February 28, 2013

The Honorable Ken Salazar
Secretary
Department of the Interior
1849 C Street, N.W.
Washington DC 20240

The Honorable Steven Chu
Secretary
Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

The Honorable Bob Perciasepe
Acting Administrator
Environmental Protection Agency
Ariel Rios Building
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Dear Secretary Salazar, Secretary Chu, and Acting Administrator Perciasepe,

The Society for Conservation Biology[1] (SCB) is concerned about the potential detrimental impacts of hydraulic fracturing ("fracking") as a rapidly expanding method of natural gas production. The practice presents serious risks to human health and to wildlife and ecosystems directly, and indirectly through a potentially large contribution to climate change by way of substantial amounts of methane that can escape during and after the fracking process. We urge you to consider all three of these risks. In this letter however, we address primarily the lack of scientific research regarding the potential biological impacts. We therefore make both research recommendations and recommendations for precautions that your departments and agencies can take while that research is conducted.

Among the 1,261 peer-reviewed studies of fracking currently published,[2] there appear to be only two investigations that directly focus on the impacts to biological diversity or ecosystem health.[3] We are encouraged that your agencies have recognized the need for more research, as evidenced

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[1] SCB is an international professional organization whose mission is to advance the science and practice of conserving the Earth's biological diversity, support dissemination of conservation science, and increase the application of science to management and policy. The Society's 5,000 members include resource managers, educators, students, government and private conservation workers in over 140 countries.
[2] We searched the terms "hydraulic fracturing", "fracking", "Marcellus", and "shale-gas" in the Web of Science database on Feb 5, 2013. Results were refined by document type and by Web of Science category.
[3] Davis, J.B. and G.R. Robinson, A Geographic Model to Assess and Limit Cumulative Ecological Degradation from Marcellus Shale Exploitation in New York, USA. Ecology and Society, 2012. 17: 12; See also, Drohan, P.J., Brittingham, M., Bishop, J., Yoder, K., 2012. Early Trends in Landcover Change and Forest Fragmentation Due to Shale-Gas Development in Pennsylvania: A Potential Outcome for the Northcentral Appalachians. Environmental Management 49: 1061-1075.

by your recent Multi-Agency Collaboration on Unconventional Oil and Gas Research Memorandum of Understanding (MOU) to ensure "the prudent development of energy sources while protecting human health and the environment."[4] This MOU calls for a prioritized research agenda that identifies critical knowledge gaps related to fracking impacts, as well as an explicit timeline for developing this document. Thus far, however, your agencies have failed to meet the MOU's mandate in a timely manner, which called for a draft research plan being published for public review and comment by October of 2012 and a final research plan being published by January of 2013. We are writing to emphasize the urgency of this research and to suggest specific biodiversity-focused research priorities. Because of the potential risks and scientific uncertainties surrounding unconventional fracking practices, SCB also is providing interim policy measures to ensure the health of our nation's aquatic and terrestrial ecosystems pending the completion of those studies.[5]

I. Introduction to Hydraulic Fracturing

Hydraulic fracturing ("fracking") is the process by which oil or natural gas is extracted from dense geologic formations through fractures created with pressurized fluid. Though fracking has been in practice since the 1940s, the recent development of horizontal drilling technology has made it profitable to scale-up gas production in low permeability geologic formations (e.g., Marcellus shale region in the Appalachian Mountains).[6] Fracking has expanded dramatically in the last decade and will continue to do so. Projections estimate that natural gas production by this method will double in the next 30 years, with an additional 60,000 wells to be constructed in the Marcellus shale region of the eastern U.S. alone.[7] Fracking requires large-scale well pad and infrastructure construction, as well as a massive volume (~5 million gallons per well)[8] of freshwater. Water is mixed with hundreds of potentially toxic or carcinogenic chemicals prior to injection under high pressure into gas-bearing formations up to ~10,000 feet below the Earth's surface. Pressurized fluid creates fissures in the rock through which gas is extracted. An inevitable consequence of this process is that fracking fluids return to the surface having accumulated salts, radioactive elements, and hydrocarbons, in addition to the chemicals intentionally added by gas companies. This highly saline, contaminated water represents a significant disposal problem due to the threat that it poses to biodiversity, especially freshwater organisms, if released into the environment. In addition to water contamination, habitat

[4] D.O.E., E.P.A., D.O.I. 2012. Multi-Agency Collaboration on Unconventional Oil and Gas Research, Apr.13, 2012. Available at: www.doi.gov/news/pressreleases/loader.cfm?csModule=security/getfile&pageid=289759

[5] While fracking is exempted from meeting the regulatory requirements of some Federal environmental laws, including the Safe Drinking Water Act, the Federal government still retains authority under other environmental protection laws, including the Clean Water Act, Clean Air Act, and the Endangered Species Act to adopt regulations to prevent environmental contamination or other damage caused by fracking.

[6] Entrekin, S., Evans-White, M., Johnson, B., Hagenbuch, E., 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9, 503-511.

[7] New York State (2009) *Supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program'* by the New York State Department of Environmental Conservation Division of Mineral Resources; EIA (Energy Information Administration), 2011. International energy outlook, EIA, Washinton, DC

[8] Abdalla, Charles W.; Drohan, Joy R. (2010) (PDF). Water Withdrawals for Development of Marcellus Shale Gas in Pennsylvania. Introduction to Pennsylvania's Water Resources(Report). The Pennsylvania State University. Retrieved 16 September 2012. "Hydrofracturing a horizontal Marcellus well may use 4 to 8 million gallons of water, typically within about 1 week. However, based on experiences in other major U.S. shale gas fields, some Marcellus wells may need to be hydrofractured several times over their productive life (typically five to twenty years or more)."

fragmentation and water scarcity associated with fracking also threaten native flora and fauna. Because fracking wells are scattered throughout broad geographic areas, a significant portion of our nation's biological diversity will likely be impacted by these operations[9] (Fig. 1). Unfortunately, independent risk assessments of this technology and peer-reviewed studies of its biological impacts lag far behind the rapid expansion of gas production.

There are important scientific questions for fracking-related research that should be addressed by your multi-agency collaboration. SCB recommends several distinct areas of scientific inquiry focusing on the impacts to biodiversity from fracking: (1) the fracturing process; (2) well construction; (3) water sourcing; (4) wastewater disposal; and (5) the cumulative impacts of the entire fracking operation. Although SCB's main focus is on direct biological impacts, we also recognize that fracking contributes significantly to climate change through the release of greenhouse gases (primarily methane).[10] Indeed, the latest science indicates that the climate footprint of shale gas exceeds that of other fossil fuels.[11] We further recognize that research regarding the *interaction* between climate change and other fracking impacts is critically needed, and that climate change predictions (e.g., drought) should be incorporated into the drilling site selection process. Finally, we also recommend that your three agencies develop interim policy measures for each stage of the fracking process to help ensure the health of our nation's aquatic and terrestrial ecosystems pending the completion of those research studies.

II. The Fracturing Process

Hundreds of chemicals are added to fracking fluid to facilitate the extraction of natural gas from shale deposits. Additives, which include surfactants, biocides, friction reducing agents, acids, and scale inhibitors, are used because they alter characteristics of water in ways that help break down rock or facilitate gas retrieval[12]. The same chemicals that change water to facilitate gas retrieval alter biologically important characteristics of water in ways harmful to biota. For example, some chemicals in fracking fluid adjust water tension, thus influencing biochemical interactions at the cellular level and in some cases acting as endocrine disrupters. The composition of these mixtures is often protected as proprietary business information.[13] Of the 353 *known* chemicals used by the natural gas industry for which health-related information is available, a recent review found 25 percent to cause cancer or genetic mutations, 40-50 percent to negatively affect internal organs, and 75 percent to disrupt sensory organs (e.g., skin and eyes).[14] These damaging effects are not limited to human health; they also likely threaten the species and natural systems that underlie our nation's economic well-being.

[9] In addition to the effects on human health and welfare when humans are exposed to a significant degree to water affected by the process, which, while not being the focus of these comments, are serious considerations that should be addressed further.
[10] Howarth, R.W., R. Santoro, and A. Ingraffea, Methane and the greenhouse-gas footprint of natural gas from shale formations. Climatic Change, 2011. 106(4): p. 679-690.
[11] Howarth, R.W., R. Santoro, and A. Ingraffea, Venting and leaking of methane from shale gas development: response to Cathles et al. Climatic Change, 2012. 113(2): p. 537-549.
[12] Entrekin, S., Evans-White, M., Johnson, B., Hagenbuch, E., 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9, 503-511. See also, Howarth, R.W., Ingraffea, A., Engelder, T., 2011. Natural gas: Should fracking stop? Nature 477: p. 271-275.
[13] Howarth, R.W., Ingraffea, A., Engelder, T., 2011. Natural gas: Should fracking stop? Nature 477: p. 271-275.
[14] Colborn, T., et al., Natural Gas Operations from a Public Health Perspective. Human and Ecological Risk Assessment, 2011. 17(5): p. 1039-1056.

Contaminated fracking fluid either remains belowground, with entirely unknown long-term effects on biodiversity (that, if negative, would be exceedingly hard to remediate), or returns to the surface as contaminated 'produced' or 'flowback' water. The proportion of fracking fluid that is recovered versus that which remains below ground varies substantially, depending on the characteristics of the geologic formation. In some areas of the Marcellus Shale formation, fluid recovery is as low as 10 percent.[15] Water that returns to the surface is contaminated beyond simply containing fracking chemicals, having accumulated additional salts, hydrocarbons, and radioactive material while underground. Of particular concern is that the quantity of salt generated during gas production—a single gas well can generate 27 tons of salt per year over a 20 to 30 year period—may contaminate freshwater sources.[16] Notably, because the chemical composition of fracking fluid is not publically disclosed, researchers are unable to fully investigate the biological toxicity of this fluid. Furthermore, this lack of disclosure may also make it more difficult to determine liability when groundwater contamination occurs.

The natural gas industry has asserted that it is not possible for migrating chemicals from fracking fluid to contaminate groundwater supplies, given the extreme depth of these shale gas formations. However, geochemical analysis of groundwater samples in northeastern Pennsylvania suggests that natural mixing (i.e., unrelated to recent drilling) occurs between deep Marcellus brine and shallow aquifers.[17] Given the existence of these conductive pathways, groundwater contamination from fracking fluid is possible. Indeed, another study provided isotopic evidence of methane contamination from Marcellus drilling in drinking water samples collected from nearby wells.[18] Finally, the Environmental Protection Agency (EPA) recently detected chemicals unique to fracking fluid in drinking water wells located near areas of gas development in Pavillion, Wyo.[19] Taken together, these studies link groundwater contamination with hydraulic fracturing, though the frequency and extent of contamination remains unknown and is likely to depend on the nature of each site and geological formation.

Fracking fluids may also enter aquifers and surface water via accidental spills and well blowouts. Blowouts are infrequent, but when they do occur can result in large-scale, potentially long-term pollution of local water resources. In Pennsylvania, thousands of gallons of contaminated water spewed into the surrounding area for a 12-hour period in 2011 following a fracking blowout.[20] While the frequency of accidents and equipment failures can be reduced through responsible development protocols, effective regulation, and enforcement, they cannot be eliminated entirely. Detailed and effective catastrophe response plans are essential, given the broad and potentially irreversible consequences of these accidents.

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[15] Entrekin, S., Evans-White, M., Johnson, B., Hagenbuch, E., 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9, 503-511.
[16] Urbina, I., 2011. Wastewater recycling no cure-all in gas process. New York Times, New York, New York.
[17] Warner, N.R., Jackson, R.B., Darrah, T.H., Osburn, S.G., Down, A., Zhao, K., White, A., Vengosh, A., 2012. Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. Proc Natl Acad Sci USA Early edition.
[18] Osborn, S.G., Vengosh, A., Warner, N.R., Jackson, R.B., 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. Proc Nat Acad Sci USA 108: 8172-8176.
[19] DiGiulio, D.C., Wilkin, R.T., Miller, C., Oberley, G., 2011. Investigation of ground water contamination near Pavillion, Wyoming, E.P.A, National Risk Management Research Laboratory, Ada, Oklahoma.
[20] Soraghan, M., 2011. Baffled about fracking? You're not alone. New York Times. New York, New York.

In addition to the broad-scale threat of water contamination, wildlife and plant populations may be exposed to the localized impacts of air pollution and increased levels of noise and/or light near the development site. Methane emissions, which represent a contribution to climate change 20 times greater than that of carbon dioxide on a per unit basis, are 30-50 percent higher in fracking compared to other forms of natural gas extraction. These emissions occur at the well site during the fracturing process (i.e., through flowback water), and through routine venting and equipment leaks, as well as during the transport, storage and distribution stages.[21] Even intermittent exposure to human-generated noise can stress wildlife, leading to reduced disease resistance, survival, and reproductive success. Recent experimental evidence, as well as *in situ* observations, indicates that noise associated with natural gas drilling reduces wildlife population viability above and beyond the effects of habitat fragmentation alone.[22] Little is known about the effects of light pollution on wildlife, but increased illumination or direct glare have the potential to negatively impact foraging, reproduction, communication, movement and species interactions.[23]

To address the potential threats to biodiversity described above, SCB recommends that the Department of Interior, the Environmental Protection Agency, and the Department of Energy incorporate the following research questions into their multi-agency research plan:

1) What is the likelihood, severity, and spatial extent of contamination (including increased salinity) of freshwater ecosystems resulting from the process of hydro-fracking? In particular:
    a. What is the likelihood, severity, and spatial extent of contamination of freshwater ecosystems via underground aquifers contaminated by fracking fluids?
    b. What is the likelihood, severity, and spatial extent of contamination from spills, leaks, and blowouts?
2) What are the known effects of *every* individual chemical constituent found in fracking fluids on wildlife and plants?
3) Given the complex chemical make-up of fracking fluid and flowback, what are the cumulative and synergistic effects of fracking fluids on wildlife and plants, at the scale of populations and ecosystems?
4) What are the known long-term impacts of contamination from fracking on wildlife and plant communities? Research should specifically focus on revisiting first generation fracking sites.
5) What are the impacts of noise, light, and air pollution (including particulate matter and methane gas that escapes from wellbore) on wildlife and plants?
6) What technologies can currently be deployed to reduce biotic impacts of noise, light and air pollution?

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[21] Howarth, R.W., Ingraffea, A., Engelder, T., 2011. Natural gas: Should fracking stop? Nature 477: 271-275.
[22] Blickley J.L., Blackwood D., Patricelli G.L., 2012. Experimental Evidence for the effects of chronic anthropogenic noise on abundance of greater sage grouse at leks. Conservation Biology 26:461-471.
[23] Longcore, T., Rich, C., 2004. Ecological light pollution. Frontiers in Ecology and the Environment 2: 191-198.

7) What factors influence the amount of methane emitted by individual wells, and what technologies can be adopted to capture methane with greater efficiency?
8) What are predicted impacts of worst-case catastrophes from fracking operations?
9) What are remediation strategies for cleanup of both above and belowground fracking contamination events or catastrophes?
    a. Are current technologies capable of adequately cleaning-up after such events?
    b. What site characteristics influence the potential for remediation, and are there identifiable site characteristics that preclude effective remediation?
    c. What are anticipated remediation costs associated with a worse case scenario clean up?
10) What are potential environmental impacts of closed wells in which fracking operations have been suspended or concluded permanently? Specifically, how long do well casings remain in tact? What is the potential for groundwater contamination from closed wells?

SCB recommends the following interim policy measures to protect ecosystems while research is conducted:

1) Require collection of baseline measurements of air and water quality, and completion of assessments of biological diversity *prior* to well construction. Biological diversity (both terrestrial and aquatic) should be assessed at the area of the well pad, in freshwater systems that are hydrologically connected downstream of the well location, and at stream sites used for water sourcing.
2) Mandate full disclosure of the chemical composition of fracking fluids and the amount of water used during the gas extraction process.
3) Require the use of non-toxic, company-specific chemical tracers in fracking fluid to increase scientific understanding of chemical migration and to determine liability in the event of freshwater contamination.
4) Rigorously enforce EPA water quality standards relating to aquatic life and ensure that all discharges of pollutants from fracking operations comply with the Clean Water Act.[24]
5) Require companies to develop response plans and provide financial assurances for all cleanup costs for incidents that result in contamination.
6) Establish mandatory reporting requirements for all accidents and spills associated with the entire fracking process.
7) Consult with the Federal Energy Regulatory Commission to ensure that the permitting of natural gas pipelines associated with fracking operations fully comply with all environmental law, including National Environmental Policy Act (NEPA) and the Endangered Species Act.

III. Well construction

On average, fracking companies clear 1.5-3.0 hectares (3.7-7.4 acres) of vegetation during well pad construction.[25] The construction of roadways, pipelines, and other associated infrastructure

[24] http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm

(e.g. holding ponds for wastewater) to support fracking operations results in further habitat loss and fragmentation. The scale and unprecedented growth of the natural gas industry has made this form of domestic energy production a significant driver of land-use change in the United States. Loss, fragmentation and degradation of habitat currently represent the most significant threat to biodiversity worldwide.[26] Decreased species abundance and reduced connectivity of populations directly inhibits dispersal, foraging, and mating success, and alters complex, interdependent relationships among species. This reduction in connectivity is especially important in the context of climate change, because of its potential to reduce species' ability to adapt or migrate. Habitat loss and fragmentation also change environmental quality by increasing the proportion of edge habitat, which is distinct in terms of light, water and temperature characteristics, to interior habitat. These changes support edge-adapted species, but can be detrimental to interior-adapted species, which, particularly in forested ecosystems, tend to be rarer and more vulnerable relative to edge-adapted species.[27] Habitat fragmentation provides access into remote areas, which may encourage hunting or poaching of sensitive species (e.g., American ginseng) and can serve as a conduit for the introduction for invasive species or disease[28]. Collectively, the negative impacts associated with landscape change represent a major driver of population decline and species extinction.[29]

SCB recommends that the multi-agency research plan address the following high-priority questions:

1) What is the total current and projected impact of hydraulic fracturing on habitat loss, fragmentation, and quality?
2) What is the optimal location and configuration of well pads in a given landscape to minimize threats to biodiversity?
3) Is there a density of gas development above which serious threats to biodiversity begin to occur?

Specific attention should be given to examining the cumulative, landscape-level impacts of habitat fragmentation, water sourcing, and potentially contamination, as discussed in more detail in the 'Cumulative impacts of hydraulic fracturing' section. These analyses should integrate biologic, hydrologic, and geologic data in order to identify ways to reduce the impacts of fracking on natural ecosystems. SCB also recommends the following interim policy measures

[25] Entrekin, S., Evans-White, M., Johnson, B., Hagenbuch, E., 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9, 503-511.
[26] Pereira, H.M., Leadley, P.W., Proenca, V., Alkemade, R., Scharlemann, J.P.W., Fernandez-Manjarres, J.F., Araujo, M.B., Balvanera, P., Biggs, R., Cheung, W.W.L., Chini, L., Cooper, H.D., Gilman, E.L., Guenette, S., Hurtt, G.C., Huntington, H.P., Mace, G.M., Oberdorff, T., Revenga, C., Rodrigues, P., Scholes, R.J., Sumaila, U.R., Walpole, M., 2010. Scenarios for global biodiversity in the 21st century. Science 330: 1496-1501.
[27] Ries, L., Fletcher, R.J., Battin, J., Sisk, T.D., 2004. Ecological responses to habitat edges: mechanisms, models, and variability explained. Annual Review of Ecology Evolution and Systematics 35: 491-522.
[28] Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology Evolution and Systematics 34, 487-515.
[29] Aguilar, R., Ashworth, L., Galetto, L., Aizen, M.A., 2006. Plant reproductive susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. Ecology Letters 9, 968-980; Fahrig, L., 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology Evolution and Systematics 34, 487-515; Cushman, S.A., 2006. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. Biological Conservation 128, 231-240; Fischer J, Lindenmayer DB. 2007. Landscape modification and habitat fragmentation: a synthesis. Global Ecology and Biogeography 16: 265-280.

to protect terrestrial and aquatic ecosystems during the pendency of the research program to address these habitat-loss related concerns:

1) Impose a fracking moratorium on public lands that contain threatened or endangered species, or areas that have been identified as national biodiversity "hotspots"[30] (i.e., containing relatively high numbers of species, particularly those that are rare).
2) Prohibit well construction on wetlands protected by the Clean Water Act and within 500 feet of freshwater springs, surface flows, or other sensitive areas such as those that are habitats for threatened or endangered species.

IV. Water sourcing

Fracking operations pose clear and direct risks to freshwater ecosystems. The fracturing of a single well requires, on average, five million gallons of water, typically collected from nearby surface streams and rivers. Up to eight well pads can be constructed in a one-hectare (2.5 acre) area. At this density, hydraulic fracturing would consume 40 million gallons of freshwater on average in an area roughly the size of a baseball field.[31] Water extraction of this magnitude can dramatically alter stream hydrology, potentially drying up critical freshwater habitats. In western states, concerns that streams and ponds will dry out or that flow rates will fall below biological baselines are acute, as water sources are already in short supply and are often over-allocated for agricultural and human use. Even when some level of flow is retained, reduced water level and low flows can substantially alter the aquatic environment, increasing water temperatures and decreasing the concentration of dissolved oxygen available to species living in that stream. Particularly susceptible are species that already live close to physiological thresholds of temperature or oxygen concentration, such as brook trout, the rare and slow-growing hellbender salamander, and other stream-dwelling amphibians. Ecologically and economically important species that may be affected include game fish, like trout, which are important to recreation and tourism in many regions underlain by Marcellus Shale.[32]

To address the issue of water sourcing, SCB recommends the following high-priority research questions:

1) What are minimum stream flow thresholds necessary to preserve biological function (i.e., environmental flows) specific to each ecological region potentially affected by fracking activities?
2) What are the direct biological impacts of water sourcing? Specifically, how many species and organisms are killed or removed during the water removal process, and what are the resulting impacts on population dynamics, viability and community function?
3) How does water sourcing influence the transmission of invasive species and disease, and what are the consequences for biodiversity and ecosystem health?

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[30] Stein et al. ed, 2000. Precious Heritage. Oxford University Press, New York; 172-173.
[31] Entrekin, S., Evans-White, M., Johnson, B., Hagenbuch, E., 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9, 503-511; Howarth, R.W., Ingraffea, A., Engelder, T., 2011. Natural gas: Should fracking stop? Nature 477: p. 271-275.
[32] The Marcellus shale formation is one of the largest unconventional gas reserves in the U.S. occupying a 240,000 km^2 area underlying six states in the Appalachian region, and containing around 59% of the total estimated recoverable gas in the country.

In addition, SCB recommends the following interim policy measures to protect water flows while research is conducted:

1) Prohibit water sourcing from streams, rivers, lakes, or ponds which are inhabited by federally threatened or endangered species, including water sources that provide resources to protected species at a single life stage.
2) Based on current research, establish precautionary minimum flow guidelines for streams and rivers that protect aquatic life.
3) Enact a moratorium on water sourcing during periods of drought.

V. Wastewater disposal

Methods for disposing of fracking wastewater vary significantly, depending on state regulations and company practices. Some states require disposal of wastewater via injection into deep wells. However, deep well disposal is unproven as a containment method in regard to fractured systems and fracking fluids, and in particular, the newer horizontally fracked formations, and as such represents a threat to human health and ecosystem integrity. There is no scientific consensus—and little evidence—as to how the complex chemical make-up of fracking fluids, *which are known to degrade the structure of otherwise impermeable rock*, will respond in the high pressure and high heat environment of waste wells. There are no data regarding how far these chemicals might migrate below ground, or the scale of potential contamination should well containment fail. Currently, no systematic monitoring protocols for tracing chemical flows to their sources exist to help inform these questions. Moreover, contamination in the event of deep well failure to contain toxic fracking chemicals would be virtually impossible to mitigate. The possibility of misjudging the safety of this disposal method therefore represents high risks to both human and natural systems.

Most other methods of wastewater disposal carry an equivalent or greater environmental risk relative to deep well disposal. Containment ponds, one of the most prevalent forms of wastewater disposal, vary substantially in design and structural integrity. Often uncovered and lined with simple rubber or cement casings, containment ponds allow seepage into nearby water systems if heavy rains result in overflow or if pond liners corrode.[33] Water treatment plants are almost never equipped to remove the myriad of chemicals, radioactive elements, or high concentrations of salt found in fracking fluid. In Pennsylvania, ~50 percent of the wastewater generated in 2008 and 2009 was disposed of without proper treatment at such water treatment plants, likely contaminating rivers and causing undocumented harm to wildlife and plants in these watersheds.[34] Although some companies have begun "recycling" fracking fluid by diluting it with freshwater prior to reuse, this strategy does not eliminate the need to ultimately dispose of highly toxic wastewater.[35] High concentrations of chemicals eventually accumulate in recycled fluid, rendering it unusable for further fracturing.

[33] Entrekin, S., Evans-White, M., Johnson, B., Hagenbuch, E., 2011. Rapid expansion of natural gas development poses a threat to surface waters. Frontiers in Ecology and the Environment 9, 503-511; See also Howarth, R.W., Ingraffea, A., Engelder, T., 2011. Natural gas: Should fracking stop? Nature 477: p. 271-275
[34] Urbina, I. 2011. Regulation lax as gas wells' tainted water hits rivers. New York Times. New York, New York.
[35] Urbina, I. 2011. Wastewater recycling no cure-all in gas process. New York Times, New York, New York.

Our most significant and immediate concern with respect to wastewater disposal is the indiscriminate spraying of untreated fluid across landscapes. As of 2011, several states, including West Virginia, Arkansas, and Colorado, permitted the land application of wastewater as a disposal method. This state policy is alarming because, in addition to salts, fracking wastewater contains *known toxins and carcinogens*. One study experimentally replicated the land application methods used by gas companies, and within several days of spraying the fracking fluid, nearly 100 percent of understory vegetation had died. Within seven to 10 days, trees began to lose foliage, and 2 years following the application 56% of trees within the treatment area were dead.[36] As another form of land application, several companies have begun selling wastewater to states and municipalities as a deicing agent for roadways. As snow and ice melt, these chemicals are transported into water systems and dispersed into the environment.

SCB recommends the following high-priority research questions:

1) What is the long-term fate and outcome of fracking fluids disposed of by deep-well injection? In particular, what is the result of the interactions of complex chemicals in high pressure, high heat environments of waste wells?
2) What is the likelihood of wastewater escape from deep-well injection sites, and how far could chemicals travel from the source?
3) What is the timeframe of natural decomposition (i.e., half-life) of the chemical compounds found in fracking wastewater?
4) What is the likelihood and risk that a holding pond will leak or that there will be migration of wastewater from containment sites?
5) When fracking wastewater is stored in holding ponds, do the chemical constituents volatilize, and if so, what are the effects on air quality and nearby ecosystems?
6) Is there consumption of wastewater by wildlife in holding ponds?
7) What technologies should be employed in the construction of containment ponds to reduce the likelihood of wastewater escape?
8) What new standards or technologies are required for safely disposing of fracking fluid at water treatment plants?
9) What are the effects of untreated or inadequately treated fracking wastewater on wildlife and plants at the species, community, and ecosystem levels?
10) Are the environmental impacts of fracking reduced when wastewater is recycled for subsequent fracking procedures at other wells?
11) What are the ecological impacts of using fracking fluid on roadways as a deicer or for dust control?

Because the risk and hazards associated with certain methods of fracking fluid disposal do not appear to have a short-term solution that can effectively safeguard biodiversity, SCB recommends the following interim policy measures to address fracking wastewater:

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[36] Adams, M.B., 2011. Land Application of Hydrofracturing Fluids Damages a Deciduous Forest Stand in West Virginia. Journal of Environmental Quality 40, 1340-1344

1) Impose a temporary moratorium on disposal of fracking-related fluids by deep-well injection pending scientific risk assessments of contamination and underground migration of chemicals[37].
2) Impose a temporary moratorium on the disposal of fracking fluids at wastewater treatment facilities not specifically equipped to treat both the high concentrations of salt and the toxic contaminants in flowback. Develop standard test methods to detect contaminants found in fracking wastewater (e.g. chemicals added to fracking fluid, radioactive elements, salts) to determine whether treatment plants are able to adequately remove these pollutants from wastewater and to standardize fracking wastewater treatment.
3) Develop best practices and minimum safety standards for holding ponds used to store fracking-fluids, including effective barriers that prevent wildlife from coming in contact with fracking fluids (e.g. drift fences for amphibians; netting for birds; impassable barriers for small mammals; high fences for large mammals).
4) Develop a protocol and system for reporting wildlife mortality at existing holding ponds.
5) Impose a moratorium on the land-based application of fracking fluids, including dispersal on roadways as a deicing or dust control agent.
6) Vigorously use the authority under the Clean Water Act to prevent contamination of waters from illegal discharges into waters of the United States.

VI. Cumulative impacts of hydraulic fracturing

Fracking impacts span both aquatic and terrestrial environments and extend far beyond local drill sites. As such, the cumulative effects of these operations are extremely challenging to identify. In general, accumulation of environmental effects from human disturbances can be additive (linear), synergistic, or cumulative.[38] Assessment of impacts on a well-by-well basis runs the risk of greatly underestimating adverse impacts to biodiversity and human welfare.

In fracking, the scale at which environmental effects are likely to occur (landscape or watershed) may not match the scale of environmental assessment conducted. For example, contaminants from projects in neighboring watersheds may not individually exceed standards for surface water pollution, but the contaminants may accumulate downstream at levels well above safe drinking water standards. These effects could compound with increased run-off from forest clearing at drill sites, pipeline right-of-ways, and existing and newly built access roads, leading to higher rates of siltation and further decreasing surface water quality.

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[37] Deep underground injection or the return of produced fluids to the same deep formation from which they came have been thought by many to be acceptable where the formations are known to be stable and capable of retaining the injected material. Produced fluids from fracking can be a problem however in new shale wells where the formation often won't take the fluids back or where the fluids may degrade otherwise stable rock leading to leakage.

[38] Bain, M. B., Irving, J. S., Olsen, R.D., Stull, E.A., Witmer, G.W., 1986. Cumulative impact assessment: evaluating the environmental effects of multiple human developments. Argonne National Laboratory, Argonne, Illinois; See *also*, Proposed methodology to assess cumulative impacts of hydroelectric development in the Columbia River Basin. Pages 408-423 in S. G. Hildebrand and J. B. Cannon, editors. Environmental analysis: the NEPA experience. Lewis Publishers, Boca Raton, Florida.

Understanding cumulative impacts also requires recognizing temporal patterns. Impacts may be either persistent (constant) or pulsed (iterative or occasional).[39] Persistent, chronic impacts associated with fracking may continuously affect landscapes over a long time period (e.g., forest clearing for well pads, roads, and power lines, or slow release of unrecovered backflow water into streams through groundwater pathways). Pulsed impacts of high magnitude and short duration (e.g., sudden releases of fracking water, pipeline spills), are usually unpredictable and can have unforeseen ecological consequences. The links among multiple stressors in space and time, and the propagation of effects downstream must be considered to fully understand cumulative impacts. Thus, if the environmental assessment process regards the past, current and foreseeable impacts but only considers impacts individually at a given site, the magnitude of total effects of fracking development across landscapes or watersheds would be grossly underestimated. To address cumulative impacts, SCB recommends the following high-priority research questions:

1) What are the best methods for evaluating cumulative, landscape-level impacts of hydro-fracking that include effects of habitat fragmentation, water sourcing, and potential contamination?
2) Given likely cumulative impacts, what are the optimal location, configuration, and density of wells and hydro-fracking pads? Are there areas that, in light of cumulative impacts, should be excluded from further development?

SCB recommends the following interim policy measures to safeguard against unknown cumulative effects on ecosystems while this research is conducted:

1) Require programmatic environmental impact statements for fracking operations that address cumulative impacts at the landscape scale. Where significant cumulative impacts are predicted, ensure that fracking operations fully address the risks posed by those impacts to biodiversity, especially those protected under the Endangered Species Act.

VII. Conclusion

Currently, many aspects of natural gas production by fracking on private and public lands lack federal oversight. In the absence of an effective and comprehensive federal regulatory regime on fracking, state agencies have developed their own regulations geared primarily toward protection of water resources. These regulations, often hastily crafted due to the extraordinarily rapid expansion of the fracking industry, vary substantially in terms of environmental protection. Federal regulations of the critical aspects of the fracking process should be enacted to ensure a consistent, baseline level of environmental protection across states. Federal oversight is essential because a single fracking operation can negatively impact multiple states, particularly in the case of water contamination and when water sourcing results in shortages. In the interim, the federal government should enforce existing regulations under the Clean Water Act, the Clean Air Act, the Endangered Species Act, and when cleanup is necessary utilize the Comprehensive

[39] Bender, E.A., Case, T.J., Gilpin, M.E., 1984. Perturbation experiments in community ecology: theory and practice. Ecology 65:1-13; Underwood, A.J., 1994. On Beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Applications 4:4-15.

Environmental Response, Compensation, and Liability Act (CERCLA) to address the risks posed by fracking. The federal government should also develop a science-based set of voluntary best practices for the fracking process. Compliance with these best practices would be evidence of a particular company's degree of civil or criminal liability should a fracking operation cause serious environmental contamination.[40]

In the absence of federal oversight, the rush to produce domestic and affordable energy may result in costly environmental damage and the permanent loss of biological diversity. Exchanging short-term economic gains for long-term environmental losses is not in our nation's best interest, particularly since many of our economically important industries (e.g., agriculture) depend directly on healthy environments. This shortsighted tradeoff is to a large degree unnecessary if sensible regulation and management strategies are adopted. For example, prohibiting the sale of wastewater as deicing fluid is a common sense regulation that will prevent widespread contamination of terrestrial and aquatic ecosystems. However, once wastewater chemicals have entered aquifers or streams, *it is virtually impossible to ensure their complete removal from the environment*. Such broad-scale, immutable consequences require a thoughtful and informed regulatory approach. In the end, proper regulation of natural gas development will be a "win-win" that will provide predictability for the natural gas industry, while protecting our unique natural heritage.

Sincerely,

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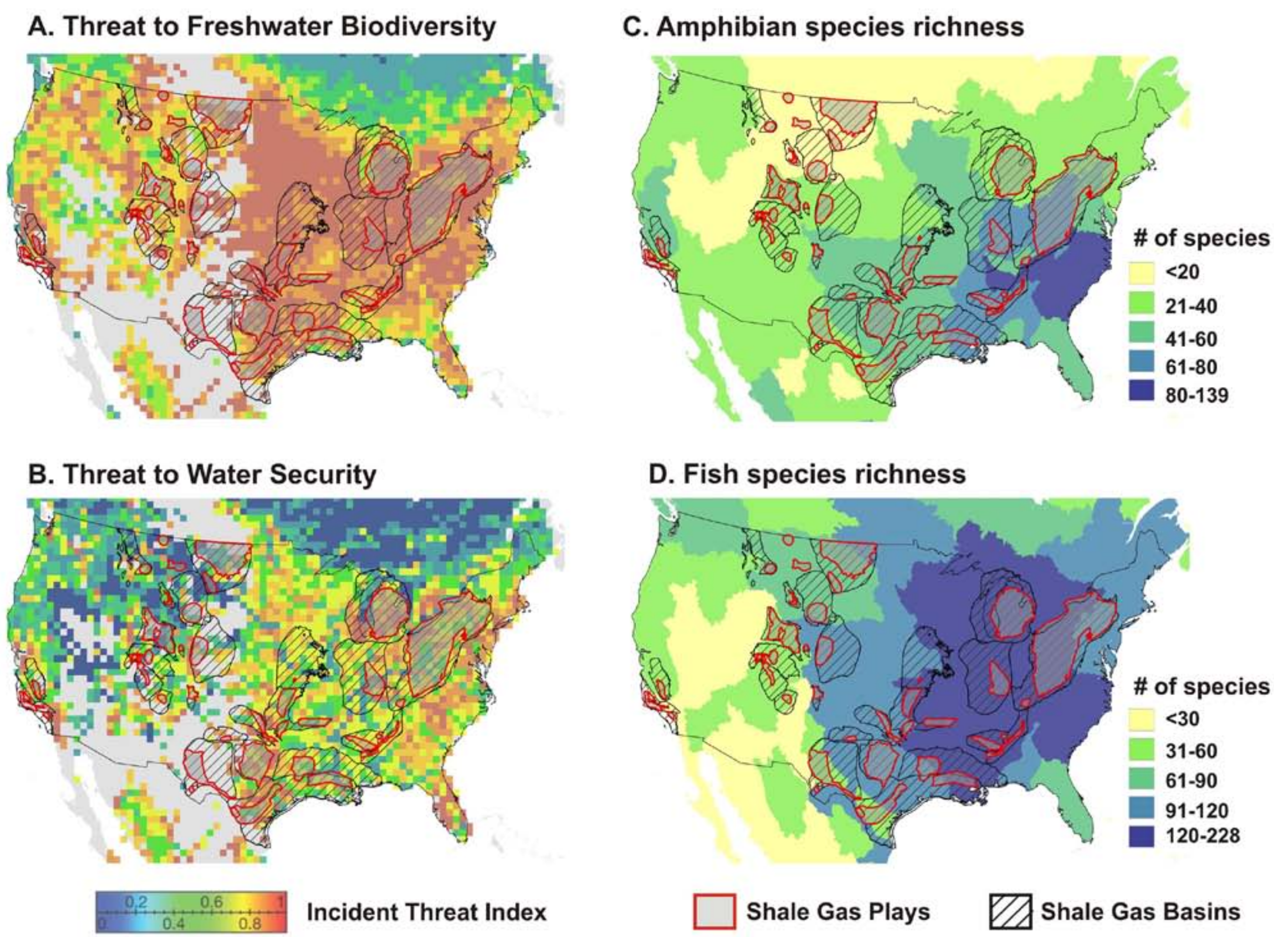
[40] This type of approach has been used recently to develop best practices in the wind energy industry. Under the U.S. Fish and Wildlife Service's Land-Based Wind Energy Guidelines, compliance with the Guidelines will be considered in determining liability under the Migratory Bird Treaty Act if a wind energy turbine is responsible for killing any migratory birds. See http://www.fws.gov/windenergy/docs/WEG_final.pdf

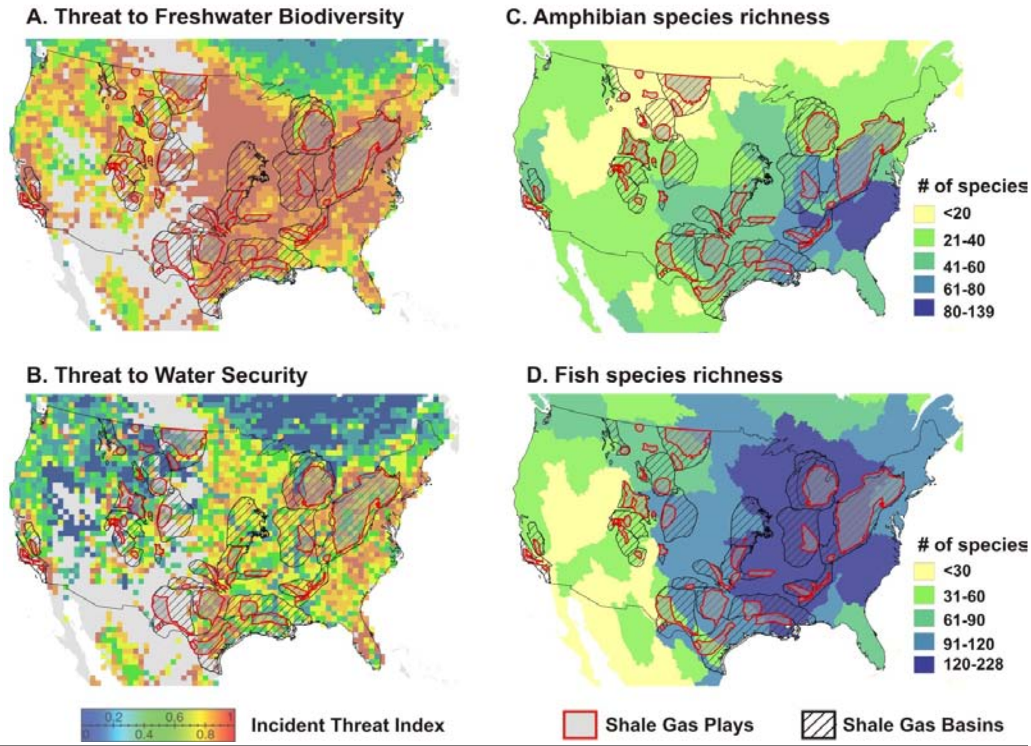
Figure 1

Figure 1. Extent of shale gas basins and plays (as of May 2011) in conterminous United States in relation to existing threats to freshwater systems (A and B) and amphibian and fish species richness by freshwater ecoregion (C and D).



Shale gas basins and plays were downloaded from the U.S. Energy Information Administration (eia.gov; accessed 13 February 2013).

Figure 1 Cont.



The Incident Threat Index for (A) Freshwater biodiversity and (B) Water security were derived by Vörösmarty et al. (2010) from a suite of 24 drivers known to affect global freshwater systems grouped in four themes: (1) Catchment Disturbance (cropland, impervious surface, livestock density); (2) Pollution (soil salinization, nitrogen loading, phosphorus loading, mercury deposition, pesticide loading, sediment loading, organic loading, potential acidification, thermal alteration); (3) Water Resource Development (dam density, river fragmentation, human water stress, agricultural water stress, flow disruption); and (4) Biotic Factors (percent non-native fish species, number of non-native fish species, fishing pressure, aquaculture pressure). "Incident" denotes the cumulative effect of the 24 drivers prior to accounting for beneficial measures taken to ameliorate water security. Lower index values (cold colors) represent low threat/stress areas; Higher index values (warm colors) represent areas under high stress for freshwater biodiversity and human water security; Areas in grey denote regions with no appreciable flow (Vörösmarty et al. 2010). The methods and data used to calculate the aggregate indices of Incident Freshwater Biodiversity Threat and Human Water Security Threat are given in the supplementary material associated with the Nature article: Vörösmarty, C.J., P.B. McIntyre, M.O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S.E. Bunn, C.A. Sullivan, C. Reidy Liermann, and P.M. Davies. 2010. Global threats to human water security and river biodiversity. Nature 467: 555-561.

The maps of amphibian and fish species richness by freshwater ecoregion (C and D) were developed by Hoekstra, J. M., J. L. Molnar, M. Jennings, C. Revenga, M. D. Spalding, T. M. Boucher, J. C. Robertson, T. J. Heibel, with K. Ellison. 2010. The Atlas of Global Conservation: Changes, Challenges, and Opportunities to Make a Difference. Ed. J. L. Molnar. Berkeley: University of California Press.

The Incident Threat Index and the Amphibian and Fish Richness data were downloaded from databasin.org (accessed 13 February 2013); all the datasets are licensed under a Creative Commons Attribution 3.0 License, http://creativecommons.org/licenses/by/3.0/.

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