VALUING THE ENVIRONMENTAL BENEFITS FROM REFORESTATION ON RECLAIMED SURFACE MINES IN APPALACHIA[1]

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Abstract. Surface mining has impacted large portions of eastern Kentucky's forestland and many of these areas are currently unmanaged. The Appalachian Regional Reforestation Initiative (ARRI) was launched in 2004 as a means to promote forest reclamation. This study evaluated four ecosystem services provided by reforestation on legacy reclaimed mine sites: carbon sequestration, water quantity and quality, wildlife biodiversity, and aesthetic and recreational value. Spatial analysis and benefit transfer methods were employed to evaluate the non-market value from reforestation. We classified the legacy lands in eastern Kentucky as barren, grassland, or shrub(scrub) land use and calculated the ecosystem benefits for each landscape type. Compared with the reclamation cost, we find that under a 7% discount rate only land in riparian zones provided net benefits from reforestation. The total ecosystem benefits provided by reforestation in these landscape positions were $1,449,690. However, under a 3% discount rate with all the land reclaimed as forest in the study area, the total value of ecosystem services generated from these lands were $456,428,682. The ecosystem service benefits from reforestation on reclaimed legacy lands depends on landscape type, the specific dynamics of ecosystem recovery, and demographics of populations nearby. The results demonstrate the importance of synthesizing essential ecological and economic concepts in mining land reclamation planning.

Additional Key Words: forest reclamation; ecosystem services; benefit transfer

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Introduction

Kentucky is one of the largest coal producing states in the U.S. Large portions of eastern Kentucky's land has been impacted by surface mining. These lands are part of the Appalachian forest ecosystem, which provides rich ecological resources and services to society. The Surface Mining Control and Reclamation Act of 1977 (SMCRA) was initiated to regulate the environmental effects of coal mining in the United States. Under SMCRA, mined lands are required to be reclaimed to a state that provides an equal or better use than the pre-mining condition. Unfortunately, the law is vague on what constitutes equal or better. As such, widespread changes in land-use from forested to hayland/pasture have occurred across Appalachia (Zipper et al., 2011). Today, these reclaimed sites are largely left unmanaged and covered with aggressive and exotic grasses or shrubs, which have little commercial value.

The Appalachian Regional Reforestation Initiative (ARRI) was launched in 2004 as a means to promote forest reclamation on surface mine lands. As part of this strategy, the Forestry Reclamation Approach (FRA) was developed as a set of practices for land reclamation to provide guidance for forest revegetation (Adams, 2017). Prior research has shown that native tree species can be reestablished on these lands for reclamation (Zipper et al., 2015). For reclaimed mining lands to become productive forests, it is necessary to minimize soil compaction, correct chemical or nutrient deficiencies, and use non-competitive ground covers or control competition to aid survival and growth of planted seedlings (Adams, 2017). The FRA can be used on active coal mines and legacy lands (lands that were reclaimed using a non-forestland post-mining land use) for productive and cost-effective land reclamation. In addition, successful reestablishment of the native hardwood forests will provide a renewable and sustainable resource that may create economic opportunities from future timber and non-timber forest products as well as other ecosystem services (Zipper et al., 2011).

The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) defines ecosystem services as the benefits people obtain from ecosystems. It divides these services into four categories: provisioning, regulating, supporting, and cultural services. Provisioning services are the material goods provided by nature that typically already have an economic value, such as food, timber, and fresh water. Regulating and supporting services control environmental processes that are essential to the survival of humans, such as carbon sequestration, wildlife habitat, and flood control. Cultural services are the non-material benefits people obtain from ecosystems through aesthetic values, recreation, spiritual enrichment and cognitive development. The traditional economic benefits from reforestation on reclaimed mining land, such as timber, wildlife and recreation, are tangible products of nature. Their values have long been recognized in the market (Sullivan et al., 2005; Krieger, 2001; Brown et al., 2007). Forest ecosystems can also provide a wide array of non-market ecosystem services that benefit society, such as water purification, carbon sequestration, nutrient recycling, and intangible aesthetic and cultural benefits (Brown et al., 2007; Daily, 1997). Such services, though often unaccounted for in decision-making, provide valuable life-support functions.

Few economic studies have been conducted to investigate issues associated with forest reclamation. Randall et al. (1978) conducted a cost-benefit analysis for reclaiming coal surface mines in Kentucky. Instead of measuring the benefits from reforestation, the study calculated the costs associated with damages created by mining that could be avoided with proper reclamation. Sullivan et al. (2005) examined the financial viability of reforesting reclaimed surface mined lands by estimating the land expectation value from reforestation and carbon offset payments. The social cost and private cost of mine land reclamation decisions, such as restoration to pasture or forests, have also been examined and compared under performance bonds (Sullivan and Amacher, 2009; Sullivan and Amacher, 2010; Sullivan and Amacher, 2013). However, there have been no studies to our knowledge that examined the nonmarket benefits from reforestation on reclaimed mining lands.

There has been substantial economic research showing that the total economic value of many ecosystems is much greater than the value of their marketed services (Costanza et al., 1998; van den Bergh, 2001; Rosenberger and Loomis, 2003). Ecosystem services are often public goods meaning that their benefits are not exclusively enjoyed by only those that pay for their provision. The Evaluation of Environmental Investments Research Program (EEIRP) initiated by U.S. Army Corps of Engineers developed planning guidance for environmental restoration projects (Feather et al., 1995). It also addressed the importance to evaluate the nonmarket benefits in the cost-benefit analysis, as the restoration projects are oriented toward ecosystems and human welfare rather than economic development. Placing a value on these services is important for making decisions about reforestation plans and reclamation land management. This study focuses on valuing four ecosystem services provided by reforestation on reclaimed mine sites in eastern Kentucky: carbon sequestration, water quantity and quality, wildlife biodiversity, and aesthetic and recreational services.

Reclaimed mining sites are found throughout eastern Kentucky and cover several different types of landscapes. Reforestation on these reclaimed mining sites would provide an array of ecosystem services depending on both the biophysical and socio-economic characteristics of these sites (de Groot et al., 2012). In our study, spatial analysis and landscape mapping were integrated with the benefit transfer method for economic valuation (Costanza et al., 1998; de Groot et al., 2012; Troy and Wilson, 2006). The values of ecosystem services from reforestation were used to conduct a cost-benefit analysis, which examines the economic tradeoffs between reclamation investment and conservation alternatives. The influence of landscape type, demographics of populations nearby, and specific dynamics of ecosystem recovery on the economic value of forest reclamation practices will be evaluated.

Methodology

The study area was located in the Eastern Kentucky Coal Fields physiographic region, which includes parts of the rugged Cumberland Plateau and Cumberland Mountains (Smalley, 1984). This region contains many narrow winding valleys that lie between steep, narrow sandstone ridges with slopes that vary from 20-80%. Flat land is seldom found except on broad ridges or in creek bottoms, and Smalley (1984) called it some of the roughest land in the eastern United States. Historically, the forest of this area was described as being part of the mixed-mesophytic association of the eastern deciduous forest (Braun, 1950). Development (housing and industrial) and agricultural cropping was limited to the flat bottomland and ridgetop landscape positions, thus leaving most of the land in forest.

Surface mining for coal changed the landscape, both physically and biologically. The surface mining process uses explosives to expose coal seams. Spoil (rock above and between coal seams) is reshaped to an approximate original contour once the coal is removed. Due to equipment limitations and slope stability concerns, the landscape tends to be more rolling to level after reclamation. The use of spoil as a topsoil substitute is allowed because the native soil is considered nutrient poor and too shallow to stockpile and replace after the mining is completed. Loss of the seedbank with the native soil limits natural regeneration on these sites (Hall et al., 2010).

Moreover, traditional reclamation approaches were not conducive to forest development and the use of alternative covers (non-native grasses and shrubs) became the norm (Adams, 2017).

Typically, the reclaimed grassland contains a mixture of non-native grasses and legumes such as Kentucky-31 tall fescue (*Lolium arundinaceum (Schreb.)* Darbysh.) and sericea lespedeza (*Lespedeza cuneata (Dum. Cours.) G. Don*). The exotic shrub Autumn olive (*Elaeagnus umbellate (Thunb.))* is often seeded in with the herbaceous species to create wildlife habitat. The competitive nature of these plants combined with compacted soil tends to inhibit natural regeneration on these sites (Zipper et al., 2011). Compacted soil also limits infiltration and promotes surface runoff, which can lead to soil erosion and sedimentation in local streams (Negley and Eshleman, 2006). Thus, FRA was developed as a set of practices to guide reforestation on these reclaimed mining lands.

In our study, to estimate the ecosystem service benefits of reforesting lands under FRA, we followed a five-step process:

1. Identify potential mine land reforestation areas and classify their landscape characteristics.
2. Define the potential biophysical changes of ecosystem services brought from reforestation.
3. Employ the benefit transfer method to estimate the value in each type of landscape for each ecosystem service for reforested land and grass/shrub land.
4. Calculate the present value of ecosystem service benefits from reforestation for each type of landscape.
5. Compare the total benefit with the total cost to determine the land area where it is beneficial to conduct reforestation.

The detail information about each step is introduced in the following sections.

<u>Landscape Classification</u>

A large portion of the eastern Kentucky region has been surface mined for coal. Most of these lands have not been reclaimed for economic development and are typically covered by grasses or shrubs. We used ArcGIS to overlay the 2011 National Land Cover Data (Homer et al., 2007) with polygon maps of mining sites boundaries (Wasson, 2012). It showed that over the study area 4,412 acres exhibited a shrub land cover type and 209,882 acres had a grassland cover type (Table 1). There are also 63,445 acres of barren land. Reforestation can be performed on existing grasslands and shrub lands using the FRA for legacy surface mines (Burger et al., 2017). These potential reforestation lands are shown in Fig. 1. They constitute nearly 214,294 acres and are considered suitable for reforestation in the near term. Similar potential reforestation lands are scattered over most of the central Appalachian region with a high density of sites located in eastern Kentucky and south-western West Virginia. Active mining sites, shown as barren land in Table 1, have yet to be reclaimed and will not be incorporated in our analysis.

Table 1. Landscape types and area of the potential reclaimed mining land.

Landscape Type	Area (Acre)	Percentage
shrub (scrub)	4,412	1.59%
grassland	209,882	75.57%
barren	63,445	22.84%
Total	277,739	100%

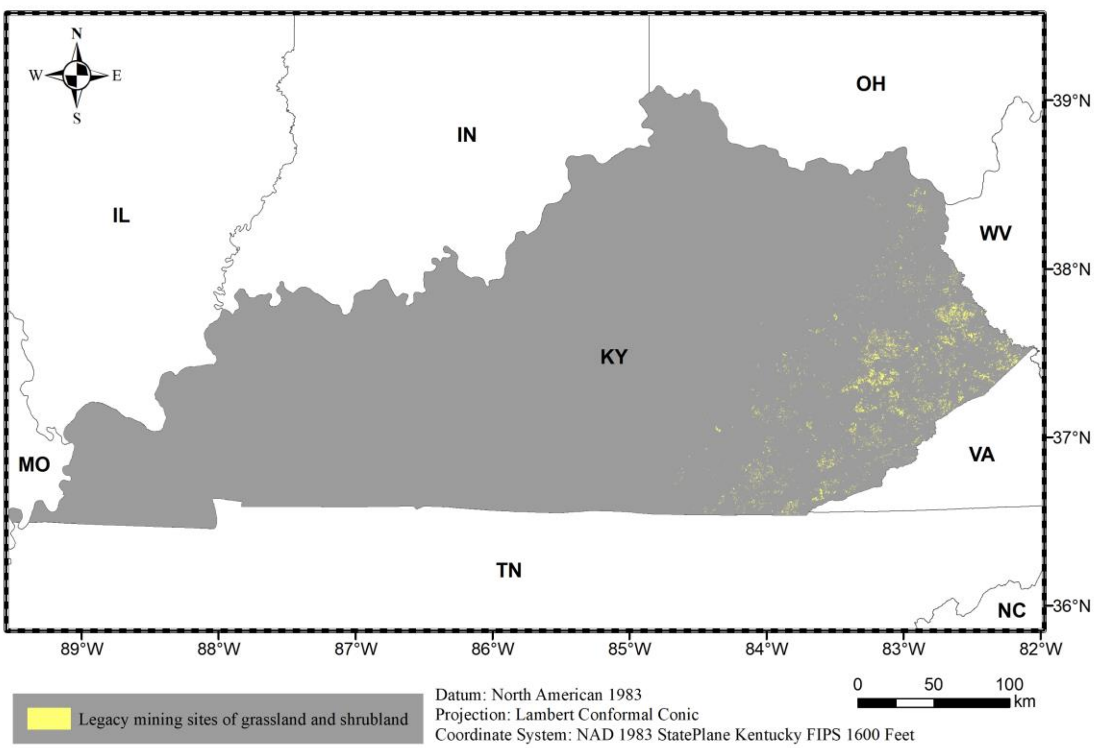

Figure 1. Potential reforestation land in eastern Kentucky (grassland and shrub lands). The study areas are highlighted yellow on the map.

We used spatial analysis tools to classify the potential reforestation sites into different landscape types (grassland or shrub lands), biophysical status, and socio-economic characteristics.

For water quality and quantity, we classified the potential reforestation land into two types, riparian and non-riparian. Although only a small component of the landscape, riparian areas provide many unique functions with regards to aquatic food webs, water quality, hydrology, and habitat that are not found in non-riparian forests (Andrews et al., 2011). ArcGIS was employed to create 100 m buffer of open water or stream in the Kentucky watershed boundary dataset. The potential reforestation sites that intersected the watershed buffers were classified as riparian zone.

For biodiversity, we classified the potential reforestation land into two types, biodiversity hotspots and base areas. The potential mine reclamation sites in Kentucky were located along the Appalachian Mountains which host great biodiversity. The Nature Conservancy developed the Southeast Resilience Database (Anderson et al., 2014) which divides ecoregions into 1000-ac. hexagons. For each hexagon, the Southeast Resilience Database indicates whether it is within a priority area for biodiversity conservation. In this study, it was assumed that sites located inside or nearby a high biodiversity region (100 m buffer) will likely have the same habitat composition and structure. ArcGIS was again used to identify the potential reforestation sites that intersected within these biodiversity priority areas and classified them as biodiversity hotspots. The remaining areas were classified as base areas.

For cultural services, the landscape of potential reforestation areas was classified into three categories - road buffers, public protected areas, and general forestland. Forests near primary roads (100 m buffer) (United States Census Bureau, 2013) were assumed to provide attractive aesthetic views, and are considered more accessible for recreational activity. Reclaimed mining sites located near protected areas with public access (100 m buffer) (US Geological Survey, 2012) were assumed to provide more opportunities for recreation activity. ArcGIS was employed to create a 100 m buffer around the road and public access areas. The reforestation sites located within the buffers were classified as the road buffers and/or public protected areas, while the remaining areas were classified as general forestland.

Biophysical Changes of Ecosystem Services from Reforestation

Previous studies investigated the biological and physical changes of ecosystem services from reforestation. The estimates of economic values in this study were based on these potential biophysical changes brought by reforestation. In the following section, the biophysical studies related to each type of ecosystem services will be summarized. The biophysical assumptions for the analysis in this study come from these previous studies.

Carbon Sequestration. Carbon sequestration occurs at a higher rate at the beginning of land reclamation with the rate slowing down after 10 to 15 years and after about 50 to 100 years, net carbon storage in reclaimed mine land is approximately stable (Akala and Lal, 2001). Amichev et al. (2008) estimated the ecosystem carbon content (including tree, litter, and soil), in forests established on surface coal-mined land under the pre-SMCRA management strategy. They showed carbon sequestered by hardwood stands to be around 321.24 Mg ac^{-1} at harvest age 60, while the non-mined hardwood stands sequestered about 518.92 Mg C ac^{-1}.

Shrestha and Lai (2010) compared the carbon pools from forests and pasture on reclaimed mine lands. Twenty-five years after reclamation, the ecosystem carbon pool increased by 264.40 Mg ac^{-1} in forest ecosystems and by 51.89 Mg ac^{-1} in pasture ecosystems. In their study, the stand age was less than the cases investigated by Amichev et al. (2008), and they didn't separately analyze the forest ecosystem by tree species. Thus, the carbon pool in their study was less than those found in the study by Amichev et al. (2008).

Kentucky is located in the central hardwood region, so we assume a mixed-hardwood forest type. The typical mature age for hardwood forest is at year 60 (Burger and Zipper, 2009). As such, we used long-term estimates of 321.24 Mg ac^{-1} for forests and 51.89 Mg ac^{-1} for grassland/shrubs were used for the analysis. These estimates are equivalent to about 52.7 tC ac-^{1} for forest and 8.5 tC ac^{-1} for grassland. As the surface mining land covered by shrub (scrub) are quite small, it is assumed it stores the same amount of carbon as grassland.

Water Regulation. Surface mining has caused serious water pollution problems in the Appalachian region (Minear and Tschantz, 1976; Tiwary, 2001). Revegetation under conventional reclamation practices has been shown to improve water quality over time (Ritter and Gardner, 1993). Even though watersheds with mine lands reclaimed using conventional practices exhibit infiltration and runoff characteristics similar to unmined watersheds under light rainfall conditions, they commonly experience elevated runoff during heavy rains (Negley and Eshleman, 2006; McCormick et al., 2009). Reforestation has been demonstrated to provide water quality improvements (Wei et al., 2011). Recent studies have indicated that the hydrologic effects by the loose-dump FRA reclamation produce characteristics similar to unmined forest lands in terms of discharge volume, peak discharges, and the duration of discharge (Taylor et al., 2009). In this study, it was assumed that the watershed services from reforestation could recover to a level that is similar to that of the native forests. Although reclaimed forests will never be exactly as they were prior to mining, research has demonstrated that many functions such as water quality and hydrology can be restored using the FRA (Sena et al., 2014; Taylor et al., 2009). No published reports are available that document the hydrologic effect of legacy surface mine FRA, however, studies have shown that seedling growth and survival rates on deep ripped legacy land is comparable to loose-dump FRA for many hardwood species (Michels et al., 2007). As such, we estimate that legacy surface mine FRA hydrologic attributes are similar to loose-dump FRA for this study.

Biodiversity. Several studies have investigated the establishment of plant and wildlife habitat on reclaimed mining land. Holl (2002) found that 68% of the plant species recorded in adjacent forests moved onto Virginia mine sites over several decades. Larkin et al. (2008) found that FRA loose spoil grading techniques increased mined site usage by small mammals. Elk habitat has also often been found on reclaimed mine land in Kentucky. However, research has also shown that non-native invasive species, such as autumn olive, often occur on older mine sites and make establishment of hardwood forest more difficult and increase management costs (Lemke et al., 2013). Because FRA reclamation is a recent practice, the mechanism for plant species and wildlife moving onto FRA reclaimed mine sites has not been well studied. Considering the favorable conditions of the FRA strategy, it is reasonable to expect greater success in the establishment of native plant communities on reclaimed sites (Groninger et al., 2007; Sena et al., 2015). Here we assumed that land reclaimed using the FRA strategy will ultimately have a similar habitat composition and structure as they would in similar nearby forests.

Aesthetic and Recreation Activity. After reforestation under FRA practices, the reclaimed lands may provide recreation opportunities from tourism-based businesses, like bird watching, hunting and horseback riding. It would also provide non-market value in the form of pleasurable aesthetic views or cultural enhancement.

From the above summaries for biophysical changes of ecosystem services, the assumption for this analysis is that the reforested land would be able to provide similar ecosystem services as natural forest after 60 years (the mature age for typical hardwood forests). Before age 60, the accumulated biomass from carbon sequestration keep increasing. After year 60, the biomass accumulated from established forest stand would be approximately stable. For the water regulation, biodiversity, aesthetic and recreation services, it was assumed that they would be similar with the grassland or shrub land before year 60 (as the recovery process of these ecosystem services is uncertain). After year 60, it was assumed that these ecosystem services would provide stable and similar benefits every year as a natural forest.

Benefit Transfer Method

Benefit transfer techniques are commonly used to value the non-marketed ecosystem services when there exists time limits or resource constraints. Benefit transfer collects available information from previous studies performed in other settings and transfers the original ecosystem service value estimates from previous study sites to the new study areas which have similar characteristics (Rosenberger and Loomis, 2003). Some accuracy is lost in measuring ecosystem service values through benefit transfer rather than site specific studies, however the high costs and time of gathering site-specific data have made benefit transfer a common and useful method for valuation of ecosystem services.

The general approach is unit value transfer. This approach identifies a single previous study that best matches the policy site and transfers this single point estimate from the original study site to the new study site. Alternatively, an average value from several similar studies can be used (Rosenberger and Loomis, 2003; Costanza et al., 1998).

The ecosystem service benefits from water regulation, biodiversity, aesthetic and recreation services were estimated by referring to previous studies which were conducted to valuate natural forests. It was assumed that these values approximate the benefits from reforested land areas at age 60 and beyond. As there are few evaluation studies which have exactly the same conditions as our study sites, we used the mean of valuation results from the relevant studies for estimates. The ecosystem service benefits generated from grassland and forests were separately estimated for further comparisons.

Carbon Sequestration. In previous literature, there exists a wide range of estimates for the social value of carbon storage (Atkinson and Gundimeda, 2006). Social cost estimates of carbon are based on the marginal damage cost of carbon emissions or the marginal abatement cost of reducing emissions. Atkinson and Gundimeda (2006) suggested that a value of $23/ton of carbon (tC) is a reasonable estimate of the social cost of carbon, and consider a range from $5.5/tC to $46/tC to be reasonable bounds on the possible range (all values have been adjusted to 2015 US$). In 2010, the U.S. government's Interagency Working Group on Social Cost of Carbon found that the social cost of carbon ranged from $5.7/tC - $73.6/tC (2015 US$) and proposed to use a mean value of $23.8/tC in regulatory impact analysis. In the voluntary carbon market, the Chicago Climate Exchange (CCX) had a mean price of $7.7/tC, with a historic range of $0.2/tC to $27.11/tC (2015 US$) (Moore et al., 2011). In the current study, $24/tC (2015 US$) was adopted as the value of carbon sequestered. This value is close to the mean of carbon values discussed above.

<u>Water Regulation.</u> A set of papers are listed in Table 2, which provide relevant estimates about the water supply and regulation services provided by natural forest. For example, Moore et. al. (2011) using the studies applicable for forests in Georgia reported benefit transfer estimates of $1,728 per acre per year (2009 US$) for riparian, rural forest, and $0 for non-riparian rural forest. While some papers directly provided the economic value with estimation unit as dollar per acre per year, some papers reported the economic value from watershed services through willingness of households to pay. For instance, the Wilderness Society provided a review that summarized previous estimates of forest ecosystem services in the U.S. (Krieger, 2001). In his estimation, water quantity value is

Table 2. Previous studies and their estimates related to the water supply and regulation services provided by forests. Year represents when the dollar value is measured.

Author	Year	Value	unit	Region
Simpson et al. (2013)	2011	$11.83	/acre/year	rural, non-riparian, Texas
		$242.34		rural, riparian, Texas
Liu et al. (2010)	2004	$1,921	/acre/year	riparian, New Jersey
		$163	/acre/year	Non-riparian, New Jersey
Moore et al. (2011)	2009	$1,728	/acre/year	Rural, riparian, Georgia
		$0		Rural, non-riparian, Georgia
Costanza et al. (2014)	2007	$107	/acre/year	Global
Krieger (2001)	2001	$57	/household/year	southeast US
Kreye et al. (2001)	2010	$7.18 -- $666	/household/year	US

$57 per household per year for the southeastern U.S. These estimated values of household willingness to pay were adjusted with the population of Kentucky and the size of landscape in the study area.

Little information exists on the economic value from water ecosystem services provided by reclaimed grasslands, but it has been reported to be much less than those for forests. The values employed by de Groot et al. (2012) for benefit transfer and they reported a total economic value of about $43 per acre per year. Costanza et al. (1998) also reported a benefit transfer value of $2 per acre per year (2004 US$) for water regulation from grasslands. This study employed the average of these two values as our estimate.

Biodiversity. Literature listed in Table 3, provides relevant estimates of biodiversity services by natural forests. There are 1.7 million households in Kentucky and 2.4 million acres of forests. The previous estimated values in Table 3 are adjusted to the study area using these demographic data. Even though the benefits from grassland for biodiversity services has been recognized by ecologists, there is relatively limited information on the value of biodiversity from grasslands. It was reported by de Groot et al. (2012) that the estimates were $0.56 per acre per year (2015 US$) for gene pool protection. The value from grassland for biodiversity service may be underestimated here, as our estimates are based on these limited previous studies. The values of ecosystem services from grassland deserve more investigation in the future.

Table 3. Previous studies and their estimates related to biodiversity services provided by forests.

Author	Year	Value	Unit	Region or Species
Nunes and van den Bergh (2001)	2001	$27 - $101	/household/year	US
Richardson and Loomis (2009)	2006	$21 - $45	/household/year	bald eagle
	2006	$39 - $130	/household/year	owls
Grado et al. (2009)	1994	$0.11–$49	/acre/year	woodpeckers
Moore et al. (2011)	2009	$123 - $322	/acre/year	Georgia, hotspots

Aesthetic and Recreation Value. Generally, aesthetic and recreation values depend more on human activity and human perception than provisioning and regulating services. Thus, these values can vary greatly with socio-economic factors, like cultural heritage, household income, and professional background (Winter, 2005; Harshaw et al., 2006). There is also substantial variability due to accessibility with regards to human recreation activities. Forests located near populated areas, close to primary roads, or conserved as public recreation areas generally have higher aesthetic and recreational value.

A list of papers and their estimates of the aesthetic and recreation services are listed in Table 4. To estimate the aesthetic and recreation value for general forest, we employ the average value from relevant studies. For the road buffer and public access area, we followed the estimates from South Georgia (Moore et al., 2011) which is similar to eastern Kentucky as a rural area with regard to demographic characteristics.

Table 4. Previous studies and their estimates related to aesthetic and recreation services provided by forests.

Author	Year	Value	Unit	Region
Costanza et al. (1998)	2007	$21.45	/acre/year	general
de Groot et al. (2012)	2007	$401	/acre/year	general
Liu et al. (2010)	2004	$130	/acre/year	general
Moore et al. (2011)	2009	$371	/acre/year	road buffer, south Georgia
	2009	$342	/acre/year	Hotspots, south Georgia
	2009	$52	/acre/year	general, south Georgia

In the estimation of the economic value of global ecosystem services, Costanza et al. (1998) summarized the recreation and cultural value of grasslands as $0.81 (2007 US$) per acre per year. Updates by de Groot et al. (2012) gives the value and estimated a value of grasslands of about $78.10 (2007 US$) per acre per year, which represents a substantial increase. Liu et al. (2010) estimated the aesthetic and recreation value of grassland to be $1 (2004 US$) per acre per year. This study again employed the average of these values for the study area.

<u>Cost-benefit Analysis</u>

To conduct a cost-benefit analysis for reforestation, it first needs to be noted that the reforestation is a long-term process. Here it was assumed that an established forest would be able to provide similar ecosystem services as natural forests after 60 years. Further, it was assumed that after year 60, the biomass accumulated from an established forest stand was relatively stable (Akala and Lal, 2001). Sequestration from photosynthesis approximately equaled to carbon emissions from decay and respiration. The benefit value from carbon sequestration was directly estimated as a perpetuity value (with a unit of $/acre). However, water regulation, biodiversity, and recreation services are estimated as annual values with units of $/acre/year. For comparison, annual values were converted to values in perpetuity with the following formula:

$$V_p = V_a / r \tag{1}$$

where V_p is the value in perpetuity; V_a is the mean of estimated annual value; i represents the i th year after year 60; and r is the real discount rate.

In economic valuation studies, it is necessary to discount future benefits and costs as people value benefits and costs that occur in the future less than they do in the present. The discount rates employed in this study were based on a real discount rate before taxes, which is consistent with literature where benefit transfer methods were utilized. We also employed a social discount rate similar to those used to evaluate government projects and environmental policies. A sensitivity analysis was conducted at three social discount rates, 3%, 5%, and 7%. Different discount rates reflect different social perceptions of how future benefits should be valued in the present. A higher discount rate would reflect a more conservative attitude of the long-term social benefit compared with the present value of reforestation cost. A lower social discount rate would favor the social benefits from reforestation occurring at a later stage.

Since we are using legacy lands for reforestation, the value of reforestation benefits would be the difference between ecosystem services provided between forests and grass/shrub lands. Based on the assumptions, the economic value of all ecosystem services in the reforested land are conservatively assumed to be equivalent to their value in grass/shrub land before year 60. After year 60, the value of reforestation benefits would be

$$V_p^d = V_p^f - V_p^g \tag{2}$$

Where V_p^d is the value in perpetuity from reforestation since year 60; V_p^f is the value in perpetuity from forest since year 60; and V_p^g is the value in perpetuity from grass land since year 60.

It should be noted that all the previous value estimates discussed are based on estimates on the ecosystem services from mature forests at year 60. The perpetuity value of benefits from reforestation would need to change to the present value, which is:

$$V_c = {V_p^d}\big/{(1+r)^{60}} \tag{3}$$

The total value of ecosystem services from the reforestation would then be the summation of the ecosystem services.

$$V_t^j = \sum V_c^j \qquad (4)$$

Here, V_t^j is the total ecosystem benefits per acre for landscape type j, and V_c^j is the present values of benefits from carbon sequestration, water regulation, biodiversity services, and aesthetic and recreation services. The landscape type is defined for every pixel of cell size 30×30m in the study area. V_t^j is calculated for each landscape type j.

Forest reclamation costs were estimated to be approximately $1,457 to $1,902 per acre (Baker, 2008). We conducted a cost-benefit analysis assuming that the timber value will be $6,800 per acre at age 60 (Burger and Zipper, 2009). The analysis indicated that the reforestation cost on reclaimed mine land was an average of $1,463 per acre (present value) larger than the financial benefits from timber production under a discount rate of 7%. It is $1,216 per acre under a discount rate of 5%, and $426 per acre under a discount rate of 3%. This suggests that landowners would lose from $191 to $868 per acre (assuming a 5% before tax and real discount rate) to conduct the reforestation effort even with future revenue from timber production. Only when the nonmarket values from ecosystem services are larger than the loss on investment would legacy mine reforestation be financially beneficial.

We conducted this cost-benefit analysis for all potential mining land reforestation sites in eastern Kentucky to determine which land would provide net benefits from FRA practices. If the present value of landscape type j, V_t^j, was larger than the loss on investment to do the reforestation, then it would be beneficial for conducting reforestation on this landscape. Otherwise, we would leave the land as grass or shrub land. The total benefits from reforestation for the whole study area would then be

$$V_t = \sum_{V_t^j > c}^{j} V_t^j * S_j \qquad (5)$$

where S_j is the area size for each landscape j and V_t is the total benefits for the whole study area and c is a payment that would compensate the land owner for the difference in the reforestation cost over future timber value.

Results

Landscape Classification

Spatial analysis indicated that there were 6,587 acres within riparian zones (Table 5), while 207,707 acres were classified as non-riparian within the study area. About 79,015 acres of the potential reclamation sites were classified as biodiversity hotspots while 135,279 acres were classified as base area. For aesthetic and recreation services, sites classified as road buffers amounted to 2,329 acres for grass/shrub lands. The size of public protected areas was 896 acres for grasslands. There were some small areas classified as both protected areas and road buffers. The other potential reforestation areas (211,073 acres) were classified as general forests. Only biodiversity hotspots cover a large portion of the potential mining land reclamation area, accounting for 36.9% of the total study area. Road buffer, public access, and riparian zones occupy only a small portion of the study area, accounting for less than 5%.

Table 5. Classification of the study area based on each type of ecosystem services.

Ecosystem Services	Landscape Type	Area (acre)	Percentage
Water	riparian zone	6,587	3.07%
	non-riparian zone	207,707	96.9%
Biodiversity	hotspots	79,015	36.9%
	non-hotspots	135,279	63.1%
Aesthetic and Recreation	road buffer	2,329	1.1%
	public protected area	896	0.4%
	general area	211,073	98.5%

Estimates Based on Benefit Transfer Method

The valuation estimates for each type of ecosystem service benefit from forestland on legacy mine land are listed in Table 6. The estimated mean value in perpetuity of carbon sequestered in reforested land is $1,264.8 per acre. For water supply and regulation services, the economic value in riparian zones ranged from $255 to $2,406 per acre per year with a mean value of $1,522. The economic value in non-riparian areas ranged from $12.44 to $204 per acre per year with a mean value of $93. For biodiversity services, the economic value in hotspots ranged from $116 to $305 per acre per year with a mean of $211, while the economic value in base areas ranged from $6.63 to $39.7 per acre per year with a mean of $22.3. For aesthetic and recreation services, the economic value is $409 per acre per year in road buffer areas and $377 per acre per year for forests near public protected areas. For areas classified as general forested areas, the economic value ranged from $24.5 to $458 per acre per year with an average value of $174 per acre per year.

The economic valuation results for ecosystem services provided by grass/shrub land before reforestation on legacy mine land were also summarized in Table 6. The value of carbon sequestration ranged from $46.8 to $625.6 with an average of $204 per acre (value in perpetuity). The economic value of water services from grassland ranged from $3 to $49 per acre per year with an average value of $26. The estimate for biodiversity is assumed to be $0.56 per acre per year. The aesthetic and recreation value of grassland is assumed to be $1 per acre per year.

Comparing the above valuation results, the ecosystem benefits from forests is much larger than grassland. The benefits from water supply and regulation services for both forest and grassland are much larger than the other types of ecosystem services.

Table 6. Value of ecosystem services provided by forestland and grass/shrub lands on legacy mine land (2015 US$).

	Landscape Type	Value
Carbon ($/acre)	Forest: general	1264
	Grass/shrub land	204
Water ($/acre/year)	Forest: riparian	1,522
	Forest: non-riparian	93
	Grass/shrub land	26
Biodiversity ($/acre/year)	Forest: hotspot area	211
	Forest: base area	22
	Grass/shrub land	0.56
Aesthetic and recreation ($/acre/year)	Forest: road buffer	409
	Forest: public access	377
	Forest: general	174
	Grass/shrub land	1

Present Value of Reforestation Benefits

The value in perpetuity of reforestation for all landscape types are summarized in Table 7. Note that because the carbon sequestration value is estimated as an estimate of carbon storage 60 years after reforestation, the value in the table does not vary with the discount rate. For the other ecosystem services, the value in perpetuity under a discount rate of 3% is about 2.3 times larger than the value in perpetuity estimated by a 7% discount rate. After the value in perpetuity are converted to present values (see equations 2 and 3), these differences become much larger. From the results, it can be seen that as the restoration of forest ecosystem services occurs over a long period of time, the present value is very sensitive to the discount rate.

Table 7. Value in perpetuity and present value of ecosystem services from reforestation. The values are estimated based on three discount rates: 3%, 5%, and 7%.

	Landscape Type	Perpetuity Value ($/acre)			Present Value ($/acre)		
		3%	5%	7%	3%	5%	7%
Carbon Sequestration	All	1,061	1,061	1,061	180	57	18
Water Regulation	Riparian	49,867	29,920	21,372	8,464	1,602	369
	Non- riparian	2,233	1,340	958	379	72	17
Biodiversity	Hotspot area	7,015	4,209	3,006	1,191	225	52
	Base area	725	435	311	123	23	5
Aesthetic and Recreation	Road buffer	13,600	8,160	5,829	2,308	437	101
	Public protected area	12,533	7,520	5,372	2,127	403	93
	General	5,767	3,460	2,472	979	185	43

Cost- benefit Analysis

Based on the above results, the value of all four ecosystem services ranged from $337 to $2,321 per acre (under 5% discount rate) depending on the landscape type (Table 8). The reforestation lands which are located in riparian zones, hotspots, and road buffer areas provide ecosystem service benefits with the highest present value of $2,321 per acre, while general areas have the lowest present value of $337 per year.

The study area can be categorized into four levels based on the ecosystem benefits from reforestation at each unit area - base, medium, high, very high (Table 8). The “base” category only includes the general land area. The “medium” category of land are biodiversity hotspots where the other types of ecosystem services are at base level. The category "very high" includes all the riparian zones regardless of the levels of other ecosystem services. It provides the highest value at unit area. The "high" category includes all the other land types left. The area of "high" or "very high" occupy only a small portion of the study area, 2,244 and 3194 acres respectively. They are scattered widely over the study area.

Table 8. The total ecosystem service benefits provided by reforestation for each land category. The study area is divided into four categories: base, medium, high, and very high. The values for each landscape type are estimated using three discount rates: 3%, 5%, and 7%. The total value is left blank if the land doesn't provide net benefits for reforestation.

Land	Area	Value ($/acre)			Total Value ($)		
category	(acre)	3%	5%	7%	3%	5%	7%
Base	144,142	1,661	337	83	239,420,224	---	---
Medium	64,713	2,729	539	130	176,601,914	---	---
High	2,244	2,809-6,185	555-1,194	133-281	7,906,875	---	---
Very high	3,194	9,746-12,143	1,867-2,321	435- 540	32,499,670	6,222,551	---
Total	214,293				456,428,683	6,222,551	---

The value of total ecosystem benefits at each unit area and the total land area for each of the four types of land categories are summarized in Table 8. Under a 7% discount rate, no land area provided ecosystem benefits that were greater than the reforestation cost. However, under a 5% discount rate, the land classified as "very high" would provide net benefits from reforestation with total value of $6,222,551. Under a 3% discount rate, the benefits of restoration outweigh the reforestation cost on all land categories, generating a total value of $456,428,683.

Discussion

Of the reclaimed surface mines in eastern Kentucky, there are about 214,293 acres of land that have potential for reforestation under legacy FRA practices. In addition to timber production, there would also be substantial forest ecosystem service benefits if mining sites were restored to forests. The potential economic values in this study were derived from the benefit transfer method taking into account different types of ecosystem functions and demographic characteristics. These results allow for a more complete cost-benefit analysis for reforestation practices in mine reclamation planning by accounting for both timber and non-marketed ecosystem services. Even though large investments are needed to reclaim the legacy land as forest, there are large economic and ecological benefits associated with these practices. Estimates of ecosystem service values for different land types enable managers and planners to determine where it is suitable to restore forests.

There are several important implications of this study's results. First, landscape characteristics are important factors in mine reclamation planning (Plummer, 2009; Nelson et al., 2009). They are highly related to the potential biological and physical functions brought by the proposed policies. Forests in riparian zones play an especially important role for water supply and regulation services (Andrews et al., 2011). Benefits from these lands generated a much larger economic value than other type of landscapes. After land in riparian areas, areas classified as biodiversity hotspots, protected, or near a road (or some combination of these) provided substantially more benefits than land not having any of these characteristics. Thus, the highest priority for establishing forests on legacy mine land should be those that are located in riparian areas followed by land that has a high degree of biodiversity, located within or near a protected area, and/or near a road.

Second, the valuation of ecosystem services is not determined solely by the ecological restoration process, but also is highly dependent on the demographics of populations nearby (Costanza et al., 1998; Rosenberger and Loomis, 2003). It is therefore important to adjust values based on the demographics of nearby communities. Moreover, from the sensitivity analysis it can be seen that the discount rate chosen, which reflects people's perception of future values, can significantly impact investment decisions (Zhuang et al., 2007). Only combining these social-economic factors together with biophysical factors, can appropriate planning decisions about the reforestation strategies on reclaimed mining land be made.

The choice of an appropriate social discount rate for cost-benefit analysis of public projects are still debated among economists. Different approaches have been employed which reflect different views on how public projects affect private investment and consumptions (Moore et al., 2013). For example, US Office of Management and Budget (OMB) uses a rate of 7% following the social opportunity of cost approach, which considers the social discount rate as a measure of the marginal earning rate for private business investment. The US Environmental Protection Agency (EPA) supports using the social rate of time preference approach, which considers the social discount rate as a measure of society's willingness to postpone private consumption. EPA recommends undertaking sensitivity analysis of discount rates between 2-3% as well as 7%. In general, the social discount rates applied in developed countries vary between 3% to 7% (Zhuang et al., 2007). These discount considerations are especially important on long-term reforestation projects where the impacts are spread over multiple generations. Some have proposed to employ declining discount rates (Weitzman, 2001) for intergenerational projects. The impact that these services will have (socially, economically, ecological) on the well being of different generations needs further consideration and study (Harrison, 2010).

In interpreting the results from this study several caveats should be kept in mind. First, the recovery of ecosystem services develops gradually over time causing the time of recovery to significantly impact the economic value. Because of limited information of ecological dynamics over the restoration process, we assume it will grow back as natural forest after 60 years. It is possible that reforestation on reclaimed mine land could start providing higher aesthetic and recreation value relative to grassland before 60 years, increasing the net benefits of reforestation compared to grassland. It would thus be useful to investigate people’s perception of the environmental benefits at different recovery stages.

Because FRA practices are relatively new, information about reforestation success on legacy mine sites is limited. Although restoration of native forests is a worthy long-term goal, scientists and managers are still making improvements with reforestation strategies and trying to solve some practical issues - such as the growth of invasive plants on reforested sites (Adams, 2017). Currently there have been no evaluation studies that were designed to investigate the nonmarket value of ecosystem services from legacy FRA lands. Therefore, we assume the ecosystem services provided by reforested land would be similar to the previous native forest in the long run. More research is needed to investigate the ecological functions from reforested lands to inform comprehensive assessments.

Using benefit transfer to evaluate the economic value from forest ecosystem services also introduces measurement errors (Rosenberger and Loomis, 2003). To estimate the value of benefits from reforestation on legacy mine land, we relied on studies conducted in other areas. As the value of ecosystem services are dependent on human perceptions and activities, different conservation programs and different forest types may have different values. In this study, we provided the potential range of values for each ecosystem service, while the cost-benefit analysis was only based on the mean present value. The uncertainty of these results should be considered. More valuation studies specific to reforestation activities on reclaimed mine lands in Appalachia should be conducted to reduce this uncertainty. Moreover, there also exists unavoidable risk and uncertainty in evaluation of future oriented projects, a full risk assessment in the planning process would help to improve the quality of decision-making (Yoe and Skaggs, 1997).

Finally, there are critics of the concept of economic valuation of ecosystem services (Schröter et al., 2014). The monetary values assigned to nature are not derived from commodities which can be exchanged in the real market. In a broader sense, only the economic value of ecosystem services is investigated here. As always, policymakers will have to consider a broader range of economic, social, and political factors to make decisions regarding energy production and ecosystem restoration. However, studies such as this can help to bridge biophysical indicators and social values in mining land reclamation planning. Studies such as this can also provide important information to the public and policymakers about the trade-offs regarding different restoration strategies.

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