ENVIRONMENTAL REVIEWS AND CASE STUDIES

Hydraulic Fracturing Threats to Species with Restricted Geographic Ranges in the Eastern United States

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High-volume horizontal hydraulic fracturing (*fracking*) is a new technology that poses many threats to biodiversity. Species that have small geographic ranges and a large overlap with the extensively industrializing Marcellus and Utica shale-gas region are vulnerable to environmental impacts of fracking, including salinization and forest fragmentation. We reviewed the ranges and ecological requirements of 15 species (1 mammal, 8 salamanders, 2 fishes, 1 butterfly, and 3 vascular plants), with 36%–100% range overlaps with the Marcellus-Utica region to determine their susceptibility to shale-gas activities. Most of these species are sensitive to forest fragmentation and loss or to degradation of water quality, two notable impacts of fracking. Moreover, most are rare or poorly studied and should be targeted for research and management to prevent their reduction, extirpation, or extinction from human-caused impacts.

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The new technology of high-volume horizontal hydraulic fracturing to extract natural gas, known as *fracking*, has gained attention in the past few years. Fracking is the process of drilling vertically and then horizontally through deeply buried shale beds, and pumping water, sand, and chemicals at high pressures into the shales to release the natural gas. Part of this chemical and water mixture returns to the surface as *frack water*, which contains toxicants such as benzene and toluene from the fracking fluids, as well as radium and salt from the shales (Rowan et al., 2011; Schmidt, 2011). Although the impacts of fracking in the eastern states on drinking-water supplies and public health have been discussed extensively, little attention has been paid to the effects of toxic chemicals, salt, habitat fragmentation, truck traffic, air pollution, noise, night lighting, and water withdrawals on ecosystems and their wild animals and plants (Davis and Robinson, 2012; Entrekin et al., 2011; Kiviat and Schneller-McDonald, 2011) The great spatial extent of industrialization and the rapid pace of development of shale-gas resources associated with fracking in the eastern United States (US) may result in environmental impacts disproportionate to economic benefits (Davis and Robinson, 2012). Many serious impacts of gas and oil mining on biodiversity have been documented in the US and Canadian West (Naugle, 2011). For example, compressor noise from gas-drilling installations was found to interfere with ovenbird (*Seiurus aurocapilla*) pairing success and alter population age structure (Habib, Bayne, and Boutin, 2007). In the Marcellus shale-gas region, it is expected that fracking will exacerbate the natural migration of salt from the deep shale beds into shallow aquifers (Warner et al., 2012), which could adversely affect wild species adapted to strictly fresh groundwaters or to surface waters into which groundwaters discharge.

The largest occurrence of commercially exploitable gas shales—the Marcellus and Utica shale-gas region—extends beneath approximately 285,000 km^2 of the Appalachian Basin (calculated from the US agency maps cited in this article's Methods section). This region supports high species diversity and many endemic species with small geographic ranges and narrow habitat affinities. The Appalachian region is a global megadiversity region for salamanders, stream fishes, freshwater mussels, and crayfishes, and is home to more than 150 imperiled species (Stein, Kutner, and Adams, 2000). Because organisms with geographic ranges concentrated in shale-gas regions are at greater risk from fracking impacts (Kiviat and Schneller-McDonald, 2011), we reviewed the potential impacts of fracking on animal and plant species with ranges substantially restricted to areas underlain by the Marcellus and Utica shale-gas region.

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Methods

We focused on species that have geographic ranges of which 35% or more is underlain by the Marcellus and Utica shale-gas region; we refer to these species as *quasi-endemic* to the Marcellus-Utica region. The cutoff of 35% has precedent in conservation science and is considered a high percentage overlap in the Natural Capital Project's habitat risk assessment model (Arkema, Bernhardt, and Verutes, 2011). By reviewing publicly available range maps, we selected 15 species that met the 35% criterion and are currently accepted as full species in standard taxonomic treatments [e.g., US Department of Agriculture (USDA), 2012].

We then studied each species' natural history, habitat needs, and legal status for indications of vulnerability to the physical and chemical effects of fracking. For example, eight species are salamanders in the family Plethodontidae. These lungless salamanders are particularly sensitive to environmental changes because they respire through their skin and require constant contact with moisture (Welsh and Droege, 2001). After selecting species, geographic information system (GIS) software was used to calculate the percentage overlap with the gas shales. We obtained geographic range data for mammals and amphibians from the International Union for Conservation of Nature (IUCN) Red List Spatial Data Download website (2012), for plants from the USDA (2012), for fishes from NatureServe (2011), and for butterflies from Butterflies and Moths of North America (BAMONA, 2012). We combined digital maps of the Marcellus and Utica shale formations obtained from the US Energy Information Administration (2012) and the US Geological Survey (2002) to create a single map layer showing the region underlain by both formations. We used ArcMap 10.0 (ESRI, Redlands, CA) to establish the overlap between each species' range and the shale boundary, to calculate the percentage overlap, and to create the maps depicting the species ranges in relation to the Marcellus and Utica shale-gas region.

Various federal agency maps indicate that the area of the combined Marcellus and Utica shales is in the range of 268,000 to 340,000 km^2. We use the conservative figure of 285,000 km^2 for our analyses.

One of the selected species, Bailey's sedge, extends northward into a small area of Québec, yet we have analyzed only the US portion of its range. Because Canadian and US practices differ with regard to managing this rare species, and the species undoubtedly varies genetically in different portions of its range, we believe it is important to protect this plant within the US regardless of its status in Canada. Another species, northern blue monkshood, which occurs in small areas of Wisconsin, Iowa, Ohio, and New York (USDA, 2012), may be part of a widespread western species, Columbian monkshood (*Aconitum columbianum*; Cole and Kuchenreuther, 2001). However, because there is a disjunction of 800 km between the Ohio and Wisconsin populations, suggesting the potential for evolutionary divergence, we have included only the Ohio–New York populations in our analysis. Evolutionary potential must also be considered when determining the ecological effects of fracking. We assessed potential impacts at the species level, but genetic variation below the species level may have an even higher overlap with the shales.

Results and Discussion

We reviewed 15 species with restricted geographic ranges having 35%–100% overlap with the Marcellus and Utica shale-gas region (Table 1 and Figure 1). Of the 15 species selected, there are 8 plethodontid salamanders, 2 stream fishes, 1 mammal, 1 butterfly, and 3 plants. The total geographic range size varies from 3 to 292,261 km^2, with a mean of 91,075.3 km^2 and median of 59,988 km^2. The mean overlap with the shale-gas region is 64.4%, and the median is 68%. Ten species have 50% or greater overlaps with the shales, and four have 40%–49% overlap. These overlap figures indicate the potential for impacts to occur over large portions of these species' ranges and, given the cumulative impacts of other intensive land uses such as coal mining, agriculture, residential development, and logging, raise substantial concerns about species survival. The sensitivities of these species to habitat degradation at the landscape and regional levels are suggested by the data in Table 1. Of the 15 species, 4 are listed as endangered or threatened at the federal level or in at least one state where the species occurs. Of the 15 species, 11 are stated to depend on good water quality, 10 to be sensitive to habitat fragmentation, 13 are either stenotopic (have narrow habitat affinities) or are sensitive to changes in habitat, and 11 are threatened by deforestation (Table 1).

Species with smaller geographic ranges are more vulnerable to extinction than are species with larger ranges (Payne and Finnegan, 2007), and species with smaller populations (numbers of individuals) are more vulnerable than are species with larger populations (Noss and Cooperrider, 1994; Slobodkin, 1986). Thus, reductions in range size are expected to make a species more vulnerable to extinction. Reductions in

Table 1. Selected species of animals and plants with restricted geographic ranges and a high degree of overlap with the combined Marcellus and Utica shale-gas region.

Species	Range (km^2)[a]	Shale (%)[b]	Status[c]	Water quality[d]	Fragmentation[e]	Stenotopic[f]	Forest[g]	References
Appalachian cottontail (*Sylvilagus obscurus*)	94,345	46			X		X	Barry and Lazell, 2008
Allegheny mountain dusky salamander (*Desmognathus ochrophaeus*)	292,261	70		X	X	X	X	Duncan et al., 2011 Gibbs et al., 2007 Welsh and Droege, 2001
West Virginia spring salamander (*Gyrinophilus subterraneus*)	3	100	E (WV)	X	X	X	X	Welsh and Droege, 2001
Wehrle's salamander (*Plethodon wehrlei*)	114,481	82		X	X	X	X	Duncan et al., 2011 Hammerson, 2004 Welsh and Droege, 2001 Wyman, 2003
Valley and ridge salamander (*Plethodon hoffmani*)	59,988	68		X	X	X	X	Duncan et al., 2011 Welsh and Droege, 2001 Wyman, 2003
Cheat Mountain salamander (*Plethodon nettingi*)	1,286	100	T (federal)	X	X	X	X	Duncan et al., 2011 Welsh and Droege, 2001 Wyman, 2003
White-spotted salamander (*Plethodon punctatus*)	11,143	45		X	X	X	X	Duncan et al., 2011 Welsh and Droege, 2001 Wyman, 2003
Shenandoah Mountain salamander (*Plethodon virginia*)	2,472	77		X	X	X	X	Duncan et al., 2011 Welsh and Droege, 2001 Wyman, 2003
Northern ravine salamander (*Plethodon electromorphus*)	113,396	58		X	X	X	X	Duncan et al., 2011 Welsh and Droege, 2001 Wyman, 2003
Tonguetied minnow (*Exoglossum laurae*)	31,622	67		X		?		USEPA, 2010
Bluebreast darter (*Etheostoma camurum*)	75,917	51	C (NY) I (OH, VA)	X		X		Losey, Roble, and Hammerson, 2011
Appalachian azure (*Celastrina neglectamajor*)	244,038	36			X	X	X	NYNHP, 2011
Shale-barrens pimpernel (*Taenidia montana*)	29,310	42	E (PA)			X		USDA, 2012 Walton, Ormes, and Morse, 2012
Bailey's sedge (*Carex baileyi*)	279,581	44		?	?	X	?	MNHESP, 2009
Northern blue monkshood (*Aconitum noveboracense*)	16,281	81	E (OH) T (federal, NY)	X		X	X	Edmondson et al., 2009 ONHP, 2007

[a] Total area of geographic range (calculations do not account for the fragmented ranges of some species, thus area occupied may be smaller than the figures shown).

[b] Percentage of geographic range that overlaps the Marcellus-Utica shale-gas region.

[c] E (endangered) or T (threatened) listing by federal or state agencies; C (critically imperiled) or I (imperiled) ranking by NatureServe (see references cited).

[d] Reported as sensitive to water quality (see references cited).

[e] Reported as sensitive to habitat fragmentation (see references cited).

[f] Reported as having narrow habitat affinities or as sensitive to habitat change (see references cited).

[g] Reported as dependent on forested environments or sensitive to deforestation (see references cited).

MNHESP, Massachusetts Natural Heritage and Endangered Species Program; NYNHP, New York Natural Heritage Program; ONHP, Ohio Natural Heritage Program; USDA, US Department of Agriculture; USEPA, US Environmental Protection Agency.

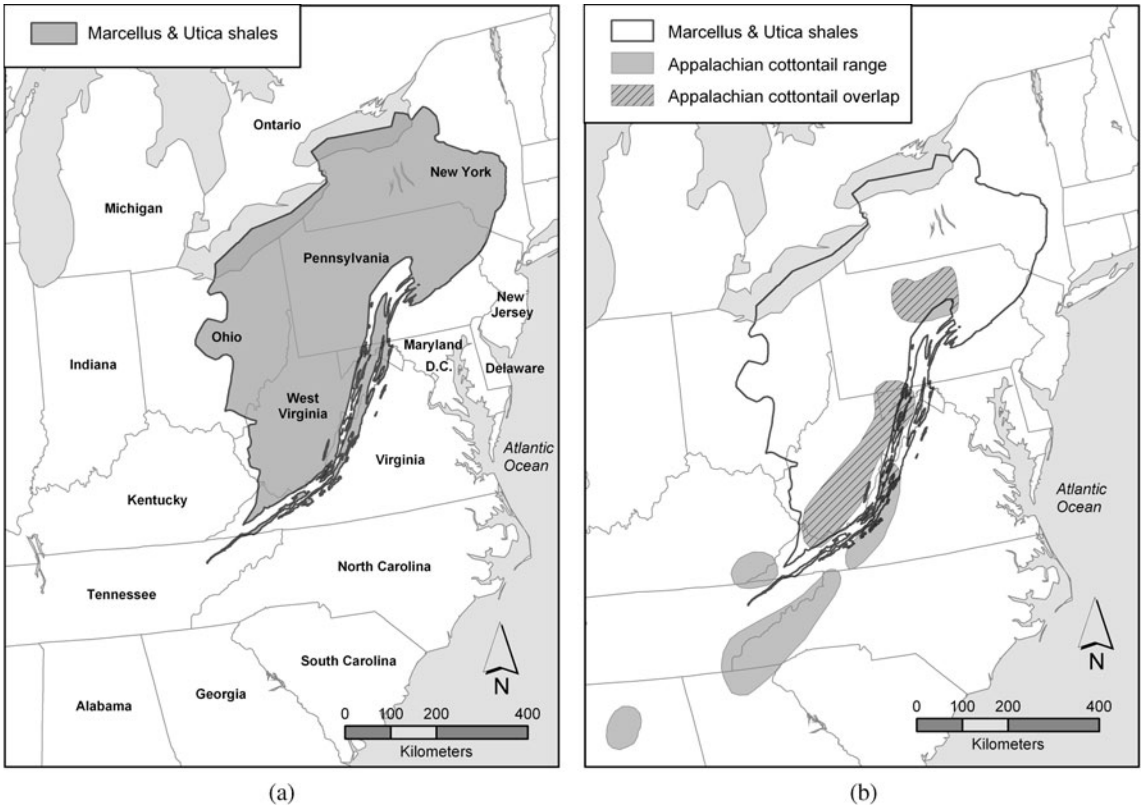
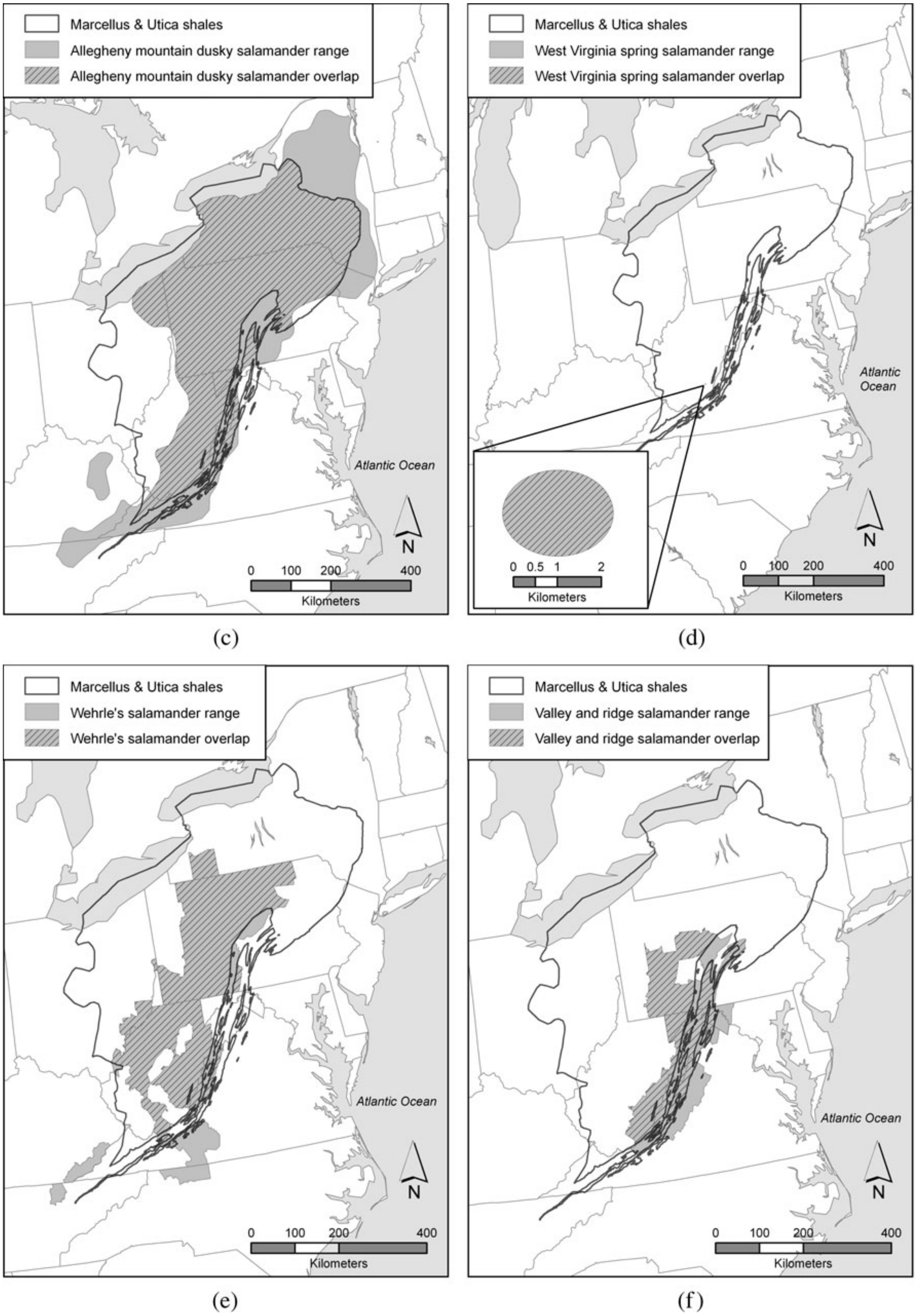


Figure 1. Maps showing the area underlain collectively by the Marcellus and Utica shale-gas region, the geographic ranges of selected species, and the overlap between shales and species: (**a**) Marcellus–Utica Shale outline, (**b**) Appalachian cottontail, (**c**) Allegheny mountain dusky salamander, (**d**) West Virginia spring salamander, (**e**) Wehrle's salamander, (**f**) valley and ridge salamander, (**g**) Cheat Mountain salamander, (**h**) white-spotted salamander, (**i**) Shenandoah Mountain salamander, (**j**) northern ravine salamander, (**k**) tonguetied minnow, (**l**) bluebreast darter, (**m**) Appalachian azure, (**n**) shale-barrens pimpernel, (**o**) Bailey's sedge, and (**p**) northern blue monkshood. Range maps for species are from the International Union for Conservation of Nature (2011), the US Department of Agriculture (2012), and Butterflies and Moths of North America (2012). See Table 1 for calculated areas of the geographic ranges and percentage overlaps with the shales.

forest area may result in great reductions of the number of species (Drakare, Lennon, and Hillebrand, 2006), and most of the species in our sample are closely associated with forests. The remainder of this discussion addresses the ecological requirements of the various groups of organisms that may make them vulnerable to fracking impacts.

Mammals

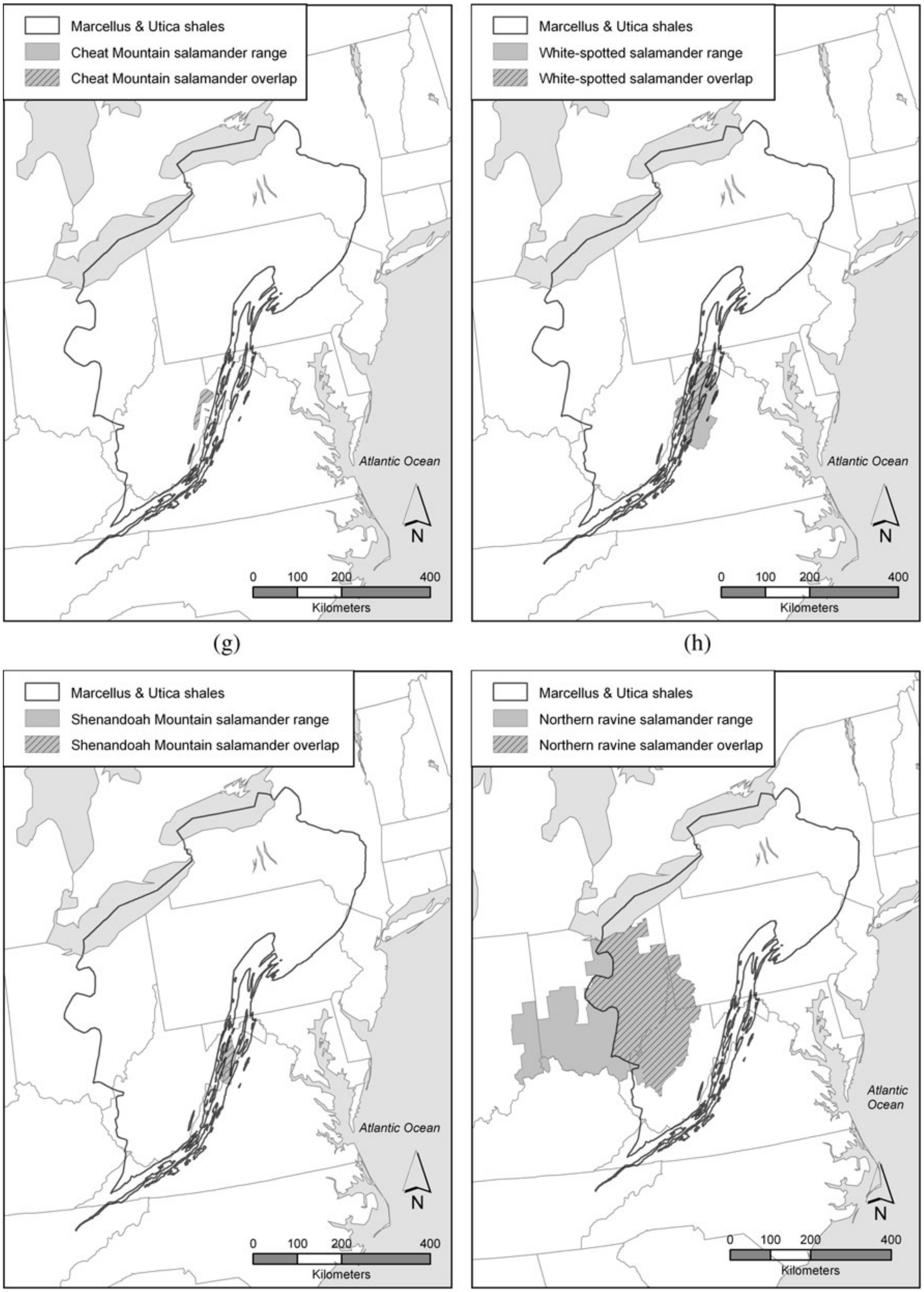
The Appalachian cottontail, recently separated by systematists from the New England cottontail, is found in mixed-oak forests with ericaceous (heath family) shrub cover (Bunch et al., 2012) and has a highly fragmented range, extending from Pennsylvania to Alabama (Barry and Lazell, 2008). Habitat needs are most likely different from those of the New England cottontail, but because this is not known, the species cannot yet be managed in a targeted way (Bunch et al., 2012). The Appalachian cottontail is declining and the number of local populations is decreasing due to habitat destruction, fragmentation, and forest maturation (Barry and Lazell, 2008; Harnishfeger, 2010). Fracking uses large areas of land for drill pads and pipelines, and roads must be constructed to enable truck traffic back and forth from drill sites. An average of 8.8 acres of forest is cleared for each Marcellus drill site and, with an additional indirect impact (through edge effects) on 21.2 acres, an average of 30 acres of forest is impacted at each site (Johnson, 2010). For a species that is threatened by habitat destruction and fragmentation, fracking could further reduce population and cause endangerment. The IUCN lists the Dolly Sods Wilderness Area, West Virginia, as a major source population for smaller populations of Appalachian cottontails



(c) (d)

(e) (f)

Figure 1. *Continued*



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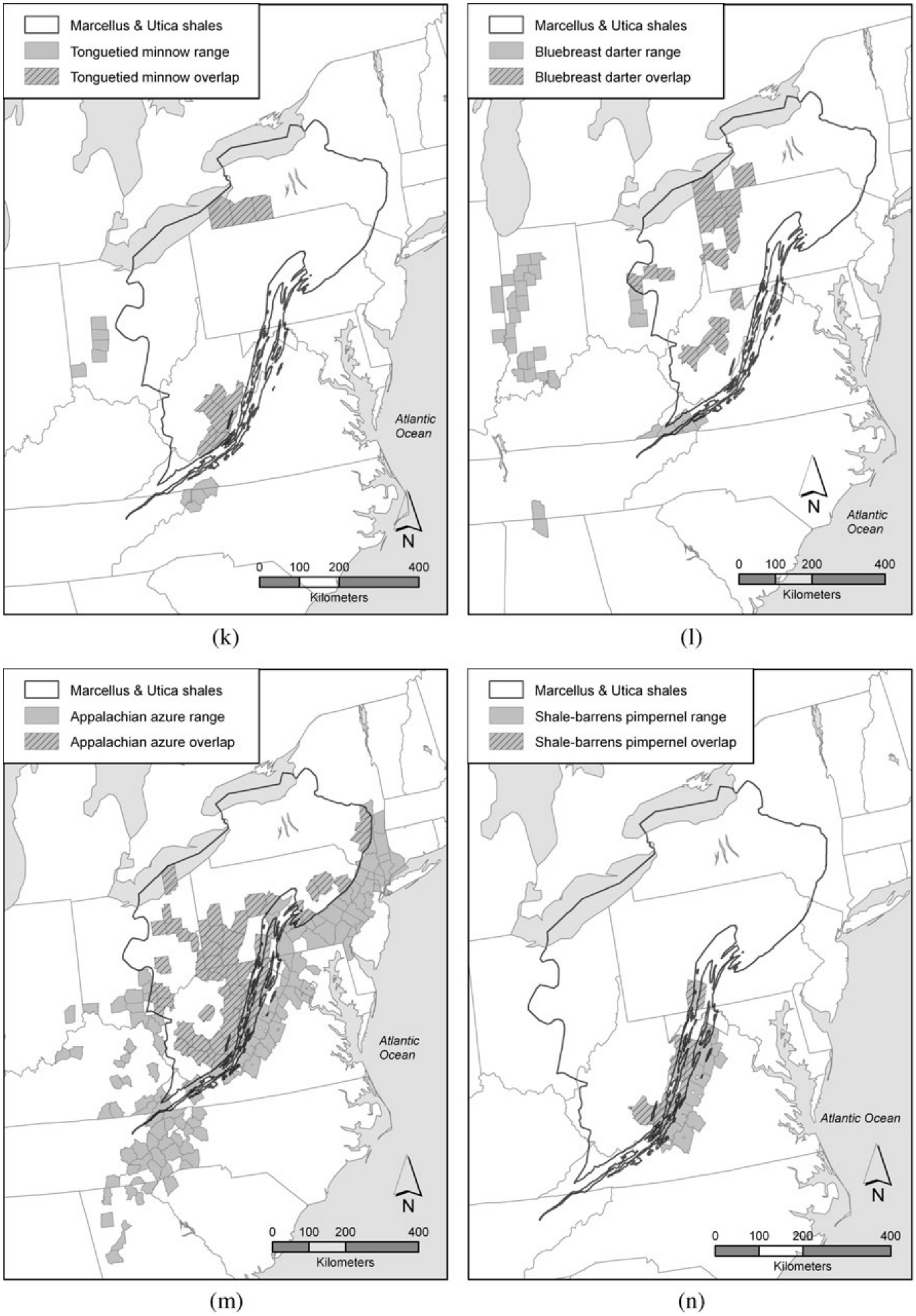
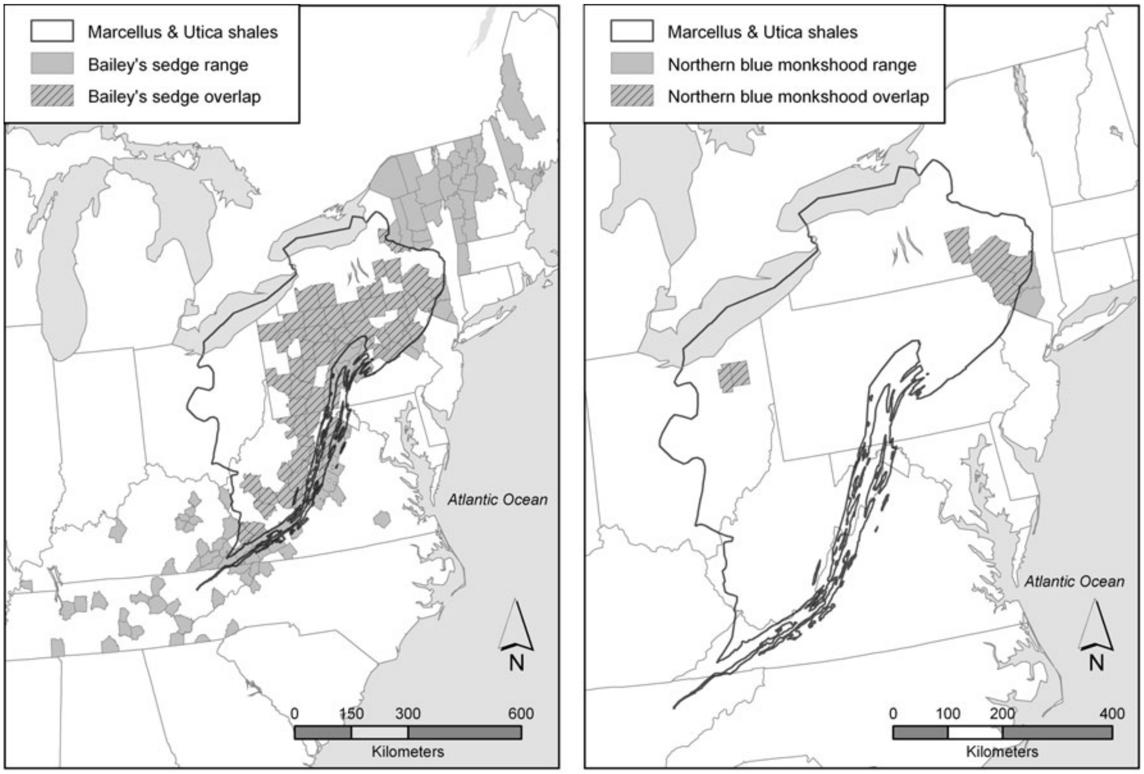


(k) (l)

(m) (n)

Figure 1. *Continued*



(o) (p)

Figure 1. *Continued*

(Barry and Lazell, 2008), and if this population were severely affected by habitat destruction or fragmentation caused by fracking, those populations that depend on Dolly Sods for gene flow would be negatively impacted.

Salamanders

The Plethodontidae, which is the largest family of salamanders, represents significant diversity (Petranka, 1998). Plethodontids are rapidly evolving, and too little is known about 43% of species to manage them successfully (Wyman, 2003). Many plethodontids, such as the Shenandoah Mountain salamander and the northern ravine salamander (Table 1), have only recently been recognized as species, and their habitat requirements and management needs are poorly understood (Highton, 1999). There is especially a lack of knowledge about the vulnerable juvenile terrestrial plethodontids (Wyman, 2003).

Terrestrial salamanders have difficulty crossing roads, and roads may reduce both their abundance and genetic diversity. Roads not only fragment habitats but may also be obstacles to salamanders (Wyman, 2003). Forest roads have been shown to reduce terrestrial salamander movement by 51%, and multiple roads could reduce dispersal by up to 97%. Although roads may not have major implications for species with large ranges and high abundances, species with limited ranges and low abundances may be severely affected by new roads because they are already impacted by fragmentation, logging, and other human activities (Marsh, Gorham, and Beckman, 2005). Plethodontids such as the white-spotted salamander and the Cheat Mountain salamander have small distributions and are currently affected by fragmentation and deforestation (Hammerson, 2004; Hammerson and Mitchell, 2004); multiple roads and truck traffic, when compounded with many other destructive factors, could imperil these species' survival. After clear-cutting, salamander communities take decades to recover from the drying of soils in logged areas, changes in the prey community, and the difficulty many salamander species have in crossing nonforested habitats (e.g., Ash, 1997; Bratton and Meier, 1998; Mitchell, Wicknick, and Anthony, 1996; Petranka, Eldridge, and Haley, 1993). The perforation of forests by well pads, access roads, and pipeline rights-of-way, with associated microclimatic drying, salinization, and other changes, presumably reduces or eliminates local populations of many salamander species in fracking landscapes, and this could contribute cumulatively to a decline or loss of species over large areas.

The wastewater from fracking installations is another potential threat to salamanders. After well fracking is completed, 30%–70% of the water injected into the well returns to the surface with contaminants from the shales and the fracking chemicals (Schmidt, 2011). In Pennsylvania and West Virginia, frack water has been sprayed on land, diluted in municipal sewage treatment plants, stored in open pits, partially reused, leaked, and spilled (Kiviat and Schneller-McDonald, 2011). Preliminary data from Pennsylvania streams indicate that conductivity was higher and biotic diversity (including salamanders) was lower in small watersheds where fracking had occurred (Anonymous, 2010). Saline wastewater can pollute streams and other bodies of water, and many stream-dwelling and water-dependent organisms are salt sensitive. Salamanders, especially those with aquatic larvae, are sensitive to water quality (Duncan et al., 2011). The West Virginia spring salamander has been found in a single cave in Greenbrier County, West Virginia; the adults reside in the mud banks next to the stream passage, and the aquatic larvae develop in the stream (Besharse and Holsinger, 1977). Fewer than 250 mature individuals of this species exist, and all of these salamanders are dependent on the stream that runs through the General Davis Cave (Hammerson and Beachy, 2004)—if this stream were to be polluted by salt or fracking chemicals, the species would be in danger of extinction. Although much of the toxicological research has been conducted on frogs rather than salamanders, amphibians in general are vulnerable to many contaminants, including organic chemicals, heavy metals, and metalloids (Herfenist et al., 1989).

Fishes

There is a high probability of water pollution from spills of fracking wastewater (Rozell and Reaven, 2012), and stream fishes are vulnerable to this impact. The tonguetied minnow is intolerant of water pollution (US Environmental Protection Agency, 2010), although there is not enough information on this species to determine how it would be affected by fracking. The bluebreast darter is critically imperiled in New York, imperiled in both Ohio and Virginia, and vulnerable in West Virginia and requires good water quality (Losey, Roble, and Hammerson, 2011; Pennsylvania Natural Heritage Program, 2012), making it particularly vulnerable to fracking activities.

Butterflies

The Appalachian azure inhabits deciduous forests, and its larval food plant is black cohosh (*Actaea racemosa*). The butterfly is scarce and has difficulty moving between forest fragments. Black cohosh is potentially threatened by nonnative plants and white-tailed deer (*Odocoileus virginianus*) (New York Natural Heritage Program, 2011), both of which are likely to benefit from fracking.

Plants

Plants will also be affected by fracking through fragmentation, increased salinity levels, and pollution by toxic chemicals. The northern wild monkshood is a federally threatened plant at risk of soil contamination, drying due to canopy loss, and nonnative plants. The monkshood occurs in only four states, of which New York and Ohio overlap with the Marcellus and Utica shale-gas region. Monkshood has narrow habitat affinities, grows slowly, is very sensitive to disturbance, and there is probably little gene flow among the isolated populations (Edmondson et al., 2009; Ohio Natural Heritage Program, 2007); forest fragmentation and increased salinity caused by fracking could imperil an already threatened species. Forest fragmentation is known to facilitate the spread of nonnative, potentially invasive, plants (e.g., Yates, Levia, and Williams, 2003).

Potential Benefits to Biodiversity

Fracking may benefit some species as well as harm others. Industrial activity creates habitats that may be used by rare or economically important species. For example, Noel et al. (1998) documented caribou (*Rangifer tarandus*) using gravel pads associated with oil drilling for insect relief habitat. Schmidt and Kiviat (2007) found a globally rare clam shrimp [*Cyzicus* (*Caenestheriella*) *gynecia*] in rain pools on a gas pipeline road in New Jersey. However, artificial industrial habitats tend to support common species that are ecological generalists (E. Kiviat, personal observations) rather than species of conservation concern. We expect that fracking installations will provide habitats for a few noteworthy species while degrading the environment for many others. Appalachian cottontail is known to use shrublands and several-year-old clear-cuts (Cannings and Hammerson, 2012); thus, gas-pipeline rights-of-way and abandoned well pads might provide acceptable habitat. Undoubtedly, other species of conservation concern could be managed for in fracking landscapes, and research to provide the basis for such management is urgently needed. Forest fragmentation in fracking landscapes, because of the dispersed character of the industry, cannot be avoided.

Summary

Hydraulic fracturing poses serious threats to a diverse group of species, including plants, butterflies, fishes, and salamanders, that have restricted geographic ranges overlapping substantially with the Marcellus and Utica gas shales. Of the 15 species we reviewed, many are so little known that targeted management would be based on insufficient evidence. Of these, 13 have narrow habitat affinities and 11 are dependent on good water quality (Table 1), making them particularly vulnerable to fracking effects such as elevated salinity and other pollution.

Conclusions

Although fracking will likely be permitted in most states underlain with gas shales, if biodiversity and human impacts are well studied, appropriate regulations can be implemented. Because New York has not yet permitted high-volume horizontal hydraulic fracturing, there is an opportunity to protect the quasi-endemic species whose ranges extend into New York, including northern blue monkshood, Wehrle's salamander, Allegheny mountain dusky salamander, and Appalachian azure. Many organisms are undergoing poleward range shifts caused by climate change, but because changes in range limits are species specific and subject to many biological and abiotic interactions (Wyman, 1991), we cannot know whether overlap percentages with gas shales will increase or decrease. Range contraction (local or regional extirpation) due to other causes may increase the percentage overlap of the remaining range with the Marcellus-Utica region, thus cumulatively increasing the risk posed by fracking; the Allegheny woodrat (*Neotoma magister*; LoGiudice, 2003) may be an example.

We reviewed species for which range maps are available; there are many more species with no range maps or so little ecological information that it would be impossible to assess how fracking may affect them. There are almost certainly many species of invertebrates, plants, lichens, and other organisms that are quasi-endemic to the Marcellus-Utica region, but lack of access to range maps and ecological information prohibited their inclusion in our study. The species selected in this study may actually have a much greater overlap with the shales (because habitat range maps are generalized or out of date), and thus potential effects of fracking could be greater than the percentages in Table 1 suggest. Also, ecological impacts like mountaintop-removal mining, logging, climate change, and other industrial activities will compound the effects of fracking, making these species vulnerable to decline and extinction. Future studies should include a broader range of taxa and field research that can measure the impacts of fracking while considering how these impacts may be compounded by other threats to biodiversity.

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 (Wilson, 1992). 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. Many of the species selected not only have restricted geographic ranges, but live in small, isolated populations that would be negatively affected by further fragmentation. A number of these species are also recently described species, and most are little known ecologically. Intensive industrial activities such as fracking that potentially affect an almost 300,000-km^2 region need to be thoroughly studied so that researchers and natural resource managers can assess impacts on biodiversity and humanity.

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