Silence of Falling Trees: Hidden Forest Loss from Shale Gas Development

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Abstract

The recent global boom in shale gas development has dramatically altered energy portfolios, local economies, landscapes, and environmental conditions. In this paper, we examine an environmental cost often overlooked when evaluating the overall impact of shale gas exploration. We examine the land cover implications of unconventional shale gas development in the U.S. by focusing on shale plays in heavily forested areas (Pennsylvania, Ohio, West Virginia, and Arkansas) that contain the Marcellus, Utica, and Fayetteville shale formations. Using a panel regression with data on forest cover from 2001 to 2016, we examine the impact of shale activity on forest loss. Our results indicate that each additional fracking pad led to 13 to 16 acres of forest loss. We also show that this forest loss is present across all forested shale formations, and these results are robust to a number of specifications. The unique nature of horizontal drilling used in shale exploration allows for a reduction in the footprint of shale-related activity through optimal spatial placement of pads. Currently, the average effective distance between pads is 0.95 miles even though pads can be placed up to 4 miles apart. If policies are instituted to incentivize drillers to place pads at greater distances, a reduction in forest loss exceeding 7 million acres could be achieved across these shale plays.

Keywords: Forest Loss; Fracking; Shale Oil and Gas; Energy and Land Use

JEL Codes: Q30; Q48; Q56; Q58

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Introduction

The combination of horizontal drilling and hydraulic fracturing ("fracking") has led to a boom in unconventional energy development in the United States over the last decade with these new technologies now positioned to unleash vast quantities of natural gas and oil in the years to come (Figure 1). Access to previously inaccessible resources has also transformed the energy outlook, and the economic and physical landscape of the U.S. (Mason et al. 2015; Munasib and Rickman 2015; Brown et al. 2016; Kelsey et al. 2017). While this contemporary energy boom has the potential to provide significant economic benefits, a number of overlooked costs could be hidden behind the boom driven positive effects, especially costs related to the environmental externalities associated with shale-gas driven landscape changes.

The development of shale-based natural gas in the U.S. and the associated transition from coal-based energy production has been touted as a solution for both domestic energy-supply issues as well as the negative environmental costs associated with usage of coal as a fuel input. Proponents of increasing usage of natural gas argue that natural gas is cleaner and less environmental harmful when compared to coal and gasoline (Office of the Press Secretary, White House). While it is true that natural gas generates less pollution at the combustion stage, summation of lifecycle pollution from the entire production process makes the overall comparative advantage of natural gas less clear. There is a vast literature that studies the local and regional environmental costs of shale gas drilling (Osborne et al. 2011; Olmstead et al. 2013; Jackson et al. 2014; Gopalakrishnan and Klaiber 2014; Muehlenbachs et al. 2015; Hill and Ma 2017; Wrenn et al. 2017). What is less well studied is the overall aggregate environmental footprint associated with shale gas development. Since shale gas production and development impacts the landscape in a potentially significant manner, the aggregate environmental footprint is a particular important issue that needs to be addressed (Abrahams et al. 2015; Drohan et al 2012).

Specifically, many of the largest shale gas plays in the U.S. are in heavily forested areas that provide important ecosystem services and environmental benefits. Shale exploration significantly impacts forests by altering the landscape and the natural environment at both local and regional levels. Using satellite land-cover data for the years 2006 and 2011 combined with data on shale drilling activity in Pennsylvania, Klaiber et al. (2017) determined that each drilling well pad led to an aggregate forest loss of approximately 50 acres over a 5-year time horizon following well development. Given this level of forest cover loss and the attendant environmental impacts, it is important to explore policy mechanisms to reduce or limit this outcome.

Fortunately, the unique nature of horizontal drilling allows for a relatively simple solution to reduce forest loss. Better management of surface drilling locations to achieve optimal spatial placement of pads can reduce the total number of well pads drilled, and limit the need for additional pipeline construction and other supporting infrastructure. In contrast to traditional vertical wells, where the wells need to be drilled directly above the seal of the reservoir to access the resource, horizontal drilling provides access to the subsurface resource anywhere within a 2-mile radius of the underground fracking location. This subterranean horizontal movement allows for numerous avenues to minimize landscape conversion. Klaiber et al. (2017) explore the reduction in forest loss from clustering up to 8 wells on 1 pad to minimize the number of wells drilled and conclude that 112,838 acres of forest in Pennsylvania could have been saved from clustering during the early phases of drilling activity in Pennsylvania.

In this paper, we examine additional conservation savings by examining the reduction in well pads and associated forest loss if pads were placed optimally to take advantage of the 2-mile effective radius of horizontal drilling. We build upon existing work (Klaiber et al. 2017) and estimating the forest loss from shale oil and gas development on U.S. shales plays in heavily forested areas and use these estimates to predict the potential impacts on forest loss across shale plays. We specifically analyze forest losses from shale development in the Marcellus, Utica, and Fayetteville shale formations, which were some of the most productive, heavily drilled, and heavily forested plays in the U.S. from 2001 to 2016.[1] Using these forest loss estimates, we estimate a panel regression to determine the latent forest acres savings under optimal future pad placement for shale gas development. The results from this study shed new light on potential environmental costs that are often overlooked when evaluating unconventional shale gas exploration and provide a potential policy solution that can reduce a major portion of the cost.

Data

We use unconventional gas well data from Pennsylvania, Ohio, West Virginia, and Arkansas that contain parts of the Marcellus, Utica, and Fayetteville shale formations. The data were gathered from each state's perspective Oil and Gas agency website and contain location information for each drilled well, the type of well drilled, and the well's spud date. To restrict our study to horizontal fracking wells, we drop all non-horizontal or non-fracking wells from our dataset. Using the data, we can determine the extent to which well pads are utilized and the spacing of the underlying well pads.

[1] We explored shale gas development in other states as well, including Wyoming and Colorado, but the data indicate insignificant tree loss because of low initial forest cover.

The Pennsylvania Department of Oil and Gas provides a unique pad identifier for each well pad, but the other states do not. To identify pads in the other states in our sample, we use Geographic Information Systems (ArcGIS) to measure geodetic distances between wells. To determine spacing and pad locations, we assume that any well located within a maximum radius of a different well is assigned to a common well pad. We use Pennsylvania well pad data to calibrate the distance to the nearest well for a common pad and determine that 15-meter is a robust and conservative radius to identify pad locations that is consistent with engineering estimates of average pad size. Figures 2 shows the 12,363 fracking wells drilled in the Marcellus and Utica shale plays between 2001 and 2016 and Figure 3 shows the 5,861 fracking wells drilled during the same period within the Fayetteville formation.

To estimate forest loss, we use a yearly panel of satellite data on Global Forest Cover Change from 2001 to 2016 (Hansen et al. 2013). Following standard practice in the literature, we reclassify all grids with less than 25% forest coverage as no forest loss to eliminate sensitivity concerns in determining baseline forest coverage. Figures 4 and 5 show the total acres of forest loss from 2001 to 2016 for the states of Pennsylvania, Ohio, West Virginia, and Arkansas. Using these data, we spatially join well and pad data at the census tract level to create a panel dataset with the acres of forest loss, number of wells drilled, and number of pads drilled for each census tract each year from 2001 through 2016. We drop all census tracts not in the shale formation due to possible differences between shale areas and non-shale areas. Finally, we divide the number of wells into the number of first, second, third, fourth, fifth wells, and wells drilled later than the fifth well on a pad in for each census tract and year.

Table 1 provides summary statistics for our merged panel dataset. We see an average of 0.20 and 0.73 wells were drilled each year in each census tract in the Marcellus/Utica and

Fayetteville areas. However, there were 0.06 and 0.52 pads drilled each year in each census tract in the Marcellus/Utica and Fayetteville areas, which suggests a higher well per pad ratio in the Marcellus/Utica region. The average forest loss in the Fayetteville region was significantly higher with 26 vs 235 acres per tract per year, but not necessarily from fracking wells as we will see in our results.

Methods

We examine the impact of shale activity on forest loss using the following panel data regression in Equation (1).

$$\Delta A_{it} = \propto_0 + \propto_1 firstwell_{it} + \propto_2 nonfirstwell_{it} + C_i + Y_t + \varepsilon_{it} \quad (1)$$

In this equation, i indexes the census tract, t indexes the year, and C_i and Y_t represent census tract and year fixed effects. We regress ΔA_{it}, the change in acres of forest in each tract between years, on the number of first wells drills, $firstwell_{it}$, and on the number of wells drilled after the first well, $nonfirstwell_{it}$. As each first well drilled requires a pad space, the variable $firstwell_{it}$ is also the number of pads in each census tract and $\propto_1$ is the marginal impact of an additional pad on forest loss. With horizontal drilling and fracking, pads can accommodate multiple wells. We control for the impact of additional wells on the pad through the control variable $nonfirstwell_{it}$ to identify the marginal impact of the pad itself apart from additional wells.

Due to the long observation period in our data, it is likely that locally varying unobservables do not adhere to time-constant assumptions common in standard panel datasets. To address this issue, we estimate the model in Equation (2) which includes spatial-by-time fixed effects at the county-by-year level to control for trends in unobserved time-varying factors at the county level that may bias into our earlier specification.

$$\Delta A_{it} = \propto_0 + \propto_1 firstwell_{it} + \propto_2 nonfirstwell_{it} + CY_{jt} + \varepsilon_{it} \quad (2)$$

To account for the potentially heterogeneous effects of placing additional wells on an existing well pad, we use Equation (3) to control for the effects of the second, third, fourth, fifth, and after-fifth wells.

$$\Delta A_{it} = \propto_0 + \propto_1 firstwell_{it} + \propto_2 secondwell_{it} + \propto_3 thirdwell_{it} + \propto_4 fourthwell_{it} + \propto_5 fifthwell_{it} + \propto_6 afterfifthwell_{it} + C_i + Y_t + \varepsilon_{it} \quad (3)$$

Finally, in Equation (4) we extend Equation (3), and we include spatial-by-time fixed effects at the county-by-year level based on Equation (2) to control local county level specific time trends.

$$\Delta A_{it} = \propto_0 + \propto_1 firstwell_{it} + \propto_2 secondwell_{it} + \propto_3 thirdwell_{it} + \propto_4 fourthwell_{it} + \propto_5 fifthwell_{it} + \propto_6 afterfifthwell_{it} + CY_{jt} + \varepsilon_{it} \quad (4)$$

In all 4 of our specifications, the coefficient $\propto_1$ is interpreted as the marginal impact of an additional fracking pad on acres of forest loss. We use this estimate to project the forest loss associated with future shale development and estimate the potential reduction in forest loss as spacing of well pads is altered to more optimally extract the resource.

To implement this projection, we first calculate the number of pads needed to fully develop shale plays assuming we continue to place pads using the current average distance between pads, which results in sub-optimal placement. We use GIS data on existing well pads to calculate the current average distance to the nearest well pad. We define this distance as the radius of the current effective shale development area of each pad. Using the average effective area per well pad, we divide the area of the shale play by the current average effective area of each pad to determine the number of pads needed to fully extract the resource under current conditions. We show that the sub-optimal pad placement fails to maximize the distance between pads with available technology. The sub-optimal placement results in more well pads relative to the optimal number of pads needed to develop the same effective area, which leads to excess forest loss.

To calculate optimal pad placement, we use a similar approach to determine the optimal number of pads needed under optimal pad placement. The only difference for optimal pad spacing is that we apply the maximum effective radius of 2 miles based on technology limits as the radius for the effect area as opposed to the average current distance between pads. The reduction in number of pads drilled using this optimal process leads to a reduction in forest. To estimate the total forest savings from optimal pad placement, we multiply the estimates for marginal forest loss of an additional pad from Equations (1) – (4) with the reduction in the number of pads to determine the total savings in forest loss from the reduction in pads.

Results

We estimate Equations (1)-(4) for different shale formations to illustrate the ubiquitous nature of fracking-related forest loss. As the Marcellus and Utica formations overlap with each other, we report only two sets of results – one for the Marcellus/Utica formation and one for the Fayetteville formation. Table 2 reports the results for the Marcellus/Utica formation. As described in the methods section, Equation (1) and Equation (3) control for spatial unobservables at the census tract level and time effects at the year level, and we cluster at each census tract. Equation (2) and Equation (4) control for spatial-by-time unobservables with the county-by-year fixed effects, and we cluster at county-by-year. Across all specifications, we find that the forest loss associated with each additional pad drilled ranges between 7 and 13 acres. Table 3 reports the results for the Fayetteville formation. Once again, we find a similar loss of 8 to 17 acres of forest associated with each additional pad drilled.[2]

Turning attention to the impact of wells drilled on existing pads based on Equations (3) and (4), we find that additional wells are not associated with significant additional impacts on forest loss. This is to be expected as the additional wells are placed on existing constructed pads and likely to share infrastructure and pipelines. Also, the estimates from Equation (2) and Equation (4) with spatial-by-time controls are larger than the estimates from Equation (1) and Equation (3) which control for spatial and time effects. The larger estimates are probably due to local fixed effects varying at the long observation period of 1 year, which makes Equation (2) and Equation (4) less biased. In our preferred specification, Equation (4), we find forest losses of 13 and 16 acres, respectively, for each additional pad drilled during the first year in the Marcellus\Utica and Fayetteville formations.

Discussion

With the immense forest loss from shale development seen in Table 2 and Table 3, there is a critical policy need to seek solutions that curtail forest loss without significantly impeding drilling activity. The unique nature of horizontal drilling allows for wells to be surface drilled 2 miles away from the subterranean fracking location. This implies the possibility of pads to be placed 4 miles apart as opposed to the current 0.95 miles and 0.40 miles in the Marcellus/Utica and Fayetteville formations. The greater distance between pads allows for a reduction in the number of pads drilled, but maintains the same effective fracking area. There are currently 3,740

2 For the estimates in Table 3 and the Fayetteville shale, we only control for up to the 4th additional well on the pad due to the limited number of 5th wells

pads in the Marcellus/Utica and Fayetteville formations, for which our estimates suggest resulted in 138,421 acres of forest loss. However, if these pads were spaced optimally, it would have reduced the number of pads to 1,134, and could have saved 122,478 acres of forest. Table 4 shows the number of pads with optimal spacing and forest savings in the existing fracking areas.

Using the estimates of forest loss from the Marcellus/Utica and Fayetteville formation, we extrapolate to the undeveloped areas in these formations to gauge how much forest can be saved if further development follows an optimal pad policy (based on the current technology of a 2-mile effective radius for fracking) as compared to the current pad placement configuration. The results are shown in Table 5. The first column and second columns show the comparison if the entire Fayetteville and Marcellus/Utica formation were to be developed. The third column shows the potential savings if all the U.S. shale formations under forest areas are developed under current pad distances versus optimal pad distances. If policies are instituted to incentivize or force drillers to optimally space pads as per Table 5, the optimization can potentially reduce 1.1 million acres, 3.9 million acres, and 7.7 million acres, or 95%, in forest loss in the Fayetteville, Marcellus/Utica, and U.S. shale plays in future development. This work suggests that there may be relatively straightforward policy solutions to mitigate the significant forest loss of shale development without hindering the production of the energy resource itself. The technology and policy learnings from the U.S. shale boom thus far can be utilized to better and more efficiently develop future shale resources.

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Table 1. Summary Statistic

	Marcellus/Utica				
	Mean	Std. Dev.	Min	Max	Obs
Wells	0.203	2.48	0	132	59,680
Pads	0.062	0.714	0	38	59,680
Total Acres of Forest Loss (2001-2016)	26.138	99.94	0	3680	59,680
	Fayetteville				
	Mean	Std. Dev.	Min	Max	Obs
Wells	0.734	4.724	0	71	1,409
Pads	0.519	3.627	0	68	1,409
Total Acres of Forest Loss (2001-2016)	235.035	414.223	0	3688	1,409

Table 2. Marcellus/Utica Main Results

VARIABLES	(1) Acres of Forest Loss	(2) Acres of Forest Loss	(3) Acres of Forest Loss	(4) Acres of Forest Loss
firstwells	4.695***	9.535***		
	(1.207)	(2.227)		
nonfirstwells	1.066*	2.435***		
	(0.581)	(0.751)		
firstwell			6.747***	13.53***
			(1.775)	(3.253)
secondwell			-3.904	-6.206
			(3.049)	(5.105)
thirdwell			1.426	3.959
			(3.594)	(5.961)
fourthwell			1.819	6.413
			(4.324)	(7.444)
fifthwell			7.416	0.402
			(4.840)	(7.921)
afterfifthwell			-0.127	3.836
			(1.413)	(2.612)
Constant	-1.560*	9.482***	-1.561*	9.482***
	(0.882)	(3.28e-10)	(0.882)	(3.15e-10)
Observations	59,680	59,680	59,680	59,680
R-squared	0.691	0.409	0.691	0.410

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Fayetteville Main Results

VARIABLES	(3) Acres of Forest Loss	(4) Acres of Forest Loss	(5) Acres of Forest Loss	(6) Acres of Forest Loss
firstwells	10.10***	16.51**		
	(3.027)	(6.758)		
nonfirstwells	5.477	14.75		
	(7.141)	(9.079)		
firstwell			6.575*	17.52**
			(3.340)	(7.226)
secondwell			49.39	-11.88
			(33.39)	(78.88)
thirdwell			24.53	5.880
			(37.71)	(109.2)
fourthwell			-17.74	165.7
			(93.89)	(202.7)
fifthwell			-78.66	-81.00
			(59.10)	(72.00)
afterfifthwell	-62.19***	297.5***	-62.34***	297.5***
	(18.82)	(0)	(18.61)	(0)
Observations	1,409	1,409	1,409	1,409
R-squared	0.801	0.400	0.804	0.400

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Forgone Optimal Pad Savings for Developed Shale Plays

	Optimal No. Pads	Existing No. Pads	Reduced No. Pads	Forest Total Loss from Existing Pads (Acres)	Potential Forest Saving (Acres)
Fayetteville	37	3,707	3,670	59,937	59,337
Marcellus/Utica	1,134	5,801	4,667	78,484	63,141

Table 5. Optimal Pad Savings

	Marcellus/Utica	Fayetteville	U.S. Forest Shale
Area (Square Miles)	207,571	8,831	408,125
Current Distance (Miles)	0.95	0.40	0.95
Optimal (Miles)	4	4	4
Number of Pads	290,382	70,166	564,490
Optimal Number of Pads	16,518	703	51,016
Reduction in Number of Pads	273,864	69,463	538,470
Efficiency	5.7%	1.0%	5.7%
Forest Total Loss from Existing Pads (Acres)	1,134,588	3,928,875	7,724,936
Potential Forest Saving (Acres)	1,123,224	3,705,381	7,285,502

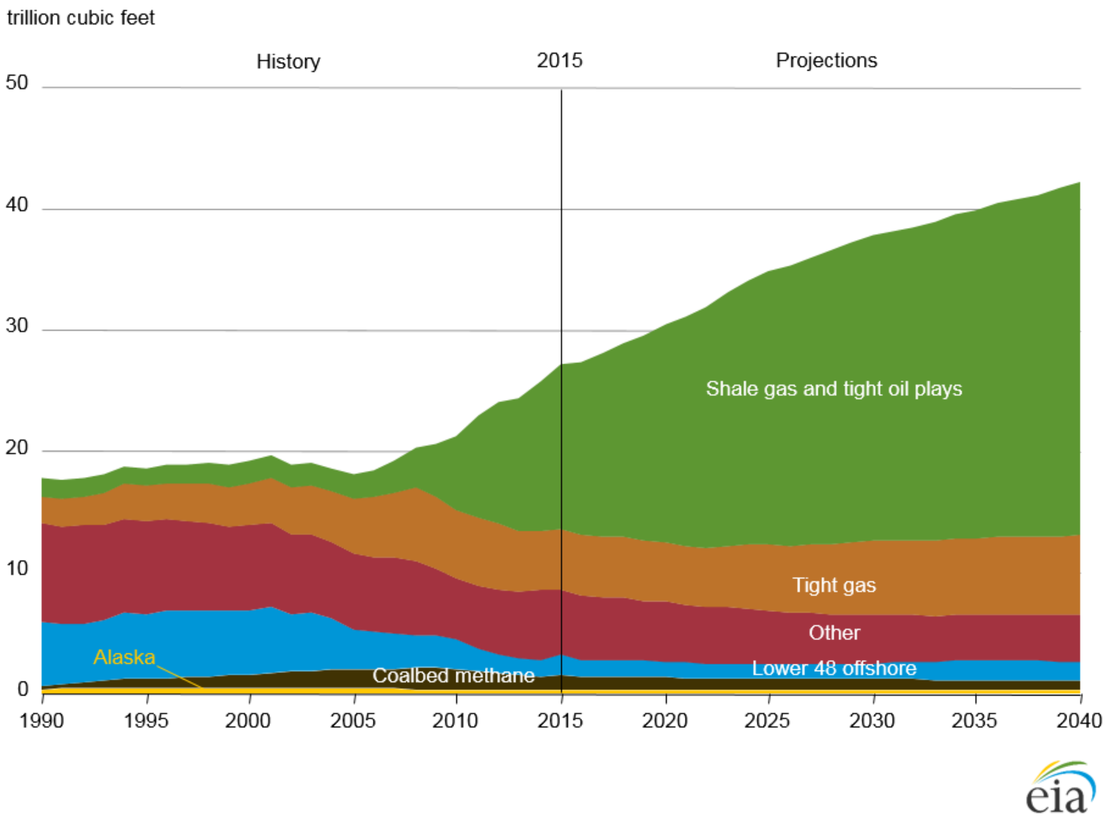

Figure 1. U.S. Shale Development and Projection

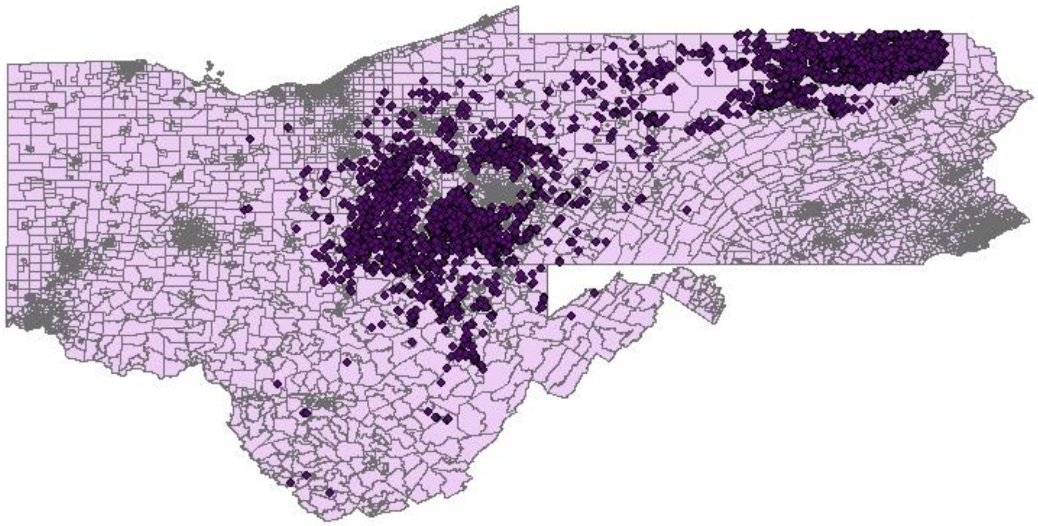

Figure 2. Drilled Wells in the Marcellus/Utica Formation

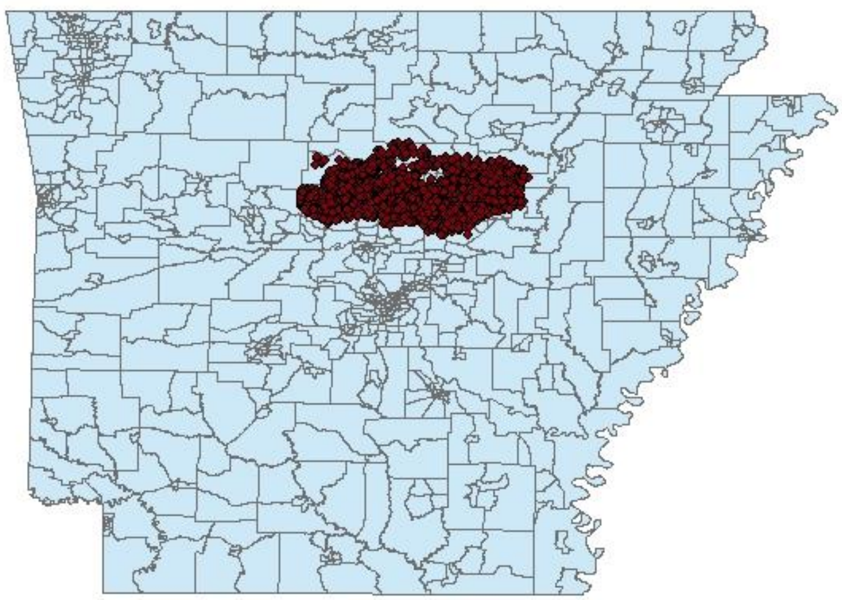

Figure 3. Drilled Wells in the Fayetteville Formation

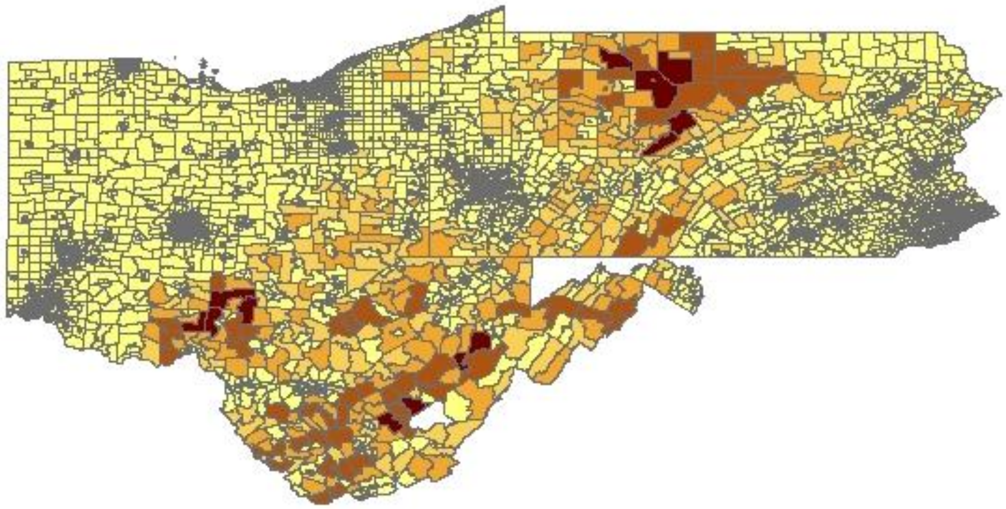

Figure 4. Total Forest Loss in PA/OH/WV

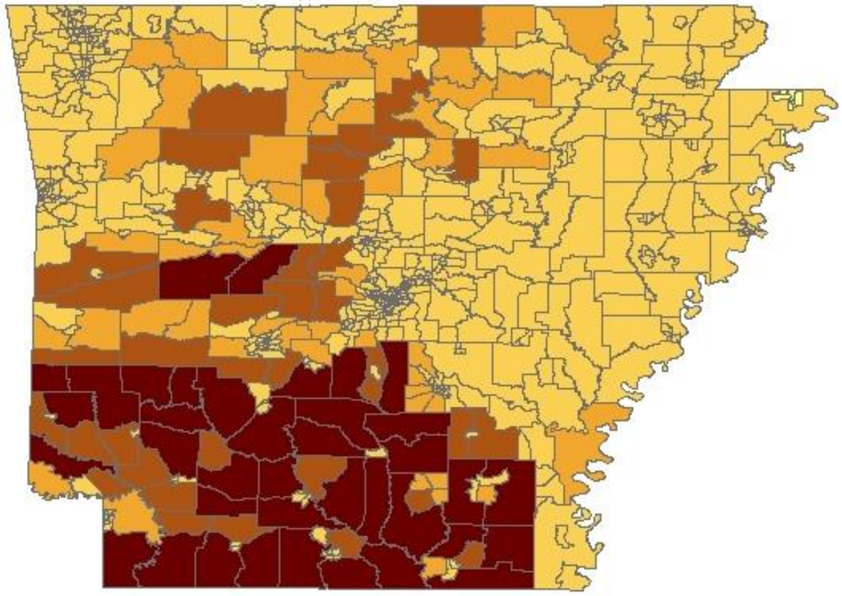

Figure 5. Total Forest Loss in AR