Drivers of landscape change in the Appalachians: Risks

One of the basic goals of ecosystem assessment efforts is to describe the impacts of key drivers of change that place the sustained delivery of ecosystem services at risk. Some of these risk factors, such as urban growth and energy extraction, themselves provide important services, and trade-offs must be considered when they compromise other ecosystem benefits. Working towards sustainable landscapes by addressing these trade-offs is one of the great challenges in natural resource management and conservation practice. Here we summarize findings concerning key risk factors from assessment efforts in the Appalachian region.

Urbanization

Urban and exurban development have been among the strongest drivers of landscape change in the Appalachian region as a whole, and the conversion of land to these uses is projected to continue at a rapid pace.

Water.— Increases in urban land uses in landscapes with strongly varied topography and steep slopes are expected in the Appalachian-Cumberland region. Coupled with forest loss, this can exacerbate discharge rates, peak flow, and stream velocity. Increased impervious surface and forest loss associated with urbanization typically result in reduced surface water availability for human consumption, and can increase concentrations of stream sediments, nutrients, and pollutants.

Timber and nontimber forest products.— Urbanization is expected to reduce the land area available to support working forests, and alter the dynamics of nontimber forest product harvest, fishing, and hunting in nearby forests. Absence of freshwater fish from degraded streams may represent significant loss of fishing expenditures.

Carbon storage.—Forest loss associated with urbanization results directly in reduced carbon storage capacity. These losses, together with similar effects of surface mining, may outstrip regional gains from forest growth, without significant changes in urban development policy, restoration efforts, timber markets, and other factors.

Rural landscape values and outdoor recreation.— The changes that come with urbanization and low-density development can have negative impacts on the unique sense of place and quality of life of rural Appalachian-Cumberland communities. Landscapes dominated by hardwoods and agriculture are likely to continue to be threatened by land-use changes associated with urbanization, in turn linked to income and population growth. As rural landscapes and water supplies are increasingly converted to more intensive uses, opportunities for outdoor recreation are expected to decline. At the same time, demand for such opportunities is expected to increase with the population growth that accompanies urban and exurban expansion, placing increased pressure on nearby accessible sites with limited capacity.

(Hayden et al. 1996, Wickham et al. 2002, US Environmental Protection Agency (EPA) 2008, Gardiner et al. 2009, Hanson et al. 2010, Jackson et al. 2012, Shifley et al. 2012, US Department of Agriculture Forest Service 2012, Bowker and Askew 2013, Huggett et al. 2013, Lockaby et al. 2013, Wickham and Flather 2013, Keyser et al. 2014, Coulston et al. 2015)

Energy development

The development of coal, gas, and wind energy resources, and the physical infrastructure supporting them, represent both historical and emerging drivers of landscape change at large scales in the Appalachian region, particularly in the central and northern Appalachians.

Water.— Areas where impervious surface cover and forest loss are increasing with the development of energy infrastructure are likely to experience altered surface hydrology and reductions in surface drinking water availability and quality. Waters discharged from watersheds containing mined sites commonly show elevated total dissolved solids and acidity, impairing those waters' biological communities. Negative effects can continue for long periods after reclamation. Watersheds containing mined land show elevated runoff during heavy rains, potentially contributing to downstream flood peaks. Negative effects may be reduced or reversed with forest-restoring reclamation practices.

Soils.— Soil loss and compaction associated with surface mining and some reclamation practices can impede forest regeneration. Although not widely adopted, alternative practices are available to minimize these effects.

Timber and nontimber forest products.— Surface mining is expected to reduce the land area available to support working forests. This is the largest driver of land cover change in the central Appalachian coalfield region, and significant loss of timber-related economic activity can result if reclamation practices do not support forest regeneration. Restoration practices are available to mitigate these losses, but common reclamation efforts can impede forest recovery. Standing timber stocks and production have remained fairly stable in recent decades, but declines may be experienced over the long term.

Carbon storage.— Forest losses associated with energy infrastructure development and surface mining are expected to result in reduced forest carbon storage. While the carbon storage potential of forest restoration on mined sites is high, successful restoration practices are not implemented on many to most sites, and some current practices may prevent significant new carbon sequestration. Assuming similar future trends in the absence of large-scale forest restoration, carbon losses from future surface mining could outstrip total regional carbon sequestration gains from existing forests.

Rural landscape values and outdoor recreation.— New gas wells and wind turbines, and associated infrastructure build-out and forest loss, are expected to strongly impact landscapes in the Marcellus Shale region of the central Appalachians over the next several decades. Surface mining is the dominant driver of land cover change in the central Appalachian coalfield region, and associated forest loss, forest fragmentation, freshwater stream degradation, and other biotic and aesthetic losses

(Merricks et al. 2007, Wickham et al. 2007, Zipper et al. 2007, Amichev et al. 2008, Pond et al. 2008, Townsend et al. 2009, Fritz et al. 2010, Hanson et al. 2010, Lindberg et al. 2011, Zipper et al. 2011, Campbell et al. 2012, Jackson et al. 2012, Chamberlain et al. 2013, Wickham et al. 2013, Evans and Kiesecker 2014, Fox et al. 2014, Hitt and Chambers 2014, Keyser et al. 2014, Daniel et al. 2015) contribute to the overall loss of natural landscape character when adequate ecosystem restoration activities are not in place. Stream degradation and toxic dissolved solids in watersheds with surface mines are associated with loss of fishing opportunities and represent a strong incentive for stream restoration. Reductions in game fish species abundances are associated with mine densities at local and regional scales. Concentrations of freshwater dissolved solids in watersheds with mined sites have also been associated with fish toxicity, deformity, and reduced biomass and species diversity.

Climate change

Long-term changes in temperature and precipitation patterns have a strong influence on the capacity of landscapes to provide ecosystem services to people. Different places will be affected differently, but all of the Appalachian region will continue to experience change.

Water.— The impact of climate change on water quality and availability is likely to vary regionally, and outcomes will depend on interactions with human population growth and other factors. Models are sometimes characterized by high uncertainty, but this will be an increasingly crucial issue to understand in the Appalachian region. Average temperature increases may broadly result in reduced water availability, although some areas may be negligibly affected. Rural populations may be more strongly affected than urban populations, due to their stronger reliance on ground water. Frequencies of precipitation extremes potentially associated with flood and drought conditions have increased in recent decades, and this trend is expected to continue. The effects of extreme precipitation events on streamflow can depend strongly on vegetation composition and structure and impervious surface cover. This is true in forested as well as more urbanized and agricultural lands. Low and high flows associated with extreme events may be mitigated, or exacerbated, by forest management practices, urban planning, and other factors.

Timber and nontimber forest products.— Habitat suitabilities for harvestable species are likely to show large-scale geographic shifts, and at the local level, expected declines in economically important species will not always be compensated by increases in economically equivalent species. Changes in temperature and precipitation may interact locally with harvest pressure to increase declines, and this risk may be of particular concern for species which are not well monitored or regulated, such as those supporting nontimber forest product markets.

Carbon storage.—The impacts of climate change on the capacity of ecosystems to store carbon are likely to vary across landscapes, and interactions with other landscape dynamics will add complexity. For example, rising temperatures can enhance forest growth and carbon storage, but this can be offset by reduced water availability during droughts, and both of these effects depend on which tree species are most common. Changes in the frequency of fire due to temperature and precipitation changes will also modify carbon storage, especially where

(Dale et al. 2001, Iverson et al. 2008, Cordell et al. 2011, Ford et al. 2011, Lal et al. 2011, Cordell et al. 2012, Jackson et al. 2012, US Department of Agriculture Forest Service 2012, Bowker and Askew 2013, Lockaby et al. 2013, McNulty et al. 2013, Prasad et al. 2013, Wear et al. 2013, Brandt et al. 2014, Brzostek et al. 2014, Butler et al. 2014, Hwang et al. 2014, Keyser et al. 2014, Matthews et al. 2014, Souther and McGraw 2014, Zolkos et al. 2014) wildland fire reduces forest cover.

Rural landscape values and outdoor recreation.— Long-term changes in temperature and precipitation patterns can have negative impacts on the unique sense of place and quality of life of rural communities, when the viability of different economic activities and the natural character of landscapes are affected. These long-term changes have the potential to re-structure forest ecosystem species compositions, and could, in combination with other stressors, endanger some unique Appalachian ecosystem types. Tourism, recreation, and long-term patterns of rural migration are also likely to be affected by changes in climate, as visitors and new residents seek out particular conditions.

Invasive species and forest pathogens

When the introduction or increased activity of invasive or pathogenic plant and animal species dramatically alters the structure and function of ecosystems, the benefits that those ecosystems provide to people are also affected.

(Kourtev et al. 2002, 2003, Ford and Vose 2007, Hanson et al. 2010, Kuhman et al. 2010, Elgersma and Ehrenfeld 2011, Hicke et al. 2012, Shifley et al. 2012, Duerr and Mistretta 2013, Lemke et al. 2013, Miller et al. 2013, Keyser et al. 2014, Brantley et al. 2015)

Water.— Colonization by invasive species and outbreaks of forest pathogens can have important hydrological effects, principally by changing the structure and function of forest vegetation. For example, the widespread and continuing die-off of Eastern Hemlock (*Tsuga canadensis*) in the Appalachians due to the invasive Hemlock wooly adelgid (*Adelges tsugae*) can alter stream hydrology, temporarily increasing stormflow peaks and causing long-term decline in total stream yield.

Soils.— Highly invasive plants, particularly when they become densely established, can change soil properties in ways that reduce nutrient and water availability for native plants. Soil microbial communities are also negatively affected by some invasive plants across large areas. These changes in soil structure and function can be long-term, negatively affecting native plant communities and ecological restoration efforts.

Timber and nontimber forest products.— Outbreaks of insect pathogens on forest trees, when they affect large areas, are one of the most important risk factors for harvested tree species. Large outbreaks can also change forest structure and composition in a way that reduces habitat quality for nontimber forest species such as harvested understory herbs. Dense colonization of forested landscapes by invasive, non-native plants can negatively influence regeneration of native tree species including those with economic value. Invasives can also alter the composition and structure of forests, potentially reducing the overall productivity of marketable timber and nontimber species. The negative effects of forest pathogens and invasives on marketable species may be exacerbated by climate change, forest fragmentation, fire, and other landscape processes which may facilitate outbreaks or invasions.

Carbon storage.—Over the short term, forest primary productivity is often significantly reduced after a major tree pathogen outbreak, slowing carbon sequestration. A forest stand can switch from a carbon sink to a source under these conditions depending on outbreak severity, but this process can reverse over the long term as forest productivity recovers. The cumulative impacts of multiple outbreaks across a landscape can reduce carbon storage and sequestration at regional scales, but the overall, long-term results of these dynamics are not well understood. Forest pathogen outbreaks are affected by climate change, because they can become more likely as extreme heat and drought events become more frequent.

Wildland fire

Wildland fire is a natural component of Appalachian ecosystems—rare in some landscapes and more frequent in others. Its effects are complex and often beneficial to ecosystem processes. However, dramatic changes in landscape characteristics resulting from human activities, including the suppression of natural fire, have changed the frequency and severity of fires in such a way that modern fire regimes can sometimes have negative effects on ecosystem services.

(Southern Appalachian Man and the Biosphere (SAMAB) 1996, Vose et al. 1999, Brose et al. 2001, US Department of Agriculture Forest Service 2012, Brose et al. 2013, McNulty et al. 2013, Peters et al. 2013, Stanturf and Goodrick 2013, Brose et al. 2014, Downey et al. 2014, Keyser et al. 2014, Liu et al. 2014, Coulston et al. 2015)

The impacts of fire interact with other drivers of landscape change in important ways. Climate change will continue to influence the frequency, size, and severity of wildland fires throughout the United States. These changes are expected to be less severe in the Appalachians than in other regions, but the western Appalachians may experience increased fire risk with warmer and drier future conditions. Interactions with urbanization may be more significant: most Appalachian wildfires are ignited by people, and the risk of fire increases as roads, housing, and growing populations increasingly interface with wildlands.

Water and soils.— Wildland fires of sufficient intensity can increase soil erosion and sediment loads in streams, and can alter soil and water chemistry in the short-term, particularly in forests of the western US. However, most fires studied in Appalachian forests have not shown large impacts of this kind, and documented impacts have typically been followed by rapid recovery to pre-fire conditions. Impacts are likely to be greater for single, intense fires after long periods of fuel build-up than for several low-intensity fires at semi-regular intervals. This suggests that fire suppression can enhance the likelihood of fires with negative water and soil impacts, whereas prescribed fires typically have little negative effect.

Timber and nontimber forest products.— Wildland fire in eastern forests is typically not intense enough to have strong negative impacts on timber productivity or quality. Natural fire has been important over the long term in helping to maintain commercially valuable Appalachian forest types, particularly upland hardwood stands. Fire suppression has resulted in declines of species such as the oaks that are important in these forests, replaced by faster-growing species that compete well in the absence of fire. When used appropriately, prescribed fire can be an effective tool for managing upland hardwoods and other fire-associated ecosystems that sustain forest product production and utilization.

Carbon storage.— Wildland fire releases carbon dioxide, the most important greenhouse gas, into the atmosphere. Conversely, forest regrowth after fire captures and stores carbon over longer time scales. Thus, fire is one driver of forest carbon cycling. The overall contribution of fire regimes to long-term forest carbon balances is not well understood, especially in eastern upland forests where fire is relatively infrequent.

Rural landscape values and outdoor recreation.— There are significant management challenges related to the cost and social perceptions of wildland fire, and of activities such as prescribed burning and fuel treatments. People living in and near lands affected by fire may be exposed to significant risk, especially in terms of the dangers of uncontrolled fire to lives and property, but also in terms of health and safety risks associated with smoke and ash. Burning activities and recently burned landscapes may also be perceived negatively by outdoor recreationists and others seeking to enjoy forest landscapes, even while the longer-term effects of fire can result in aesthetically and ecologically desirable forest conditions. Difficult trade-offs in terms of the timing and location of different activities will be necessary to 'live with fire' and maintain a variety of compatible ecosystem services in fire-prone landscapes.

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