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Understanding and mitigating impacts of unconventional oil and gas development on land-use and ecosystem services in the U.S.

Maureen R. McClung and Matthew D. Moran

Abstract
Unconventional oil and gas development has expanded dramatically in the United States during the last 15 years. This change in the energy industry has developed, modified, and fragmented large areas of the terrestrial landscape, resulting in hundreds of millions of dollars of annual ecosystem services costs, including negative effects on agricultural production, plant and wildlife populations, animal migrations, and human well-being. The locations of the most active unconventional oil and gas regions overlap ecologically valuable and, in some cases, relatively intact natural habitats, but there are few detailed studies that comprehensively investigate local ecosystem services impacts of this recent activity. We highlight impacts on the terrestrial landscape in three areas of the U.S. that deserve particular attention: the eastern temperate deciduous forest of the mid-Appalachian region, the prairies of the Great Plains, and the Chihuahuan Desert of west Texas and southern New Mexico. These regions cover large geographic areas that are rich in ecosystem services, and recently they have experienced some of the highest levels of unconventional oil and gas activity. We make a call for targeted studies to improve our understanding of how this development will impact these ecosystem services and which strategies can mitigate the negative impacts. The lessons learned from these analyses could be applied to new energy development abroad, which is currently under consideration by many nations with probable unconventional oil and gas resources.

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Ecosystem services, Deciduous forest, Desert, Prairie, Restoration, Unconventional oil and gas.

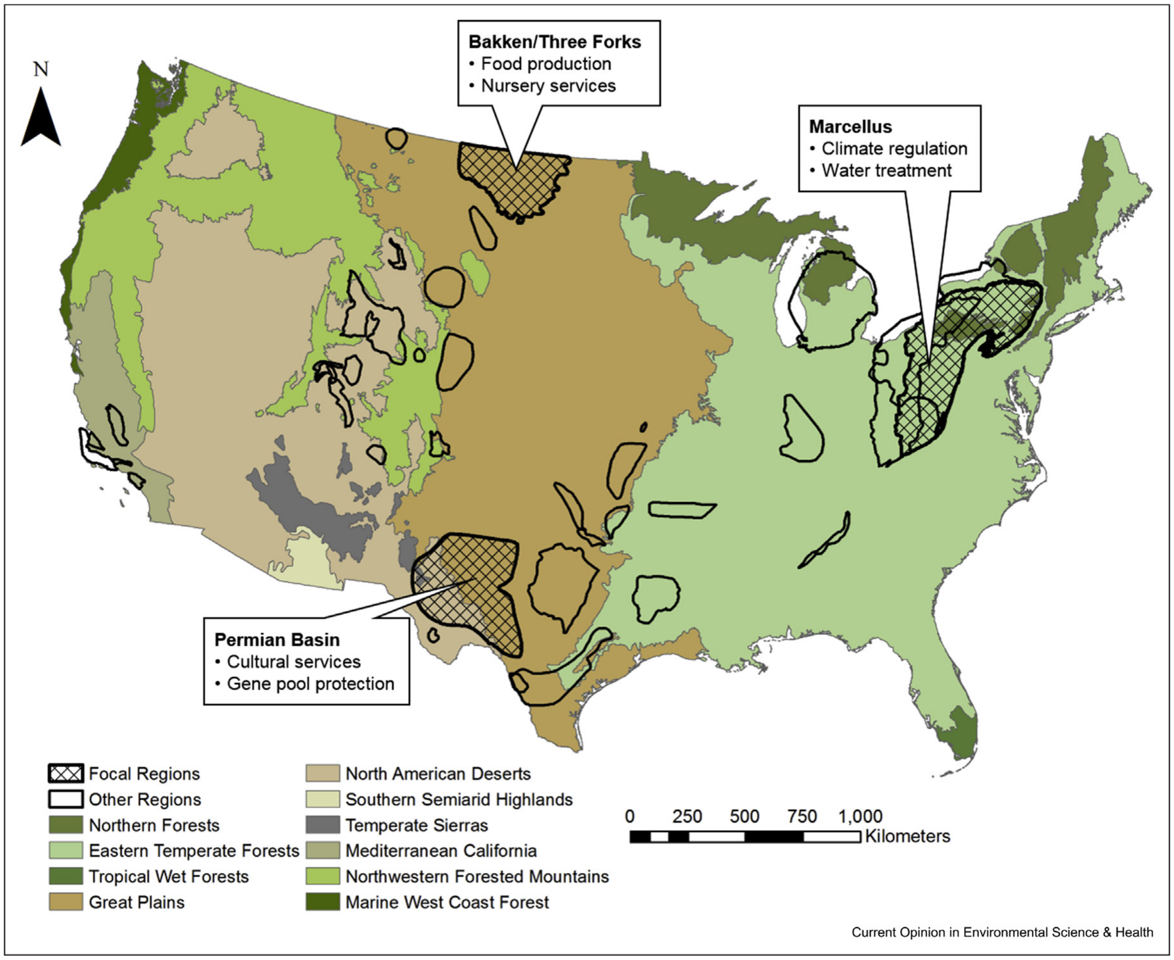
Introduction

Natural landscapes provide numerous benefits to humanity that are often under-appreciated by the public. This value extends to semi-natural landscapes that have been modified by humans, yet retain some semblance of their natural state (e.g. grazing lands). These benefits have been described and quantified by environmental scientists and referred to as ecosystem services [1–3]. Examples of ecosystem services delivered at the local scale include drinking water, raw materials, and recreational opportunities. Landscapes also provide services with benefits that manifest on a global scale, such as carbon storage, moderation of climate, and maintenance of biodiversity. Ecosystem services therefore provide a measureable monetary benefit to human societies that has been estimated to equal more than the gross world product (i.e. total economic output [4–6]).

Land-use changes from human activity can have extensive impacts on ecosystem services through the conversion and modification of land, a process that degrades ecological function. One of the biggest drivers of land-use changes in the past and projected into the future is energy development [7–12]. In particular, the increase in unconventional oil and gas (defined here as the combination of horizontal drilling and hydraulic fracturing, often referred to as fracking [13]), currently accounts for large amounts of land conversion across the U.S. [12,14–16], with one estimate amounting to more than 200,000 ha as of 2015 [11]. This land-use trend is expected to continue in the U.S. and could expand globally in the near future [17,18]. Unconventional oil and gas development threatens the biodiversity and ecological functioning of several temperate ecosystem types, especially grasslands, deciduous forests, and deserts [11,15,19,20] (Fig. 1), as well as aquatic resources [21,22]. If these landscapes continue to suffer high impacts from this activity, we stand to lose significant amounts of ecosystem services, which could translate into high economic, social, and environmental costs [11,15,22–29].

Unconventional oil and gas development tends to leave a characteristic footprint on the landscape. Well pads, access roads, and other supporting infrastructure completely convert natural landscapes into artificial structures. Pipelines typically alter landscapes from natural cover into degraded or modified habitats

Fig. 1



Depending on the habitat, certain ecosystem services play a larger role than others. In the U.S., major active unconventional oil and gas regions disproportionately impact particular ecoregions. We highlight three major production areas (i.e. Marcellus, Bakken/Three Forks, and Permian Basin) that have recently had rapid unconventional oil and gas development and where important ecosystem services are likely being lost. Since these areas represent distinct bioregions with different prominent ecosystem services, there is a need for region-specific analyses of ecosystem services costs related to land-use changes that accompany this development. These analyses can then be used to make appropriate mitigation and restoration recommendations suited for the regional services.

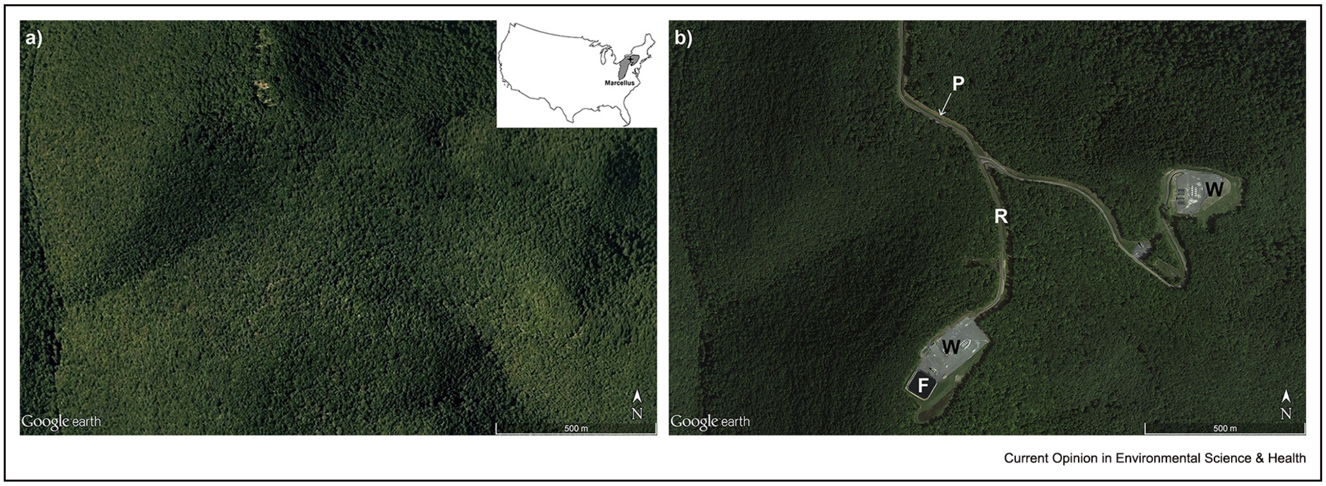
[11,16,30–32]. All of these activities fragment habitat [14], a process beyond conversion that has profound effects on many ecosystems [33,34] (Fig. 2). Unconventional oil and gas development occurs in particular areas of the U.S., and therefore, certain bioregions are disproportionately affected, specifically eastern temperate deciduous forest, southwestern desert, and short- and mixed-grass prairie [11,19] (Fig. 1). Several of the largest development areas overlap or are expanding into some of the last remaining and best examples of these ecosystems [35–39]. In this paper, we describe how the terrestrial systems of three of these unconventional oil and gas regions are being affected by the boom in development, and discuss approaches to minimize the land-use changes and their subsequent impacts on ecosystem services.

Examples

Appalachian deciduous forests

The Marcellus Shale, located in the central Appalachians, is the largest (in terms of land area and well count) unconventional gas region in the U.S., covering about 124,000 km^2 [40]. Most of the landscape is covered in natural forest, with some ecoregions within the Marcellus Shale over 80% forested [41–43], and it represents one of the largest and best remaining examples of temperate deciduous forest in the world [35]. It has seen the construction of over 10,000 wells and associated facilities since the year 2000 [32]. The primary ecosystem services provided by this region include water provisioning, timber production, and recreational opportunities, which are heavily utilized by the large urban centers located nearby (about 52 million people

Fig. 2



Satellite view of temperate deciduous forest in the Marcellus Shale of Pennsylvania (a) in 2005 before, and (b) in 2016 after unconventional gas development. Gas development is evidenced by the presence of structures such as well pads (W), roads (R), frackwater ponds (F), and pipeline rights-of-way (P).

live in the states that substantially overlap the Marcellus Shale, i.e. New York, Pennsylvania, Ohio, Maryland, and West Virginia). The annual ecosystem services of the Delaware River Basin alone, which overlaps about 9% of the Marcellus Shale, is estimated at $21 billion, dwarfing any benefits of the shale gas economy, estimated at $425 million per year [44]. Given the rate of shale gas well drilling and associated changes in land-use [32,35], water pollution levels [45–48], and local responses in wildlife [48,49], it is likely that the ecosystem services costs are considerable and negatively affecting human well-being in this region [22,50,51].

2: North American prairies

The prairies of the North American Great Plains, where most natural grasslands survive, contain several areas where unconventional oil and gas activity is high, including the Bakken/Three Forks formations of North Dakota and Montana, Barnett Shale of Texas, and Niobrara Shale of Colorado, Kansas, Nebraska, and Wyoming. Most of the landscape is either natural grasslands used for grazing or highly modified land used for row-crop agriculture, which both deliver important provisioning ecosystem services in form of food production to the greater U.S. and beyond [52,53]. The natural habitat that remains is also one of the more endangered bioregions in North America (i.e. short- and mixed-grass prairies and sagebrush steppes [36,38], thus it likely provides valuable habitat services that are not well-represented elsewhere [15]. Since 2000, tens of thousands of wells (mostly unconventional) have been constructed in the Great Plains, which has resulted in large land-use impacts, such as land conversion and fragmentation [8,54,55]. Subsequently, the large range of ecosystem services of this region are at great risk [15].

The Chihuahuan Desert

The Chihuahuan Desert boasts a high amount biodiversity [56], important renewable resources [39], and unique cultural services [39]. Large areas of the Chihuahuan Desert have historically experienced low development [57]. However, the northeast corner that overlaps the Permian Basin, has seen decades of conventional oil and gas development [58]. With the development of high-volume hydrofracturing technology, oil and gas drilling has increased rapidly [59] in the Permian Basin, and thus the Chihuahuan Desert has become one of the fastest growing unconventional oil and gas regions in the U.S. This activity is also threatening to expand outside the traditional boundaries of the Permian Basin into other parts of the Chihuahuan Desert (e.g. the Big Bend region) that may be particularly valuable for ecosystem services [39,60].

What unites these three regions is the high conservation value they retain. Although habitat throughout much of the U.S. has been highly altered by human activity, these regions have particular conservation and biodiversity interests represented at the landscape level. Recent oil and gas activity threaten the ecosystem services of these region, and we argue that they are worthy of enhanced protection and strategic development decisions.

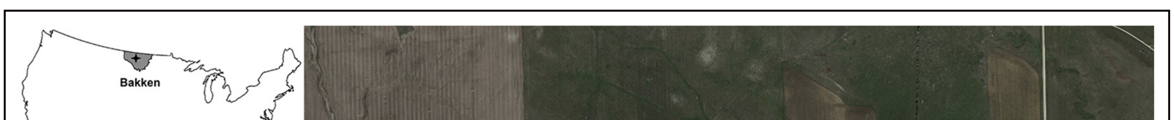
Recommendations

While ecosystem services costs of unconventional oil and gas development have been estimated at a national level [11,15], there is need for detailed, location-specific assessments of the major producing regions. Ideally, ecosystem services values would be estimated before oil and gas development proceeds, and thus plays a role in determining where this activity should take place and help minimize ecosystem services costs when development does occur. If two regions are under consideration, the region with highest total ecosystem services values could be spared development. For example, large areas of the Marcellus Shale are composed of mature, nearly contiguous, and biodiverse deciduous forest. The ecosystem services of this area likely have increased importance because of the area's close proximity to large human populations, most notably the Northeast Megalopolis (i.e. Boston – Washington Corridor [61]).

If development is inevitable, placing new wells within the existing oil and gas infrastructure (e.g. roads, pipelines) could minimize the overall land-use changes associated with this activity [31]. Such a strategy has been implemented in the Bakken/Three Forks region of North Dakota where new oil development sometimes occurs along "energy corridors" that already have easy road access, with the goal of lessening impacts on important food production lands [8,62] (Fig. 3). A more comprehensive approach could include developing geographic models that incorporate variables of interest to multiple stakeholders, which could lead to economic benefits while limiting ecological impacts [63]. In addition, planning could occur at the regional level so that mitigation of impacts at one site might offset impacts at another site [64,65].

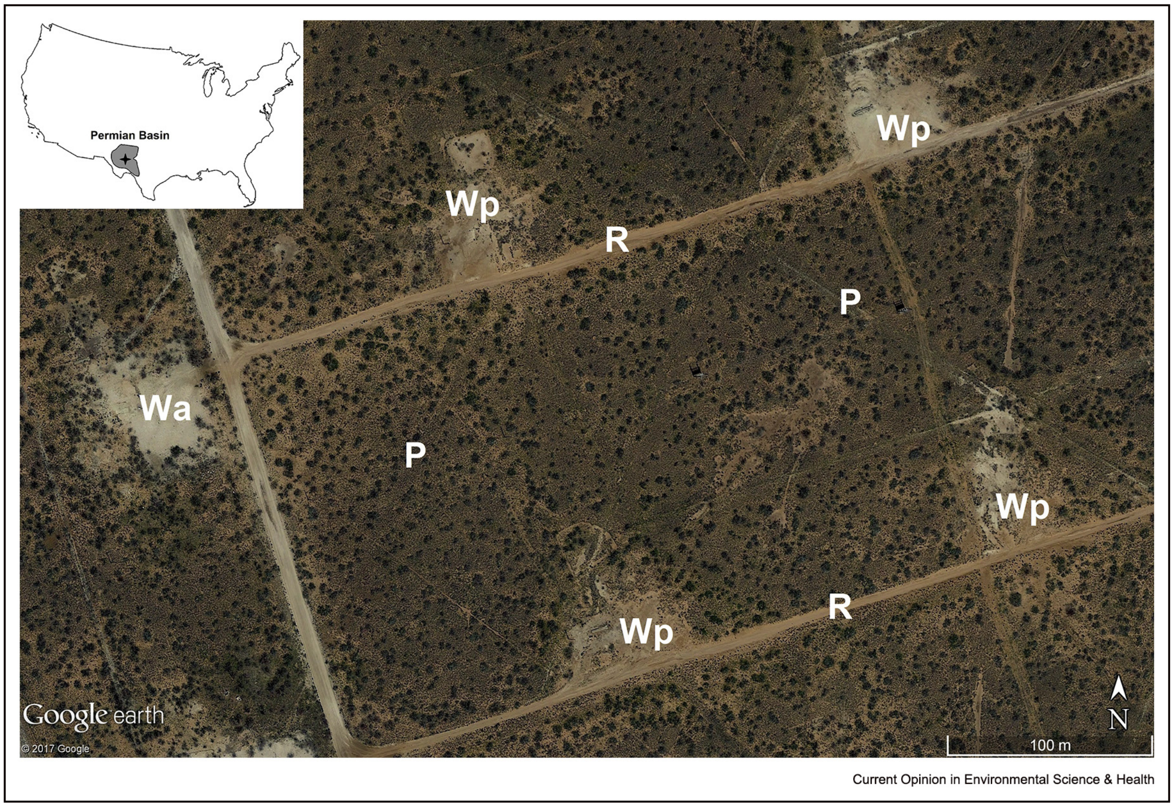
Ultimately, we should also consider restoration of damaged landscapes. The oil and gas industry has left behind degraded landscapes impacted by old well pads, roads, pipelines, and other infrastructure (Fig. 4). These degraded lands represent an opportunity to lessen the current damage being inflicted by the unconventional fossil fuel revolution. We argue that the U.S. should pursue a mandatory restoration policy when new oil and gas development is proposed on ecologically valuable land. In short, if you develop and/or degrade an area of land, you must restore an area of similar habitat and quality so that total ecosystem services are retained. This type of restoration plan would focus on the services provided by the landscape and not necessarily the size of the area restored. Therefore, knowledge of the ecosystem services provided by different regions needs to be improved since currently, the region-specific information is lacking [11]. Further research into restoration benefits in specific watersheds, ecoregions, or areas of particular conservation interest (e.g. areas of high endemism) would also be valuable in determining where to focus restoration resources and what benefits would

Fig. 3



Satellite view of an "energy corridor" in the Bakken/Three Forks oil and gas region of North Dakota showing well pads (W), roads (R), pipeline rights-of-way (P), associated infrastructure (Inf), intensive agricultural fields (A), and natural grasslands along a riparian zone (N).

Fig. 4



Satellite view of a portion of the Permian Basin region near Monahans, TX, showing abandoned oil wells and their long-lasting surface modifications to natural landscapes. Features labeled include plugged wells (Wp), active wells (Wa), roads (R), and pipeline rights-of-way (P). The four wells labeled Wp were abandoned between 1965 and 1998 [58].

be gained (e.g. agricultural productivity, raw materials, carbon storage, etc.) Another major issue would be the legal aspects of this plan. Onshore oil and gas drilling is typically permitted by state governments (with the exception of federal lands), so an effective restoration policy would probably have to be developed in each state, no doubt a difficult undertaking in such diverse political climates.

Since measurements of development and modification of landscapes from oil and gas are reasonably well-studied [8,9,11,16,28,31,35,66], we have a good understanding of the land-use footprint of this industry. What is needed now is how that footprint translates into ecosystem services costs. Once the area impacted and the ecosystem services costs are known, these values can be used to designate an area that could offer equivalent ecosystem services for restoration. An example of this model is the “Alpine High” gas field in southwest Texas that is expected to host 3000 wells [59]. Although the exact placement of this development is still uncertain, the overall process will likely have a predictable land-use footprint of modification and fragmentation. Nearby areas of the Permian Basin in the same bioregion have extensive numbers of plugged and abandoned wells that continue to incur ecosystem costs (Fig. 4), including reduced climate regulating services (from lack of vegetation) and reduced recreational value. Since this habitat is similar to the Alpine High field, these sites are an appropriate place to focus restoration efforts to counterbalance the impending ecosystem services costs in the Alpine High field.

The more than 1.1 million wells that are currently classified as abandoned, dry, or plugged in the U.S. [58], represent an opportunity to restore some of these important conservation landscapes that we have lost due to oil and gas development. Restoration organizations are active in some oil and gas regions (e.g. Oklahoma Energy Resources Board, funded by a small tax on producers and royalty owners), but considering the number of inactive wells in the U.S., increased funding for restoration efforts is clearly warranted.

The energy industry is predicted to be the largest driver of land-use change in the U.S. into the near future [9], and major conversion and fragmentation have already been documented in the short span of this current boom

[8,11,15,35]. Unfortunately, this unconventional oil and gas activity is focused in some of the North American landscapes that still provide a great range of ecosystem services. Even though these landscapes have experienced anthropogenic impacts (e.g. logging and mining in the Appalachians), in some cases they have partially recovered to the point of being some of most ecologically and culturally valuable landscapes remaining in the U.S. These potential impacts are not confined to North America. Unconventional oil and gas development is predicted to intensify across the globe, including regions where similar habitats retain conservation value and valuable ecosystem services, such as temperate forest in China's Yangtze Platform region and temperate grassland in Argentina's Parana Basin [18].

While the mitigation strategies we suggest (i.e. ecosystem service assessments, wise placement of new development, and restoration) could reduce the impact of unconventional oil and gas development, we should also consider the long view. Unconventional oil and gas is a temporary solution to our energy problems [67, 68] with modest economic benefits at best (and sometimes net costs) for local communities [69]. We should consider whether we want a short-term activity to leave behind long-term damage and what costs to human well-being future generations will incur because of our decisions.

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This paper provides an economic analysis of the unconventional oil and gas boom in the major production basins of the U.S. When quality of life measurements are included, they find that the economic effect is modest in some regions and actually negative in others.