturing the rock formation. In high-volume hydraulic fracturing (HVHF) operations, highly pressurized fluid, consisting of water and various chemicals, is used to create these fractures. Suspended in the fluid is a propping agent, typically sand, which maintains the openings and allows gas to migrate to the well (Carter et al. 1996, Entrekin et al. 2011). To increase the volume of rock accessed by a single vertical well, operators rotate the drill and bore horizontally through the shale bed. Up to fifteen separate HVHF operations are possible per well (Kargbo et al. 2010).

OBJECTIVES

Concerns regarding the potential impacts to humans and the environment have grown in conjunction with the rapid expansion of shale gas development. Issues regarding water withdrawal, water contamination, habitat loss and degradation, impacts to terrestrial and aquatic ecosystems, and greenhouse gas (GHG) emissions surround HVHF operations. Moreover, no data exist on the possible adverse influence these operations have on bat populations. Because of recent concerns regarding rapidly declining bat populations in the northeastern US, there is increasing concern about the additive effects HVHF operations could have on already imperiled bat species. This report will focus on the environmental effects associated with shale gas development and the potential impacts to bat populations in the region.

ENVIRONMENTAL IMPACTS

Water withdrawal. The HVHF process requires large volumes of water per well to fracture shale formations. Estimates ranging from 2 to 7 million gallons of water are used per operation, depending on conditions of the site (NYDEC 2011, Susquehanna River Basin Commission [SRBC] 2010, US Environmental Protection Agency [USEPA] 2011). In 2006, the estimated 35,000 fractured wells across the US used between 70–140 billion gallons of water, equivalent to the total amount withdrawn from drinking resources each year by 40–80 cities with populations of 50,000 people, or 1–2 cities of 2.5 million people (Halliburton 2008, USEPA 2011). Source water comes from either surface (e.g., streams or lakes) or ground water (e.g., aquifers). Water can be withdrawn from a nearby source or transported by trucks or a pipeline, and stored on-site by large tanks or impoundments (GWPC and ALL Consulting 2009). Because ground and surface water are hydraulically connected, changes in the quantity and quality to one likely influence the other (Winter et al. 1998).

In the northeastern US, shale formations (e.g., Devonian, Marcellus, and Utica) underlie a number of sensitive watersheds, such as the upper Delaware River, a designated Wild and Scenic River that supplies drinking water to >15 million people. Stakeholder concerns include the high rate of water removal from small streams at the headwaters of these watersheds (Maclin et al. 2009, Myers 2009). Withdrawals of large quantities of water at these locations can significantly affect the hydrology and hydrodynamics of surface water resources. Changes in water depth can alter the flow regime, velocity, and temperature of springs, streams and lakes, affecting *in situ* flora and fauna (Zorn et al. 2008). Additionally, removal of significant volumes of water can reduce the dilution effect and increase the concentration of contaminants in surface water (Pennsylvania State University 2010).

Ground water resources (e.g., aquifers) also are tapped for HVHF operations. Rapid withdrawal from aquifers can lower the water table levels, changing water quality by exposing naturally occurring minerals to an oxygen-rich environment, potentially causing chemical changes that alter mineral solubility and mobility, leading to salination of water and other chemical contaminations. Lower water tables also may cause upwelling of lower quality water and other substances (e.g., methane) from deeper within an aquifer and could lead to subsidence or destabilization of the local geology. (USEPA 2011)

Water contamination and toxic exposures. In addition to water, HVHF fluids typically include a combination of additives that serve as friction reducers, cross-linkers, breakers, surfactants, biocides, pH adjusters, scale inhibitors, and gelling agents (New York State Department of Environmental Conservation [NYSDEC] 2010). The goal is to achieve an ideal viscosity that encourages fracturing of the shale and improves gas flow, while discouraging microbial growth and corrosion which can inhibit recovery efficiency (US Department of Energy [USDOE] 2009). The percentage of chemical additives in a typical HVHF operation is <0.5% by volume but can reach as high as 2% by volume (Soeder and Kappel 2009, NYSDEC 2011). Thus, an HVHF operation using 5 million gallons of water can use 25,000 to 100,000 gallons of chemical additives. The types and concentrations of chemical additive and proppants vary depending on conditions of the specific well being fractured, and companies typically create fracturing fluid tailored to the specifics of the formation and needs of the project (USEPA 2011). The New York State Department of Conservation (2011) lists chemicals proposed for use in the state by shale gas developers, including 235 products in hydraulic fracturing fluids, containing 322 unique chemicals and at least 21 additional compounds.

In 2011, the US House of Representatives Committee on Energy and Commerce launched an investigation examining HVHF practices. The Committee found that "between 2005 and 2009, 14 oil and gas service companies used more than 2,500 additives, containing 750 chemicals and other components", including "29 chemicals that are: (1) known or possible human carcinogens; (2) regulated under the Safe Drinking Water Act for their risks to human health; or (3) listed as hazardous air pollutants under the Clean Air Act" (Waxman 2011). The Committee revealed that over the 4-year period these additives included lead, ethylene glycol, benzene, toluene, and xylene compounds. Moreover, the investigation reported that over 32 million gallons of diesel fuel, one of the only additives regulated by the Safe Drinking Water Act, were injected across nineteen states.

Wastewater is generated during the HVHF process in the form of flowback (i.e., fluid returned to the surface after HVHF has occurred, but before the well is placed into production) and produced water (i.e., the fluid returned after the well is placed into production) (USEPA 2011). During injection, HVHF fluids come in contact with the bedrock, often affecting the mobility of naturally occurring substances in the subsurface, particularly in the hydrocarbon-containing formation. These substances include formation fluids (e.g., brine or sodium chloride; Piggot and Elsworth 1996), gases (e.g., methane, ethane, carbon dioxide, hydrogen sulfide; Zoback et al. 2010), trace elements (e.g., mercury, lead, arsenic; Harper 2008, Leventhal and Hosterman 1982, Tuttle et al. 2009, Vejahati et al. 2010), naturally occurring radioactive material (e.g., radium, thorium, uranium: Leventhal and Hosterman 1982, Harper 2008, Tuttle et al. 2009, Vejahati et al. 2010) and organic material (e.g., acids, polycyclic aromatic hydrocarbons, benzene, toluene, xylene; URS Corporation 2009, NYSDEC 2011). Some of these substances may be liberated from the formation via complex biogeochemical reactions with the chemical additives found in hydraulic fracturing fluid (Long and Angino 1982, Falk et al. 2006). New York tested flowback from Marcellus Shale gas production in Pennsylvania and West Virginia and found 154 chemicals, many of which are health hazards and are regulated via primary and secondary drinking water standards (NYSDEC 2011). A list of chemicals identified in flowback and produce water is presented in USEPA (2011; Table E2).

Estimates for recovery of fracturing fluid in flowback for the Marcellus Shale range from 10–30% (Arthur et al. 2008). The physical and chemical properties of wastewater vary with fracturing fluid, geographic location, geology and time (Veil et al. 2004, Zielinski and Budahn 2007, Zoback et al. 2010, Rowan et al. 2011). During or prior to treatment, flowback and produced water often are retained on-site in storage tanks, open-air impoundments or evaporation ponds (GWPC and ALL Corporation 2009). Later, these fluids are transported to treatment facilities, injected underground, or discharged to waterways and the environment. Underground injection is the primary method of wastewater disposal from all major plays, except for the Marcellus Shale (Horn 2009, Veil 2007, 2010). For some operations, fluids are transported to wastewater treatment at publicly-owned treatment works or commercial wastewater treatment facilities. However, few facilities are capable of treating fluids containing dangerous contaminants (e.g., radioactive materials), brine (high salinity fluids), and unique compounds, which often are expensive to remove, generated by HVHF operations (Veil 2010, US General Accounting Office [USGAO] 2012).

Contamination from wastewater can occur at any time during operations. Large HVHF operations require extensive quantities of supplies, equipment, and vehicles, which may increase the risks of accidental releases, such as spills or leaks. Surface spills or releases can occur as a result of tank ruptures, impoundment failures, overfills, vandalism, accidents, or improper operations. Released fluids also may flow into nearby surface water bodies or infiltrate into the soil and near-surface groundwater (NYSDEC 2011). Entrekin et al. (2011) reported that 80% of Marcellus Shale gas wells are located within 200 m of riparian areas and 100% are within 300 m. Regulating the rapid expansion of HVHF operations is problematic and violations are common (Entrekin et al. 2011). For example, between January 2008 and December 2011 a total of 3,355 violations of environmental laws by 64 different Marcellus Shale gas drilling companies were reported by the Pennsylvania Department of Environmental Protection. Of these, 2,392 violations of these that likely posed a direct threat to our environment and were not reporting or paperwork violations (Staaf 2012).

The ability of naturally occurring but toxic substances or fracturing fluids to reach ground or surface waters is possible if fractures extend beyond the target formation and reach aquifers, or the casing or cement around wells fails causing contaminants to migrate into drinking water (USEPA 2011). Contamination also can occur through mismanagement and improper operating procedures, inadequate waste treatment practices, improper storage, or inadequately constructed impoundments or well casings. Occurrences of improper well construction and operation, allowing subsurface pathways for contaminant migration resulting in water pollution have been reported (State of Colorado Oil and Gas Conservation Commission 2009a, b, c, PADEP 2010, USAEPA 2010, McMahon et al. 2011). A study in the Marcellus Shale region concluded that methane gas was seventeen times higher in water wells closer to natural gas wells. (Osborne et al. 2011). The concentration of methane in these wells fell within the defined action level for hazard mitigation recommended by the US Office of the Interior (Eltschlager et al. 2001).

Sub-lethal impacts of shale gas development also may adversely influence aquatic environments and interfere with ecological interactions, such as whole-stream metabolism, decomposition of organic matter and accrual of macro-invertebrate biomass (Evans-White and Lamerti 2009). Land clearing during well pad and infrastructure (e.g., roads and pipelines) development, and increased road traffic throughout operations can increase sediment runoff into adjacent streams, lakes and wetlands (Williams et al. 2008, Entrekin et al. 2011). Excessive sediment in aquatic habitats results in higher levels of suspended and benthic particles, which may reduce stream flow, alter light, temperature, dissolved oxygen, and pH levels, and degrade spawning habitat for macro-invertebrate insects (Wood and Armitage 1999, Williams et al. 2008). Reductions in feeding efficiencies or the availability and abundance of prey can lead to negative effects on reproduction and growth of higher trophic-level animals (Peckarsky 1984, Sandheinrich and Atchison 1989, Burkhead and Jelks 2001). Moreover the introduction of chemicals associated with shale gas development (i.e., HVHF fluids and wastewater) can lead to a decline in production by eliminating sensitive taxa representing a majority of community growth and or biomass (Woodcock and Huryn 2007).

Habitat loss and degradation. Habitat loss or degradation is commonly associated with anthropogenic activities, including those of the oil and gas industry. Historically, with vertical drilling, one well pad equaled one well, but horizontal drilling allows for multiple wells per well pad (GWPC and ALL Consulting 2009). However, with the rapid expansion of this energy sector, hundreds of thousands of well sites are projected over the next twenty years, many of which are slated for forest habitat. For Marcellus Shale operations in Pennsylvania, an average, 8.8 acres (3.6 hectares [ha]) of habitat are required for each well pad and associated infrastructure (e.g., storage areas, roads and pipeline corridors) (Johnson 2010). The cumulative impact of all operations in a region can result in landscape level changes in habitat. For example, the projected number of wells by 2030 in Pennsylvania alone ranges from 6,000 to 15,000 (Johnson 2010). Given that nearly two thirds of these wells are expected to occur on forest lands, the potential area of forest to be cleared varies from 33,800 acres (13,800 ha) to 83,000 acres (32,700 ha). Additional habitat loss is likely as other formations, such as the Utica Shale, are developed.

Damage to forest habitat can occur from mechanical clearing during site development and from mismanagement of wastewater. At the US Forest Service Fernow Experimental Forest, damage to over two dozen trees and ground vegetation adjacent to a well pad occurred when HF fluid escaped the well bore during drilling (Adams et al. 2011). The release of fluid drifted over the immediate area causing browning of foliage and loss of leaves and ground vegetation. A major component of the HF fluid, and likely cause of damage, at this site was hydrochloric acid (15% by volume). Subsequent to this accident, fluids were experimentally applied to forest patches. Temporal and spatial development of the applications suggested that direct contact and uptake from the soil by the roots resulted in detrimental effects. A total of 147 trees (11 species) were affected. The application resulted in a much more open canopy than either control or recently burned plots, resulting in significantly more light penetration.

Removal of forest habitat, regardless of method, creates an associated edge effect ranging from 100–300 m into the interior forest stand. Increasing light and wind exposure, and changing temperature can alter vegetation dynamics, causing avoidance by many birds, mammals, reptiles and amphibians (Gibbs 1998, Flashpohler et al. 2001, Marsh and Beckman 2004). Disturbed areas also are more vulnerable to invasive plants (Meeking and McCarthy 2001, Harper et al. 2005). Furthermore, the distribution of clearings will increase forest fragmentation, resulting in species isolation and loss of genetic diversity (Lee et al. 2011). In Pennsylvania, Johnson (2010) estimated an additional 21 acres (8.6 ha) of interior forest habitat would be affected for every 8.8 acres (3.6 ha) of cleared forest for Marcellus Shale development. Thus, a total of direct and indirect impacts to forest habitat could equal 30 acres (12.3 ha) per well pad, resulting in 81,500 to 200,300 acres (33,340–81,940 ha) of forest habitat loss or degradation (Johnson 2010). Drohan et al. (2012) indicated this level of impact was enough to substantially alter the Pennsylvania landscape.

Greenhouse gas emissions. During combustion, natural gas emits less carbon dioxide (a greenhouse gas [GHG]), nitrogen oxide and sulfur oxide (two contaminants contributing to acid rain) than coal (Entrekin et al. 2011). However, during extraction, shale gas development produces considerable amounts of methane, a major component of natural gas and a powerful GHG (Howarth et al. 2011). The amount of fugitive emissions of methane into the atmosphere during HVHF operations compared to conventional operations may contribute more to global warming than other fossil fuel development (USEPA 2010). Howarth et al. (2011) calculate that during the life cycle of an average shale gas well, 3.6–7.9% of the total production of the well is emitted to the atmosphere as methane, which is at least 30% to 50% as great as estimated for a conventional well. Methane dominates the GHG footprint for shale gas on a 20-yr time horizon, contributing 1.4–3 times more than does carbon dioxide emission, resulting in a GHG footprint for shale gas at 22%–43% greater than that for conventional gas.

POTENTIAL IMPACTS TO BATS

Bats of the northeastern US are insectivorous and are the primary consumers of nocturnal arthropods, including many agricultural and forest pests. Given the relatively large volumes of insects consumed (up to 100% of bats body mass/night; Kurta et al. 1989) and extensive foraging home ranges, bats play a major role in suppressing nocturnal insect populations and transporting nutrients across landscapes (Fenton 2003, Jones et al. 2009). Moreover, bats provide an economic benefit by saving US farmers an estimated $22.9 billion (range: $3.7–$53 billion) each year in pesticide use (Boyles et al. 2011). Because of their important role in ecosystem services, bats often are used as indicators of habitat quality (Wickramasinghe et al. 2003, Kalcounis-Rupell et al. 2007, Jones et al. 2009). Bats may serve as the proverbial “canary in the coalmine” because many of their life history traits make them sensitive to human-induced environmental changes (Estrada et al. 1993, Medellin et al. 2000, Moreno and Halffler 2000, 2001, Estrada and Coates-Estrada 2001a, b, Clarke et al. 2005a, b, Hayes and Loeb 2007, Kunz et al. 2007). Bats have low reproductive potential (i.e., reproducing once per year and typically only having a single pup) and require high adult survivorship to avoid population declines (Barclay and Harder 2003, Podlutsky et al. 2005). Because bats are not able to recover quickly, large-scale changes may put populations at risk (Findley 1993, Henderson et al. 2008).

Historically, contamination from pesticide use and loss or disturbance of suitable habitat contributed to population declines. In recent years, both anthropogenic and natural forces have adversely affected North American bats, particularly in the northeast. Since 2003, wind energy development has resulted in potentially hundreds of thousands of bat fatalities (Kunz et al. 2007, Arnett et al. 2008). Although wind-powered turbines primarily affect migratory tree-roosting bats, cave-roosting species (e.g., little brown bat [*Myotis lucifugus*] and tri-colored bat [*Perimyotis subflavus*]) can compose approximately 20% of fatalities (Arnett et al. 2008). In 2006, the first fatalities from White-nose Syndrome (WNS) were documented in New York. Over the past six years, the fungus (*Geomyces destructans)* causing WNS has spread across nineteen states and killed millions of bats from six different species (Bat Conservation International; www.batcon.org). Little brown bats, once considered common, have shown the greatest mortality of all species affected by WNS (Frick et al. 2010b), but northern long-eared (*M. septentrionalis*), eastern small-footed (*M. leibii*), Indiana (*M. sodalis*), and tricolored bats also have experienced severe mortality (Kunz and Reichard 2011). Turner et al. (2011) estimated an 88% decrease in the total number of hibernating bats, with 98%, 91% and 72% declines in hibernating northern long-eared, little brown bats, and Indiana bats, respectively.

The perilous decline in bat populations is exacerbated by the additive nature of both WNS and numerous anthropogenic activities, possibly including shale gas development (USGS 2009). Coincidentally, the Marcellus Shale lies within the same area as the epicenter of WNS. The impacts associated with natural gas exploration and extraction in this region may further imperil already decimated bat populations (Matteson 2010). Of particular concern are the Indiana bat, currently listed under the Endangered Species Act, the northern long-eared and eastern small-footed, recently petitioned for listing by the Center for Biological Diversity (Matteson 2010), and the little brown bat, a species predicted to be extirpated from a significant proportion of its range by 2026 (Frick et al. 2010b, Kunz and Reichard 2011). Although there are no publicly available studies investigating the impacts of shale gas development on bats, we can infer potentially adverse effects based on other human-induced landscape-level changes.

Water withdrawal. Aquatic habitats play a critical role in the ecology of bats, both as sources of water and insect prey (Racey and Swift 1985, Grindal et al. 1999, Downs and Racey 2006, Hayes and Loeb 2007). Bats have relatively high rates of evaporative water loss, and must obtain much of their intake from available surface water resources (Kurta et al. 1989, 1990, McClean and Speakman 1999, Webb 1995, Neuweiler 2000). Kurta et al. (1989) estimated that bats may drink up to 26% of their daily water intake from open water sources (e.g., ponds or streams) to maintain water balance. Available water is vital for reproductively active females, particularly lactating bats, which require a sufficient amount of water while nursing young (Johnson et al. 2011). Adams and Hayes (2008) observed lactating female bats drinking 13 times more often than non-reproductive bats. Moreover, studies have shown that pregnant and lactating female bats select foraging areas, in part, based on proximity to water (Speakman et al.1991, McClean and Speakman 1999, Adams and Thibault 2006). For example, Johnson et al. (2011) observed eastern small-footed bat roosts within 500 m from water sources.

Riparian areas and other hydric habitats (e.g., lakes, ponds, and wetlands) are important resources because they support higher concentrations of nocturnal insects (MacGregor and Kiser 1998). Many bat species are opportunistic foragers and select areas where abundant and available prey occur (Thomas 1988, Barclay 1991, Barclay and Brigham 1991, Hart et al. 1993, Krusic and Neefus 1996, Grindal et al. 1999, Broders 2003). Murray and Kurta (2002) found that aquatic insects compose a large proportion of the diets of Indiana bats in the northern part of the species range. Commuting and foraging activity for many species is typically higher in riparian areas than in upland sites (Furlonger et al. 1987, Krusic et al. 1996, Grindal et al. 1999, Zimmerman and Glanz 2000, Seidman and Zabel 2001, Veilleux et al. 2003, Leput 2004, Menzel et al. 2005) and some species spend significant proportions of their nightly activity in these areas (LaVal et al. 1977, Brigham et al. 1992, Barclay 1999, Fellars and Pierson 2001, Waldien and Hayes 2001). Thus, the extensive withdrawal of water resources from the environment, particularly in sensitive areas or areas under drought conditions, will presumably affect roost-site selection and abundance and availability of prey.

Water contamination and toxic exposures. Riparian habitats support large numbers of insects and are prime foraging areas for insectivorous bats (Vaughn et al. 1996,). However, the inflow of heavy metals and other toxins from industrial wastes can adversely affect water quality and the invertebrate community (Mason 1997, Jones et al. 2009). Bats have been observed congregating and drinking from holding ponds at industrial sites (Huie 2002). Clark and Hothem (1991) reported the occurrence of bats dying by asphyxiation after drinking solutions containing cyanide from open holding ponds of gold mining operations. Similarly, open pits containing flowback and produced water associated with HVHF operations could expose bats to toxins, radioactive material and other contaminants.

Exposure to environmental contaminants is a suspected factor in the decline of North American bat species (US Fish and Wildlife Service [USFWS] 1999, Schmidt et al. 2002). Metabolic processes of insectivorous bats are rapid and bats consume large quantities of food relative to their body mass (Kurta et al. 1989, Schmidt et al. 2002). Because dietary accumulation and metabolic capacity increase at higher trophic levels, and because insectivorous bats are apex predators, bats are likely more susceptible to contaminants (Allerya et al. 2000, Eisler and Wiemeyer 2004, Jones et al. 2009). Toxic contamination can occur during normal operations, accidentally or by improper management. In such an event, contaminated drilling mud or water may migrate into caves and fissures used by bats, which can be ingested by grooming or be inhaled (Adams et al. 2011). Toxins often accumulate in fat, and are more likely to have adverse physiological effects when bats are depleting fat reserves, such as during hibernation, migration, or lactation (Kurta et al. 1989, O'Shea and Clark 2002).

Three heavy metals, cadmium, mercury, and lead, commonly associated toxins in wildlife studies, are contaminants reported in HVHF operations. Cadmium affects a number of systems, including reproductive and renal systems (Chmielnicka et al. 1989, Walker et al. 2007). A paucity of information exists on the occurrence and affect on cadmium in bats. However, Clark et al. (1988) postulated a relationship between cadmium concentrations in the guano of grey bats (*M. grisescens*), a federally endangered species, and kidney lesions. Mercury concentrations in aquatic and terrestrial food webs of the northeastern US are considered detrimental to local bat populations (Driscoll 2007, Osborne et al. 2011). Observed consequences of mercury exposure in mammals include reduced immune function, hormonal changes, impaired function of the central nervous system and motor skill impairment, and reduced reproductive success (Wiener and Spry 1996, Nocera and Taylor 1998, Evers et al. 2004, Schweiger et al. 2006). Lead is the most ubiquitous toxic metal and has been associated with a wide range of toxic effects from neurological, hematological, renal, and reproductive (Goyer 1996). Several studies have reported the potential negative impacts of lead on both wild and captive bats (Zook et al. 1970, Sutton and Wilson 1983, Hariono et al. 1993, Skerratt et al. 1998, Walker et al. 2007), including a possible link between elevated concentrations of lead and still births in big brown and little brown bats (Clark 1979).

Data on the impacts of other toxins and radionuclides on bats is limited (Eisher 1994, Ma and Talmage 2001, O'Shea and Clark 2002). The majority of data on bats and environmental contaminants comes from studies investigating the impacts of pesticides, and, to a lesser extent, heavy metals (O'Shea and Clark 2002, Schmidt et al. 2002). However, if contaminants associated with HVHF operations are introduced into aquatic ecosystems and are readily transferrable through insectivorous food chains, bats will presumably accumulate these substances and potentially suffer adverse effects.

Habitat loss and degradation. Fragmentation is considered a primary threat to global biodiversity (Franklin et al. 2002) and has the potential to directly impact bat populations by limiting essential roosting and foraging resources (Fenton 2003, Safi and Kerth 2004, Lane et al. 2006, Henderson et al. 2008). Anthropogenic changes in ecosystems often result in fragmenting forest landscapes and typically occur at rates dramatically faster than long-lived organisms are capable of adapting, thus disrupting life history cycles and ecological processes (Duchamp and Swihart 2008). Rapid ecosystem changes are associated with population declines in many bat species (Jones et al. 2009, Safi and Kerth 2004). In North America, the result of human-induced changes often results in patchy species distributions rather than range contraction (Pierson 1998). Recent studies have focused on temperate bat communities in greatly modified ecosystems, finding a positive association between bat abundance and diversity, and remnant natural habitat, such as forests and wetlands (Walsh and Harris 1996, Jaberg and Guisan 2001, Russ and

Montgomery 2002, Gehrt and Chelsvig 2004, Duchamp and Swihart 2008). Negative effects on bats from forest cover loss also are well documented from processes such as forest harvesting (Grindal 1996, Patriquin and Barclay 2003) urban expansion (Evelyn et al. 2003, Duchamp et al. 2004, Sparkes et al. 2005a) and agricultural intensification (Russ and Montgomery 2002, Lesinski et al. 2007).

Intact, mature forest stands possess structural features such as snags and large, overstory trees that are vital for cavity- and foliage-roosting bats, respectively (Jung et al. 1999, Cryan et al. 2001, Carter and Feldhamer 2005, Broders et al. 2006, Perry and Thill 2007, O'Keefe et al. 2009). In summer, bats select specific structures that offer protection and appropriate thermoregulatory conditions for survival and development of young (Humphrey et al. 1977). Loss of forest cover and degradation of forested habitats have been cited as part of the decline of Indiana bats (USFWS 1983, Gardner et al. 1990, Garner and Gardner 1992, Drobney and Clawson 1995, Whitaker and Brack 2002). Presence of northern long-eared bats, an interior forest species, is dependent on mature, contiguous deciduous forests for both roosting and foraging habitat (Sasse and Perkins 1996, Hutchinson and Lacki 2000, Lacki and Schwierhojan 2001, Broders and Forbes 2004, Carter and Feldhamer 2005, Broders et al. 2006, Perry et al. 2007, Henderson and Broders 2008). Moreover, this species forages almost exclusively in closed canopy forests and avoids forest gaps and open areas (Owen et al. 2003, Patriquin and Barclay 2003, Schirmacher et al. 2009).

Many forest-dwelling bats frequently switch roosts (Lewis 1995), but tend to remain loyal to specific roosting and foraging areas. Site fidelity is advantageous, allowing bats to become familiar with suitable roost trees and the local spatio-temporal variation in prey abundance and availability, thus decreasing time spent commuting and foraging (Avital and Jablonka 2000, Broders et al. 2006). Studies of Indiana bat roost-site selection show reproductively active females returning to the same home range year after year to establish maternity colonies. (Humphrey et al. 1977, Gardner et al. 1991a, 1991b, Gardner et al. 1996, Callahan et al. 1997, Menzel et al. 2001, Kurta and Murray 2002, Britzke et al. 2003, Whitaker and Sparks 2003, Whitaker et al. 2004). Roost tree reoccupation of up to six years has been documented in a number of studies (Garner et al. 1991b, Whitaker et al. 2004, Barclay and Kurta 2007). Maternity colonies of Indiana bats also appear to be faithful to their foraging areas within and between years (Cope et al. 1974, Humphrey et al. 1977, Gardner et al. 1991a, 1991b, Murray and Kurta 2004, Sparks et al. 2005b). Similarly, northeastern long-eared, eastern small-footed, and tri-colored bats select specific areas, often re-using sites within and among years (Kalcounis and Hecker 1996, Sasse and Pekins 1996, Brigham et al. 1997, O'Donnell and Sedgley 1999, Weller and Zabel 2001, Menzel et al. 2002, Willis and Brigham 2004, Perry and Thill 2007).

The philopatry observed among numerous species requires consideration by natural resource managers who often permit harvesting trees during winter when bats are hibernating, a practice intended to limit directly harmful effects of development (Arnold 2007). However, because females consistently return to the same site(s), this practice may do less to mitigate the immediate effects of habitat loss than anticipated. Bats, already pregnant, arrive to sites after hibernating for seven months and migrating for up to 500 kilometers (km), at a time of cool, wet weather, which likely limits prey availability (Humphrey et al. 1977, Kurta et al. 1996, Murray 1999). The loss or alteration of forest habitat places additional stress on females, and may increase thermoregulatory costs and potentially disrupt social bonds of a colony (Kurta and Murray 2002). Such impacts have been documented in other bat species. Brigham and Fenton (1986) documented a 56% decline in reproductive success of a big brown bat colony that was excluded from their maternity roost. Sparks et al. (2003), demonstrated that the natural loss of a single primary maternity roost lead to fragmentation of the colony (bats used more roosts and congregated less) the following year after roost loss.

Hibernacula and the habitat surrounding these sites also warrant protection from development, particularly drilling operations. Hibernating bats select sites within caves and mines possessing specific microclimate (e.g., temperature, humidity, and airflow) conditions (Clawson et al. 1980, Tuttle and Kennedy 2002). Alterations to this microclimate, whether natural or human-induced, often render a site less suitable for hibernation (Johnson et al. 2002). Moreover, disturbing bats during winter hibernation may result in additional arousals causing bats to lose fat reserves and possibly abandon the roost. Adams et al. (2011) highlighted the importance of understanding the connectivity of karst geology in proximity to winter hibernacula prior to development. Modifications to the surface habitat surrounding hibernacula also can contribute to changes in microclimate conditions, as well as influence the suitability of foraging characteristics. The landscape surrounding hibernacula supports foraging and roosting needs of large numbers of bats during fall swarming periods, when bats are building up crucial fat reserves to survive the winter (Hall 1962). Areas surrounding hibernacula also provide important summer habitat for male Indiana bats that do not migrate far from the winter roost.

Habitat use by forest bats is complex and varies by species. Bats rely on extensive resources over large areas (Duchamp et al. 2009). The magnitude of shale gas development predicted over the next twenty years is expected to have similar effects on forest landscapes (i.e., habitat loss and degradations) as other anthropogenic activities, but at a much greater level due to the proliferation of projected drilling sites. Therefore, providing conditions necessary to support bat populations will require a combination of designating certain forest areas as off-limits and implementing forest management practices that perpetuate suitable roosting and foraging habitat (Duchamp et al. 2009).

Greenhouse gas emissions. The effects of climate change on bats have not been studied extensively. However, it is believed that insectivorous bats may be among the most affected species because seasonal temperature changes may affect hibernation, food abundance and availability, and recruitment (Jones et al. 2009). Most bat species have specific temperature regimes that are conducive for surviving over half the year in hibernation. For example, Indiana bats hibernate in caves or mines where the ambient temperature is consistently below 10° C (Hall 1962, Meyers 1964, Henshaw 1965, Humphrey 1978, Tuttle and Kennedy 2002). Tuttle and

Kennedy (2002) reported that populations hibernating with temperatures between 3–7.2° C remained stable or increased, whereas populations hibernating at temperatures above or below this range were unstable or declined. With winter conditions expected to become shorter and warmer, disruptions to the mammalian overwintering energy budgets are expected (Gu et al. 2008). Milder winter conditions may force bats to enter hibernacula later than usual, presumably with inadequate fat reserves if food availability decreases in late fall (Matteson 2010). Warmer temperatures in winter also may result in unsustainable arousal frequencies (Humphries et al. 2002). Because arousals account for up to 80% of the energy budget (Thomas 1995) of hibernating bats, any increase in frequency or duration could decrease survivorship.

It has also been posited that changes in temperature may disrupt bat reproductive physiology. In winter, altered temperature regimes may diminish the viability of spermatozoa stored in the female reproductive tract, thus females may not become pregnant upon emergence, or become pregnant too early and undergo embryonic development and parturition earlier in the spring, which may lead to declining recruitment if conditions are not suitable for young (Jones et al. 2009). In summer, dwindling water resources caused by warmer temperatures and reduced precipitation can lead to lower reproductive rates as female are not able to meet their water budget to produce milk for nursing pups (Kurta and Rice 2002, Barclay et al. 2004, Adams and Hayes 2008, Rodenhouse et al. 2009). Adams (2010) observed reductions in reproductive behavior and increases in non-reproductive female bats in years with above average temperature and below average precipitation, conditions similar to predictions of regional climate warming and increased drought.

Changes in precipitation and temperature also are anticipated, thus diminishing water availability during summer and altering the distribution, abundance, and phenology of insects (Hughes 2000, Bale et al. 2002, Parmesan 2003, Menendez 2007, Rodenhouse et al. 2009). Reductions in insect abundance and availability will have detrimental effects on bat populations, particularly during critical periods (i.e., during pregnancy, lactation and fall swarming). Frick et al. (2010a) concluded a direct relationship between cumulative summer precipitation and probability of survivorship in little brown bats.

Climate data indicates we are in a rapid period of change, which already is being observed across a range of ecosystems (Jones et al. 2009). Climate change is likely to affect roosting and foraging behaviors and opportunities, particularly during times when bats are most vulnerable. Anthropogenic activities that increase the global GHG footprint, including HVHF operations, presumably will exacerbate adverse impacts on bat populations. Thus, methods to reduce the fugitive emissions of methane from shale gas development should be explored and implemented.

CONCLUSIONS

Bats are vital in terms of their ecological and economic roles, and are well suited as indicators of environmental health (Fenton 2003, Jones et al. 2009). Worldwide, bats function as pollinators, seed dispersers, and biological controls for nocturnal insects (Kunz and Parsons 2009). In North America, most species are insectivorous and consume large quantities of night-flying insects, many of which are agricultural and forest pests. Regrettably, many bat species are experiencing population declines and range contraction in response to both natural and human-induced environmental stressors (Jones et al. 2009). White-nose Syndrome has decimated hibernating bat populations in northeastern North America, including declines of nearly 98% and 88% in Pennsylvania and New York, respectively (Turner et al. 2011). Species affected include the little brown bat, a once common species, and the federally endangered Indiana bat (Frick et al. 2010b). At least three additional species are being considered for listing (Matteson 2010 Kunz and Reichard 2011). A sense of urgency exists among bat biologists because bats have low reproductive rates and respond slowly to rapid population declines (Barclay and Harder 2005). Compounding the devastation of White-nose Syndrome are human activities associated with the degradation and destruction of suitable habitat and resources for these imperiled species (Kunz and Parsons 2009). As with other industrial practices, shale gas development contributes to water withdrawal and contamination, habitat loss and degradation, and the emission of GHGs resulting in detrimental effects on bat populations and their environment. Immediate action is required to reduce these adverse impacts and to ensure that bats and the ecosystems they serve are considered during shale gas development and production.

Eastern small-footed bat (*Myotis leibii*). Photo credit: Bat Conservation International.

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