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

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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.

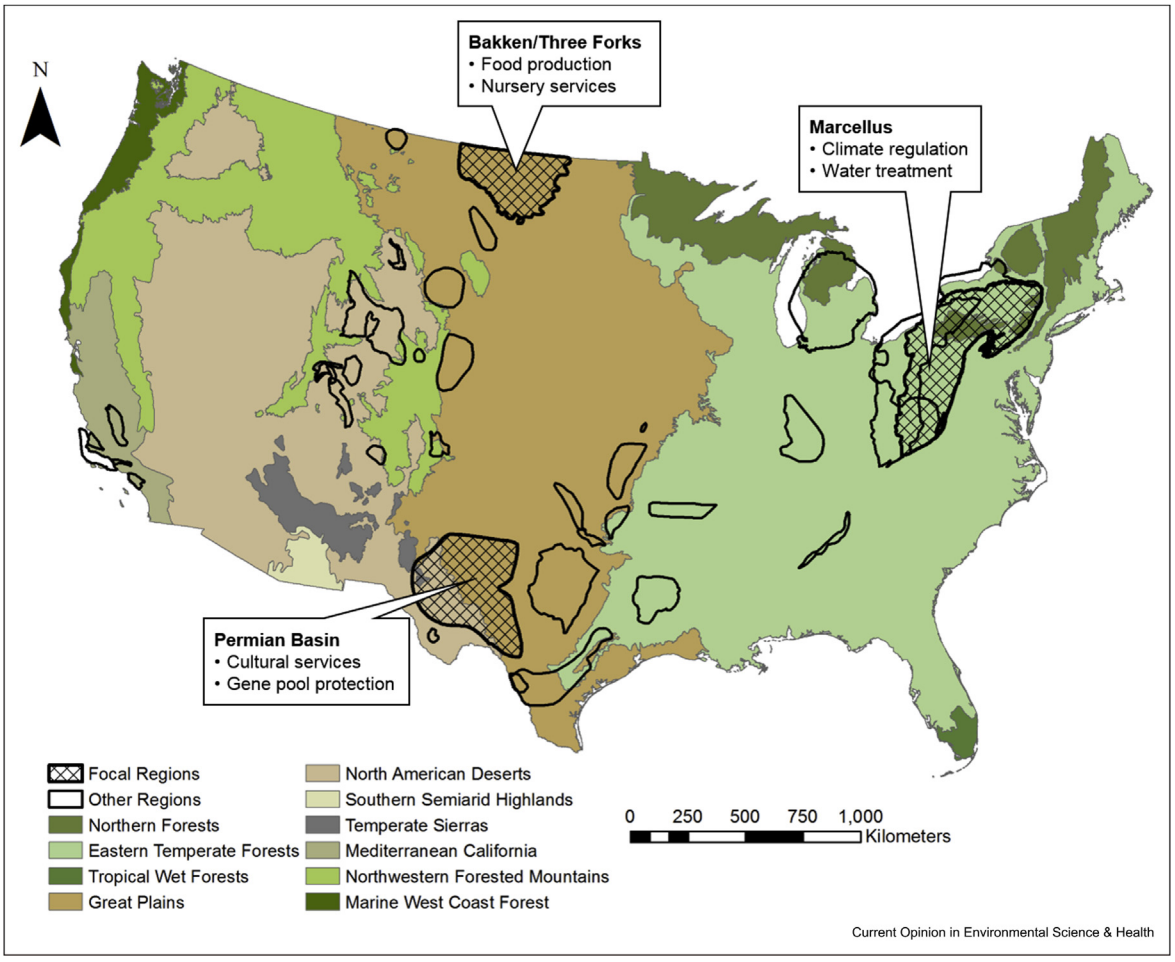
Introduction

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