5-4-2023

Biodiversity in Eastern Kentucky: Effects of Habitat Change, Surface Top Mining, and Current Reclamation Practices

Sydney Pardieu
spardieu2@bellarmine.edu

Recommended Citation

Pardieu, Sydney, "Biodiversity in Eastern Kentucky: Effects of Habitat Change, Surface Top Mining, and Current Reclamation Practices" (2023). *Undergraduate Theses*. 112.
https://scholarworks.bellarmine.edu/ugrad_theses/112

Biodiversity in Eastern Kentucky:

Effects of Habitat Change, Surface Top Mining, and Current Reclamation Practices

Sydney Pardieu

May 1, 2023

A Senior Honors Thesis Presented in Partial Fulfillment of the Requirements of the Bellarmine University Honors Program

Under the Direction of Dr. Martha Carlson Mazur

Reader: Dr. Kate Bulinski

Reader: Dr. Michele Abee

ACKNOWLEDGEMENTS

I would like to thank Dr. Martha Carlson Mazur for her guidance and help throughout this entire project, advising me on both research and writing.

I would like to thank Dr. Michele Abee for her expertise in ArcGIS and providing guidance through difficult portions of the data collection and data analyses, along with being a reader.

I would like to thank Dr. Kate Bulinski for initially inspiring me to do a thesis on this topic through her classes, and for being a reader that provided multiple perspectives and writing advice.

Finally, I would like to thank Timothy Rader and Lucas Graham from the Division of Abandoned Mine Lands for their help in informing me how reclamation works in Kentucky, and for their transparency with related obstacles they are facing in their field.

Table of Contents

ABSTRACT 5

INTRODUCTION 6

Societal Impacts 7

Surface Top Mining and Native Biodiversity Conditions 12

The Importance of Biodiversity 21

Reclamation and Conservation 24

Research Question 30

METHODS 31

Study Area 31

Data Collection 33

Statistical Analyses 36

Reclamation Meta-Analysis and Interviews with Division of Abandoned Mined Lands 36

RESULTS 37

Impacts on Biodiversity and Reclamation Meta-Analysis 37

Interviews with the Division of Abandoned Mined Lands for Kentucky 40

DISCUSSION 43

Policy Recommendations and Intervention Points 50

CONCLUSION 58

Future Research 59

REFERENCES 61

APPENDIX A... 76

ABSTRACT

Biodiversity is a key component in maintaining the valuable ecosystem services that are vital to the way humans interact with and rely on the environment. The Appalachian Region in Eastern North America is one of the most biodiverse temperate broadleaf forests in the world and is home to hundreds of endangered or endemic species. Despite the high biodiversity, the region is also heavily mined, particularly by mountain top removal, causing habitat change and pollution. Current reclamation practices for mined lands are lacking in effective reclamation criterion, and state statutes provide little or no attention to the preservation of biodiversity. Therefore, this study investigated the effect of surface top mining on biodiversity in the Central Appalachian region of Eastern Kentucky using publicly available biodiversity indices and geospatial data analysis at the watershed scale while also examining reclamation effectiveness through interviews with government officials and a meta-analysis of current reclamation research. Fish biodiversity was significantly impacted in areas with high percentages of surface mines. A positive correlation was observed between surface mining and herbaceous, shrub, and barren land cover, suggesting the utilization of the grassland reclamation approach as a primary method of reclamation. Analyses indicated insufficiency in reclamation to support biodiversity in Eastern Kentucky despite policies that outline the process for reclamation being effectively written, suggesting a root cause in lack of enforcement or funding. More stringent land use approval processes and stricter enforcement are needed, along with increased funding for divisions responsible for reclamation to utilize ecologically beneficial reclamation methods that support biodiversity.

INTRODUCTION

The Appalachian Mountain Range located in the Eastern United States is one of the most biodiverse areas in the world, providing habitat for hundreds of endemic and endangered species. In 2012, the World Wildlife Fund (WWF) created its “Global 200” list to highlight areas of special importance regarding conservation due to their exceptional levels of biodiversity (WWF 2012). One of the regions that was placed on this list is the Appalachian Mixed Mesophytic Forest region, which encompasses Eastern Kentucky, including Ecoregions 69d and 69e (EPA 2022) (Fig. 1), and is one of the largest temperate broadleaf deciduous forests in the world, providing the greatest reserve of temperate broadleaf forest flora and fauna in North America (Woodward 2012).

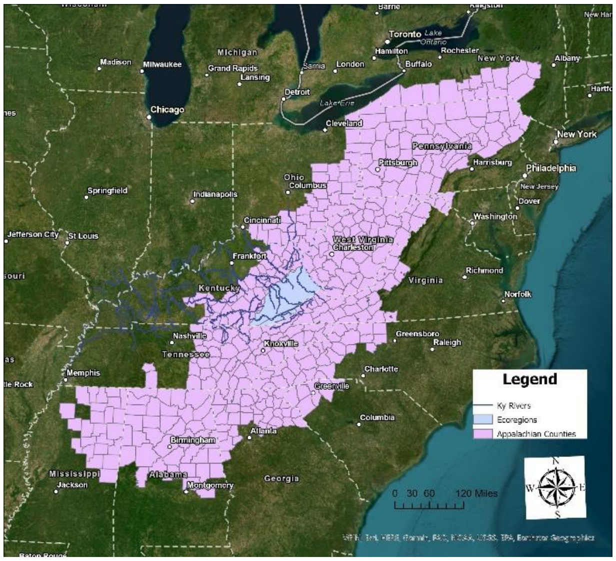

Figure 1. Location of study area within greater Appalachian Region.

This forest region, however, is also one of the most heavily mined areas in the world. Since 1976, roughly 1.5 million acres of forest have been destroyed in Central Appalachia from surface top mining alone (Pericak et. al. 2018). The mining companies operating in Appalachia utilize a vast array of methods to reach natural resources such as coal, surface top mining being among them. Surface top mining includes methods such as mountain top removal, strip mining, open pit mining, dredging and highwall mining. Each category of mining has individual characteristics that bring their own array of environmental issues and impacts on biodiversity. For example, mountain top removal is the process of removing the tops of mountains using explosives to reach the coal seams below. The tops of these mountains, called overburden, are dumped into nearby valleys, called valley fill sites. These valleys are formed by streams that create the important riparian environments that support biodiversity and ecosystem function in Appalachia. An estimated 2000-4000km of stream length in Central Appalachia has been negatively affected by valley fill sites (Williamson and Barton 2020). In this way, the coal industry is destroying one of the most biodiverse areas in the world, and at the same time incurring drastic societal impacts.

Societal Impacts

Ever since Kentucky was settled by European settlers, subsistence farming and isolation have played a major role in the societal structure in Eastern Kentucky, laying the foundation for the coal industry to take root. This eventuality was exacerbated through two major developments in history. First, modernization of agriculture was unable to infiltrate into Eastern Kentucky as easily as other areas such as the large tobacco farms of Central Kentucky due to geographic and environmental constraints (Pudup 1990). Secondly, once industrial development made its way to Louisville, the Ohio River became a major transportation route for Kentucky, which drew industry away from Eastern Kentucky. This issue was further magnified by difficulties for railroads to initially develop in the region due to the mountainous geography of the region (Pudup 1990). These factors led to the isolation of Eastern Kentucky, making the role of subsistence farming that much more integral to the functioning of society.

Due to the large role of small-scale subsistence farming for families in Eastern Kentucky, the profitability and control of the local economy was stunted, which allowed outside investors to develop the area as they wished. Because most needs were met from farming and trading among families in the region, a lucrative economy based on exports did not develop as it did in many other areas of Kentucky. This led to a lack of local investment in larger industries, such as coal. Once coal was discovered in Kentucky, locals were unable to benefit, as they lacked economic capital to develop the industry themselves (Pudup 1990). Consequently, outside investors were able to monopolize the area, controlling the way that the industry developed with little consideration and sometimes intentional exploitation of the people residing in the region.

The effects of the way the coal mining industry developed are apparent through the long and tenuous history within the state of Kentucky, starting at the end of the 18th Century (EIA 2022). The coal mining industry has since provided the foundation upon which many Eastern Kentucky communities were founded. These early “coal camps” were formed when mining companies built all the infrastructure needed to house the local miners and their families, complete with schools, stores, and doctor’s offices. From there, coal mining and extractive industry took root in Appalachia, supporting Appalachian economy and livelihoods (Evans and Freeman 2016) and forming strong cultural ties within the community.

For many people in Eastern Kentucky, mining jobs are among the few well-paying jobs that provide the health insurance and financial support that people living in Appalachia rely on, a fact that is frequently used by mine companies to maintain control and profits (Evans and Freeman 2016). Adding to the complexity of the issue, mine jobs are transient in nature. The job of a miner is only semi-guaranteed while the mine is in operation, after which they must find a different mine or face unemployment. In several instances, miners have gone on strike to gain better working conditions and protected rights (e.g., wages, healthcare, retirement funding, family benefits), even forcing some to unionize to gain protected rights. In 1973, union workers went on a 13-month strike against the Brookside mine in Harlan County, Kentucky, to gain access to higher wages and safer working conditions (Kopple 1976). As of 2015, however, there are no more union mines in Kentucky (Lovan 2015), leaving workers without guaranteed benefits or protections.

During the first boom of the industry in the 1800s and early 1900s, many of these strikes ended in violence and fatalities. One of the most famous examples of these strikes is “Bloody Harlan” in 1931. Harlan County miners went on strike in response to the coal companies cutting wages by 10% to maximize profits, resulting in at least 4 fatalities during stand-offs. By late 1931, miners were making as little as 80 cents a day, and only working a few days a month (Hennen 2008). Many of the mine companies were comprised of outside investors, controlled by people that had no cultural ties to Eastern Kentucky, which likely led to disregard for the local community, mine safety, and local health.

In today’s world, violence on the scale of some of these previous strikes such as Bloody Harlan would have detrimental repercussions to the image and operations of the mining companies. Instead, the companies utilize other tactics to maintain control of the workers in the industry. For example, one method for maintaining control includes discreetly firing the workers who are protesting for better conditions and hiring company-endorsed miners (Evans and Freeman 2016; Kopple 1976). But even if a worker were to remain loyal to the company and work in the dangerous environment, the worker would not be guaranteed protected retirement and healthcare due to instability and transience in the mining industry.

Due to lack of sufficient enforcement of state statutes, companies frequently file for bankruptcy to avoid paying miners’ retirement or healthcare (Mistich 2022). In 2013, Patriot Coal company attempted to file for bankruptcy with agreements that cut off retiree healthcare (Evans and Freeman 2016). Mining presents multiple occupational health hazards that lead to a variety of healthcare concerns. The most common of these adverse health effects is Silicosis, more commonly known as black lung disease. This disease primarily affects underground miners who breathe in the silica dust that comes from blasting out the excess rock to reach the coal seams. Silica is a fine crystalline material that is naturally found within the earth's crust that, when inhaled, gets trapped in the alveoli of the lungs, causing a persistent cough. Repeated coughing and inflammation of the alveoli can cause scar tissue to form and impact respiration (American Lung Association 2022). Despite being more prevalent among underground workers, the disease can still be found in surface top mine workers who do blasting and drilling without proper ventilation (Castranova and Vallyathan 2000). These negative health effects underscore the need for secure access to healthcare for the workers and their families.

The longstanding dependence on subsistence farming, raising of livestock, and reliance on water wells in rural Appalachia further indicate how essential sufficient access to healthcare is to the region. The reliance on land and water resources is threatened by pollution from surface top mining. Typical pollutants associated with this industry include heavy metals, such as mercury, selenium, and lead, along with other forms, such as acid mine drainage. Pollution from mining operations enters into the soil or nearby streams via runoff, which then transfers and deposits the pollution away from the mine. The proximity between surface mines and people allows this pollutant runoff to contaminate the soils and waterways utilized by people in the region, posing a health risk hazard. Vegetation mitigates some impacts of pollution as various plants are able to absorb heavy metal contamination through their roots (Cataldo and Wildung 1978), which means a greater diversity in flora can lessen the impact on the people in the region.

Despite the detrimental impacts to human health and the environment caused by surface top mining, and the potential for reclamation practices implemented on the close of mining operations to minimize the ongoing impacts, substantial adverse effects from mining persist. The mining industry holds lobbying power over both politicians and the people of Appalachia (Evans and Freeman 2016). For example, Kentucky state senator, Mitch McConnell has received over 1.2 million dollars in campaign contributions from the mining sector since 1982 (Sen. Mitch… 2023). The lobbying done in the service of pro-mining relations has led to less effective reclamation and environmental regulations, which has lasting impacts on stakeholders and biodiversity in the region.

There is no denying the important role coal played in bringing America to the forefront during the Industrial Revolution and the benefits it has brought to the Kentucky economy. Today, most of the coal being extracted remains in the state, going on to power 71 percent of the state's electricity through coal-fired power plants (EIA 2022). At the same time, the reliance on surface top mining produces detrimental impacts on the economic benefits stemming from biodiversity and aesthetics, such as ecotourism. Here-in lies a trade-off between relying on an industry that depends on a finite resource, associated with detrimental impacts on society and biodiversity, as opposed to relying on more beneficial sectors that would serve to bolster Appalachian communities.

The roughly 60 percent of mines in Kentucky that are surface mines contribute only 20 percent of the state's coal production (EIA 2022). The transition to surface top mining has also increased unemployment in the region as fewer workers are required to run operations on the site, providing added stress to those relying on this industry for income and other benefits. Surface top mining, however, is frequently considered safer for mine workers, faster, and less expensive than its more productive underground counterpart (Kentucky Geological Survey). Despite the strong reliance on the mineral, Kentucky coal production is experiencing strong decline (KEEC 2022). Biodiversity has the potential to benefit the economy in various ways, such as harvesting native crops with medicinal properties like ginseng, increasing ecotourism and forestry, and supporting various recreational relationships like hunting or fishing (Todd et al. 2010, Li et al. 2018). Understanding the full effects of surface top mining and its impacts on biodiversity will be important in trying to improve conditions for the stakeholders that live in the region who have been historically disenfranchised by the industry.

Surface Top Mining and Native Biodiversity Conditions

Surface top mining comes in many different forms and is used to mine several different minerals, including coal. The first step for any surface top mine is surveying and logging. Once geologists have determined the location and amount of mineral that can be extracted, the land is cleared to begin extraction. Deforestation is a common consequence of anthropogenic land use change, leading to extreme flooding, habitat loss, and an increase in carbon dioxide (Chakravarty et al. 2012). Sometimes, mining companies want to expedite the process, so they might dump the timber into valley fill sites as overburden rather than generating revenue from lumber. As coal reserves are being depleted, more land area is needed to get the same amount of coal out of thinner seams. In 2010, roughly 15m^2 of land was required to produce one metric ton of coal; by 2015, however, that amount doubled to 30 m^2 (Pericak et al. 2018). Since coal is declining in use for energy production, the negative environmental effects may be expected to decline in tandem. However, Pericak et al. (2018) showed the opposite. Despite coal production being on the decline, attempts to preserve the industry will lead to more areas being deforested to extract similar amounts of coal as previous years. The negative effects of deforestation will still be prevalent throughout Appalachia unless additional interventions are implemented.

Once the surface of the land has been cleared of vegetation, explosives are used to reach the underlying mineral seams in a pre-mining process that has its own environmental consequences. Noise pollution can have detrimental effects on bird populations, especially forest birds (Wilson et al. 2021). Also, the dust clouds created from blasting this rock have been shown to have negative health impacts for workers in the area (NIOSH 2011). The overburden resulting from this process is dumped into nearby valleys and streams, consequently changing the topography and soil composition of the area. This three-dimensional aspect of surface top mining leads to greater detrimental impacts than other forms of land use change (Ross et al. 2016). Two-dimensional forms of land use change, such as agriculture, do not alter land shape and slope, despite having the initial deforestation in common with surface mining, suggesting that reclamation of surface top mines will need to be more robust than typical reclamation methods utilized for other forms of land use change.

In an attempt to contextualize the full extent of mountaintop mining in West Virginia regarding changes in topography and downstream waters, Ross et al. (2016) found that the cumulative amount of overburden determined from the 1544 valley fill sites within their Appalachian study area equated to the amount of debris in the volcanic eruption of Mt. Pinatubo in 1991. One single valley fill site in West Virginia holds roughly 200 million m^3 of overburden in a $2.9km^2$ area, enough fill to match the amount of material deposited from the Mt. St. Helens eruption in 1980 (Ross et al. 2016). Further, these values are likely to be underestimates of the actual amount of overburden created by mountaintop mining in West Virginia, since the focus was on valley fill sites and did not account for the overburden used in reclamation or reforming ridgelines (Ross et al. 2016).

The three-dimensional impacts stemming from changes in topography and soil composition are particularly detrimental to the native flora and fauna of the region due to the unique geologic and evolutionary history of the region. Most of the sedimentary rock that can be seen in the Appalachian Mountain Range today has been dated to the Paleozoic age, meaning this mountain range has had 500 million years to develop (Dykeman 2019). By comparison, the Rocky Mountain range in the western portion of the United States is only 55-80 million years old (USGS). Today, the Appalachian Mountains span from Northern Alabama and Georgia through Southern portions of New York. The geologic events that transpired through the hundreds of millions of years that these mountains were forming have created the specific substrates and conditions that these rare species need to thrive (Korner et al. 2005).

Longer time periods over which evolutionary processes can proceed leads to greater biodiversity (Economo et al. 2018). Ecosystem degradation following a loss in biodiversity happens at an accelerated rate, a rate at which biodiversity regeneration cannot match (Cardinale et al. 2012). Appalachia is a highly diverse landscape because it spans such a large area and has a rich developmental history. The variation in elevations and latitudinal gradients create various microhabitats that bring different biota. The extreme level of habitat change brought on by surface top mining destroyed millions of years of evolutionary processes within a few years. For example, a 30% increase in slopes lower than 25 degrees has occurred where mining is present, a characteristic that was rare in the unaltered Appalachian landscape (Ross et al. 2016). This three-dimensional aspect of surface top mining stemming from elevational destruction leads to greater detrimental impacts on native flora and fauna of the Appalachian region compared to other forms of land use or underground mining.

Understanding the influence of elevational gradient on plant diversity and animal diversity is necessary for assessing how surface top mining will alter ecological communities into the future and how best to reclaim mined out areas to promote the return of endemic species. Elevational gradients are closely associated with changes in various abiotic factors such as temperature, precipitation, land area, soil formation, topography, and geological substrates (Sundqvist et al. 2013). Plant communities typically exhibit a unimodal biodiversity distribution with peak richness at mid-level elevations, which provide a less stressful environment allowing more species to grow and access more abundant resources. Plant communities, however, have more functional trait diversity at higher elevations, indicating that biological drivers such as competitive exclusion and niche partitioning are prevalent in structuring the ecological community (Sundqvist et al. 2013). Surface top mining effectively removes all diversity at higher elevations due to the complete removal of soil and underlying rock during mountain top removal practices. Further, the complete destruction of the environment inherently alters resource and niche availability, suggesting irreversible effects that will affect recolonization by endemic organisms after mining ceases unless reclamation practices are targeted at restoring prior habitat structure.

Moreover, the impact of elevational gradient on microbes is less studied than plants and animals despite the essential role of the soil microbial community, in particular, in ecosystem functioning. Microbial richness decreases with an increase in elevation, and microbes tend to be grouped based on phylogenetic similarities within elevational gradients (Bryant et al. 2008). As a result, microbes tend to be more heavily influenced by the typical abiotic features of elevational gradients, as opposed to biological drivers. The decrease in microbial functional trait diversity at higher elevations indicates that the organisms within the high-elevation microbial community rely on specific abiotic factors (e.g., cooler temperatures, sandy loam soil-textures, Yutsek et al. 2013) for survival. Surface top mining detrimentally affects the soil composition and other abiotic factors that microbes at higher elevations rely on (Mummey et al. 2002). The lack of functional trait diversity suggests a lower resiliency and less likelihood that some groups will survive when these abiotic factors are changed. This decrease in microbial presence has the potential for lasting impacts on other organisms that rely on the ecosystem services provided by microbes at higher elevations.

Central Appalachian forests are defined as mixed mesophytic, including species such as sugar maple, beech, hemlock, white oak, northern red oak, yellow birch, and yellow buckeye. These communities are characterized by high species diversity that can be quantified using the species richness, or number of species within a given area, and Shannon Diversity Index that takes into account richness and evenness of species distributed within a community (Greenberg et al. 1997). Riparian zones dominate lower elevations of Central Appalachia and are important for controlling water quality, aquatic biota composition, nutrient and sediment loading, and streamflow (Hedman and Van Lear 1995), all of which influence higher order streams located further downstream. Typical early successional tree species located in the lower stand riparian zones of Appalachia include tulip poplar, black birch, white basswood, and black cherry. This stand is characterized by extremely steep slopes with little overstory coverage. Before the turn of the 20th Century, American chestnut dominated and outcompeted shade intolerant species such as tulip poplar and black cherry, but deforestation and blight decimated American chestnut in these zones (Hedman and Van Lear 1995). Late-successional species located in riparian zones include more tolerant species such as white pine, oaks, and hemlocks. Riparian zones in this region are also dominated by certain invasive rhododendron species that outcompete other native understory species such as partridgeberry, windflower, violet, and galax (Hedman and Van Lear 1995).

Many of these riparian zones, however, are altogether destroyed by the burial of headwater streams by valley fill sites, impacting higher order streams further away. Mixed mesophytic old growth forests are also characterized by many interdependent relationships between organisms, such as germination time and shade-competition that alter forest composition leading to high species variability. Further, these forests support rich avian and mammal populations, along with rich herpetological populations that are rarely found in other forests (Greenberg et al. 1997). Increasing plant diversity increases the amount of habitat variation and variation in food for herbivores, which has a bottom-up effect on the diversity of animal species (Scherber et al. 2010), increasing overall biodiversity in the region.

The overburden created through surface top mining consists of both topsoil and large pieces of blasted rock, creating a soil substrate consisting of rock debris that is unable to foster plant life and retain moisture properly. The removal of topsoil during the initial stages of mining leaves an extremely rocky substrate for vegetation to grow on, one that is incompatible with the native flora of the region (Kundu and Ghose 1997). The Hans Jenny soil forming factors are a set of criteria that explain the development and health of soils. These criteria are climate, biota, topography, parent material, and time (Jenny 1941). Climate refers to the amount of water that enters the soil acting as a solvent and method of transportation. Also included in this factor is temperature, which influences rate of reactions, and wind, which influences erosion rates. Biota influence weathering and erosion rates, nutrient availability, and organic matter in soils (Jenny 1941). Soils that have been impacted by surface top mining typically lack organic matter (Asensio et al. 2011), which has lasting impacts on the future development of plants.

Topography refers to slope and microclimates related to elevation. Parent material refers to the where the soils originated (fluvial, glaciated, bedrock, etc.), which impacts the ratios of silt/clay/sand affecting particle size and distribution (Jenny 1941). Normal land use change typically only affects the potential biota of the soil; however, surface top mining affects all five factors (Ross et al. 2016).

Surface top mining detrimentally affects the natural hydrology of the ecosystem beyond filling the natural valleys and streams of the ecosystem. Small particles in soil, typically less than 2mm, are responsible for water and nutrient storage. Larger particles cannot hold enough water to sustain plants through the summer (Sheoran et al. 2010). Before reclamation, the soil is porous due to the uncompacted nature of the substrate, full of larger particles created in blasting of rock and deposition of overburden. The high porosity, in combination with the decreased slope of the land, causes an increased residence time of water that can increase the extraction rates of pollutants and cause acid mine drainage (Ross et al. 2016). Following reclamation, however, the highly compacted nature of the soils decreases water infiltration, increasing runoff and flooding during rain events (Gyawali et al. 2022). The dynamic nature of the effects on hydrology stemming from surface top mining provides multiple issues, all of which must be addressed during reclamation aimed towards returning natural hydrologic processes to the region.

Physical changes to the soil and hydrology are not the only issue; chemical pollution is also a major factor that influences the flora and fauna of the region. Coal is a pyritic material in which iron disulfide (FeS_2) is the primary sulfur component. When oxidized, the FeS_2 becomes sulfuric acid, otherwise known as acid mine drainage that is composed of sulfur oxides and dissolved iron and has the potential to dramatically lower the pH of water surrounding the surface mine (Ross et al. 2016). In contrast, other limestone quarrying operations in other parts of Kentucky extract primarily carbonate materials, which have the opposite effect on pH. Carbonate materials are basic and typically raise the pH of the soil. If the pH of the soil strays too far from neutral in either direction, noticeable effects on the vegetation are observed (Sheoran et al. 2010). For example, one important aspect to consider when examining soil health is nitrogen fixation because nitrogen-fixing bacteria typically cannot grow in acidic soils where the pH drops below 5.5 (Sheoran et al. 2010). Native flora in Appalachia grow best with soil pH between five and seven (Adams et al. 2017). Without these symbiotic relationships between the microbes in the soil and plants, plant growth will be stunted and leave soils without necessary nutrients (Gaiero et al. 2013). The limited access to nutrients and other factors in the soil stemming from surface top mining presents another issue that must be addressed during reclamation.

Pollution stemming from surface mining of coal not only alters pH, but it contains common heavy metals and other harmful elements including mercury (both the organic and inorganic forms), selenium, lead, arsenic, cadmium, and sulfur. Mercury is often associated with the direct extraction of coal, whereas organic mercury, also known as methylmercury, requires microbial transformation. Mercury has been found to magnify across food webs in riparian environments once it has been transformed into methylmercury (Gerson et al. 2020). Certain characteristics of the pollutants affect the level of soil contamination including solubility of the metal. For example, more soluble metals will be more readily dissolved into the soils. Solubility is also impacted by the microorganisms present, which produce byproducts with high affinity for metals, leading to increased metal uptake within the soils. Other factors that affect pollutant concentration in soils are physical characteristics of the metals, particle size and distribution in soils, reactivity, and mineralogy (Cataldo and Wildung 1978). Understanding how pollutants infiltrate the soil and the detrimental health effects on various organisms is important to biodiversity conservation in general.

In a study of West Virginia valley fill sites, researchers found that selenium concentrations measured in valley fill effluent were found to have up to 19.3 ppb selenium, while the maximum contaminant level set by the U.S. Environmental Protection Agency is 5 ppb (Ross et al. 2016). Mercury is known to cause congenital defects in infants, along with fatality in cases with acute toxicity (Boudou and Ribeyre 1997). Further, heavy metal contamination in streams causes structural lesions and functional disturbances in fish, which then pose a health risk to predators who ingest the fish, such as birds or mammals (Mehana 2014). The known adverse health effects of these heavy metal contaminants pose a serious public health issue to people living in Eastern Kentucky. Many people living in the area rely directly on the environment for food and water. Streams that flow onto their land have the potential to be contaminated in terms of water quality but also contain contaminated fish that are then consumed by people. Further, the crops grown and consumed have the potential to be contaminated due to the metal uptake capabilities exhibited by plants. This again highlights the importance of reliable access to healthcare for the region, which is lacking in the mining industry.

Surface top mining changes the landscape so drastically that not only is the ecological community structure irreversibly altered, but the evolutionary trajectory for the entire ecosystem and underlying geology are fundamentally changed through the effect of mining on habitat change and pollution, two of the largest drivers of biodiversity loss (Fagundez 2012). Understanding the environmental impacts of surface top mining in the context of habitat loss, hydrology, soil properties, and pollution is important to determining the full extent of impacts on native biodiversity for the region, which has lasting effects on the society in Appalachia.

The Importance of Biodiversity

Biodiversity is the foundation for all life on Earth and can be put in terms of morphological, taxonomic, or functional diversity, all of which respond differently to various stressors (Belcik et al. 2020). Cardinale et al. (2012) compiled previous research on biodiversity, identified common themes, and created six consensus statements that describe the importance of biodiversity. The first of these consensus statements is: "Biodiversity loss reduces the efficiency by which ecological communities capture biologically essential resources, produce biomass, decompose, and recycle essential nutrients" (Cardinale et al. 2012). Biodiversity is a key component in maintaining the valuable ecosystem services that are vital in the way humans interact with and rely on the environment (Costanza et al. 1997; Millennium Ecosystem Assessment 2005). Biodiversity creates the complex relationships necessary to do certain ecosystem processes such as nutrient cycling, while also providing the environment to practice recreational relationships such as hunting and fishing.

In general, ecosystem services rely on the complex relationships between the biotic and abiotic features in any given ecosystem whose intricacy is in part due to the functional biodiversity of these organisms (Millennium Ecosystem Assessment 2005). In such an ancient ecosystem as Appalachia, these functional traits have coevolved, leading to complex and interconnected relationships among the biota of the landscape. For example, nutrient cycling relies on the composition of the biological communities found in the soil, each of which plays a different role in creating the service (Mace et al. 2012). Ecosystem services provide clean air, clean water, nutrient cycling, pollination, and other things from which humans and all living things directly benefit.

The explanation for why biodiversity is so important in maintaining ecosystem services can be found in four of the other consensus statements. The first is: “Diverse communities are more productive because they contain key species that have a large influence on productivity; increase in the difference of functional traits of various organisms increases the total resource capture” (Cardinale et al. 2012). This connects closely to another consensus statement that concludes: “Functional traits of organisms have large impacts on the magnitude of ecosystem functions which gives rise to plausible extinction of ecosystem function” (Cardinale et al. 2012). Functional traits can be defined as morphological, biochemical, or behavioral characteristics of organisms that are relevant in the response of said organism to the environment and/or their effects on ecosystem properties (Voille et al. 2007). Functional traits are vital in determining how an organism will contribute to any given ecosystem service and how that organism will respond to environmental stressors (Suding et al. 2008; Belcik et al. 2020). Given the importance of functional traits to ecosystem services and ecosystem resiliency, it would follow that a decrease in diversity of functional traits for any given community could lead to the decline in ecosystem function. If the decrease is significant enough, the ecosystem functionality could cease to exist entirely.

Diversity of functional traits plays an important role in ecosystem resiliency thereby improving ecosystem stability overall. In the deciduous Taihang Mountain Range in China, Geng et al. (2019) studied the relationship between ecosystem stability and resilience versus resistance. The authors defined resilience as the ability to recover, whereas resistance was defined as the ability to remain unchanged. The researchers concluded that ecosystem stability is more dependent on resiliency than resistance (Geng et al. 2019). The following consensus statement was: “Loss of diversity across trophic levels has the potential to influence ecosystem functions more strongly than loss within specific trophic levels" (Cardinale et al. 2012). This refers to the intricate relationships among organisms in any given food web, whereby the loss of just one top predator in a higher trophic level influences primary producers at least as much as turning a diverse group of primary producers into a monoculture (Cardinale et al. 2011).

The direct reliance on biodiversity for ecosystem functioning and services is supplemented by a temporal aspect to the relationship. The final two consensus statements refer to the relationship between biodiversity and ecosystems through a temporal lens, the first of which concludes that: "Biodiversity increases ecosystem stability through time" (Cardinale et al. 2012). Multiple studies have shown that ecosystem stability is highly correlated with vegetation diversity, indicating that an increase in vegetation diversity could increase ecosystem stability (Geng et al. 2019; Hautier et al. 2015; Tilman et al. 2001). The next consensus statement follows closely, concluding that: "The impact of biodiversity on ecosystems is nonlinear meaning that change accelerates as biodiversity loss increases" (Cardinale et. al. 2012). Both statements follow the logic regarding functional traits and ecosystem services and resiliency; because the relationship is nonlinear, a decrease in diversity of functional traits could lead to an exponential decrease in ecosystem services and resiliency.

Reclamation, in general, is the process of reversing what degradation has taken place in order for previous ecosystem function to return. As such, reclamation has the potential to mitigate the loss of ecosystem services by creating the environment for native biodiversity to return and facilitate the processes upon which ecosystem services rely. These consensus statements directly show the importance of proper reclamation practices in any given area where biodiversity is being threatened. For example, effective soil reclamation and conservation must be implemented such that the native flora and microbial populations can return. This will bolster nutrient cycling and native plant populations that humans harvest such as ginseng originally harvested for medicinal purposes. Ginseng is a native understory plant that grows under the dense shade of native deciduous hardwoods such as sugar maple and tulip poplar (Beyfuss 1999). If biodiversity cannot be placed on an untouchable pedestal due to the absolute need for anthropogenic development and expansion, proper tending during the remediation stages must occur such that the ecosystems are restored to, or as close as possible, the pre-development levels of diversity. Further, actions to support biodiversity must be taken immediately and efficiently given the temporal aspect of accelerated ecosystem decline following loss in biodiversity.

Reclamation and Conservation

Given the rapid decline in biodiversity and ecosystem function due to the impacts of surface top mining combined with the fact that more mines are going out of business than new ones opening (Harfoot et al. 2018), proper reclamation will be needed to minimize further economic and environmental harm to the region. Reclamation is the process of assisting the recovery of severely degraded ecosystems to benefit native biota through the establishment of habitats that are similar but not necessarily identical to the surrounding, naturally occurring ecosystems (Gerwing et al. 2021). Three of the primary aspects that must be addressed when reclaiming a site include the soils, hydrology, and biology (flora/fauna) of the ecosystem. Even though fewer and fewer new mines are being opened, the new mines are moving into more biodiverse areas with specialist species adapted to live under specific conditions (Harfoot et al. 2018). Not only is reclamation important for these new mines, but also the abandoned mined lands in the region. Following this trend, proper reclamation processes will be needed for the restoration and protection of the natural habitats in Central Appalachia.

Two main forms of reclamation for mined lands are currently used in Appalachia if the chosen post-mining land use is natural lands/recreation: the Grassland Reclamation Approach and Forestry Reclamation Approach (FRA). Both have differing ecological impacts; however, the FRA provides substantially greater benefit to the environment (Macdonald et al. 2015). Grassland Reclamation utilizes ecologically competitive non-native grass species that prevent natural species from inhabiting the reclaimed land (Pericak et al. 2018). The non-native grasses prevent the establishment of native pioneer species that would inhabit the land and lay the foundation for the later native hardwood successional species that are a staple of the old growth forests associated with Appalachia. Grassland Reclamation also leaves the land extremely flat and changes the physical properties of the soil. Soils associated with the Grassland Reclamation Approach are characterized by being highly compacted, limited in water filtration, rooting, volume, and soil structure (Williamson and Barton, 2020; Sheoran et al. 2010). These soils also tend to be devoid of organic matter and show reduced carbon sequestration, otherwise known as carbon storage, capabilities as well (Fox et al. 2020). The Grassland Reclamation Approach creates a monoculture consisting of these highly invasive species that reduce biodiversity of the plant communities. Increasing plant diversity is frequently positively correlated with an increase in animal diversity as well (Castagneyrol and Jactel 2012), making proper reclamation practices important to the return of all forms of biodiversity to the region.

In contrast, the Forestry Reclamation Approach was created for the purposes of reclaiming mines whose chosen post-mining land use is forest lands. This approach attempts to outline methods that would produce the environmental conditions more conducive to supporting biodiversity. This approach involves five steps that outline the proper soil criterion for plant growth. The first two steps outline how to achieve proper soil conditions conducive for growing native flora. These steps include creating a suitable root medium no less than four feet deep consisting of topsoil, weathered sandstone, or “the best material available.” Further, the topsoil must be loosely graded to combat the compacted nature of the substrate following mining practices (Adams et al. 2017). The remaining steps relate to plant growth and types of plants utilized to colonize the area. Groundcover species must be compatible with growing trees, and two types of trees must be planted: early successional native hardwoods and a commercially valuable crop tree. Finally, proper tree planting techniques must be used during this approach (Adams et al. 2017). However, an effective reclamation approach such as the Forestry Reclamation Approach will only be successful if implemented properly and on a large scale. Biodiversity needs to be addressed when enacting any reclamation process, and specific conditions regarding the soils, biology, and hydrology of the site should be met such that natural succession processes can occur.

More drastic and widespread effects stemming from surface top mining, such as flooding and landslides, are made worse through improper reclamation. July and August 2022 showed some of the worst flash flooding in Eastern Kentucky’s history. Experts determined that both climate change and the substantial presence of mining in the area contributed to the level of devastation brought on by the floods (Gyawali et al. 2022). Improper reclamation practices that were allowed to occur due to lack of responsibility and insufficient concern of mining companies have led to soils with less water retention ability, lack of vegetation that would naturally impede the flash flooding, and a paucity of natural water drainage basins (Bruggers 2022). Improperly reclaimed mines that have been abandoned represent other dangers in the form of unstable rock faces, the innerworkings of mountains that have been blasted to exposure. The instability increases chances of landslides, especially with increased rainfall (Bruggers 2022). Although the root cause of the floods stemmed from more severe storms exacerbated by climate change and lack of water retention due to altered soil properties and changes in topography, proper reclamation could have increased the lag time between when the rain fell versus peak flood stage consequently mitigating the effects on losses of life and property damage in the region.

Beyond the ecological limitations of current reclamation practices, effective reclamation is actively hindered by the values and policies of both the state and federal government. The concepts of biodiversity conservation and the management of ecosystem services are complex when interpreted individually, but even more so when discussing them together. Reyers et al. (2012) explored the underlying values and preconceptions that surround the concepts of biodiversity conservation and ecosystem services and what management practices would be best utilized for the common goal, biodiversity conservation. In general, a more holistic approach must be taken when trying to promote biodiversity conservation. The message cannot be articulated as benefiting biodiversity alone, but rather put into context within the recreational, cultural, and ecological services biodiversity provides. The long history of extraction driving economic growth in the United States and a capitalistic economy focused on profit indicate a prioritization framework with a strong value on provisioning services that include raw extractive materials like coal. If the primary societal goal instead focuses on biodiversity conservation, bolstering the other three ecosystem services that both serve to enhance biodiversity and provide essential services to society will provide the best results. Therefore, when proposing changes in policy and reclamation methods, the way in which the argument is framed and managed will be vital to the success of the proposed amendments.

Within Kentucky, the responsibility for government control of mining operations stems from the Kentucky Energy and Environment Cabinet (KEEC) which serves the public by regulating laws relating to natural resources and the environment. However, there are major obstacles inhibiting the ability of the KEEC, more specifically the Division of Mine Reclamation and Enforcement (DMRE), to hold mines responsible for reclamation. Mine companies have been able to evade responsibility for reclamation by filing bankruptcy once the violations become too much for the mine to remain profitable or once all the coal has been mined (Mistich 2022). These companies then open another mine, under a different name, only to repeat the same actions. Another method that mines utilize to avoid obligations to workers and environmental responsibilities is the transfer of permits and assets to smaller subsidiary mines (Mistich 2022). Mines will pass these responsibilities between subsidiaries; meanwhile, the pensions never get paid, and the reclamation continues to remain undone.

The effects on stakeholders are not only environmental, but also economic. Congress is frequently forced to raise taxes in order to fund lost obligations to pensions, healthcare, and reclamation projects (Mistich 2022). Some people involved in the industry such as unionizers, miners, and legislators strongly oppose any legislature that could impede mining (Montrie 2000) For example, the United Mine Workers union generally promotes the preservation of mining jobs and safety over the protection of the environment (Montrie 2000). As such, passing ecologically beneficial legislature that could potentially have negative impacts on the industry will face pushback from some of the stakeholders mentioned above.

The consequence of this process is that many abandoned mines use government funding for reclamation, or otherwise go without reclamation and pass the environmental and social impacts onto stakeholders (Bruggers 2022). The government currently has no method of holding abandoned mines responsible once bankruptcy is filed. They can only attempt to prevent the mine from reopening under a different name (T. Rader and L. Graham, pers. comm., 15

November 2022). Another obstacle to holding mines responsible for reclamation is the method with which reclamation bonds are calculated and enforced. Pursuant to KAR 405 10:040, when a mine company is applying for the permits needed to operate a new mine, they must post a reclamation bond that acts as an insurance policy to hold the mine responsible for reclamation. The bond is not created with the intent to cover the complete cost of reclamation, but rather to add monetary incentive to complete reclamation. After "successful" reclamation, the mine can receive the bond back.

Kentucky, however, is a state that has primacy. In general, the Office of Surface Mine Reclamation and Enforcement (OSMRE) within the U.S. Department of the Interior is tasked with determining bond amounts and enforcing federal regulations laid out in the Surface Mine Control and Reclamation Act (SMCRA). When a state is granted primacy, as is the case with Kentucky, that state is allowed to create its own regulatory program that has been approved by OSMRE. This allows the Kentucky government to take responsibility for permitting, inspection, and enforcement of SMCRA. In cases such as Kentucky, OSMRE only oversees the implementation of the regulatory program. Afterwards the state assumes the position of the regulatory authority (OSMRE). This effectively allows Kentucky to regulate the amounts deemed necessary for bonds, permits, and funds.

Frequently, the cost of reclamation is much higher than that of the reclamation bond, so the surety company often forfeits the bond to the regulatory authority to complete reclamation for that specific site (KRGF 2020). After this happens, the next question becomes whether the regulatory authority has enough money to complete reclamation properly. In 2011, OSMRE determined that the surety bonds being permitted by Kentucky were insufficient for the cost of reclamation (KRGF 2020). Consequently, Kentucky established the Office of the Reclamation

Guaranty Fund that oversees a pool system that mine companies must pay into upon creating a new mine but different from the surety bonds, as the companies do not receive this money back as “bond release.” The purpose of this pool is to cover excess costs not covered by the initial reclamation bonds; however, estimates show that this pool system will also be insufficient to pay for proper reclamation (Savage 2021). The guaranty fund receives monetary input from multiple sources: a fee of $1500 per permittee for every coal company, $10 per acre within all permit areas for any given permittee, and a one-time fee of $10,000 for every new permittee before gaining insurance for their first permit. Production fees also contribute, such as 7.57 cents per ton of “surface” created during surface top mining, $10 per bonded acre deemed “non-productive” including roads, spill ways, etc. By the end of the 2020 fiscal year, the guaranty fund had a total balance of $53 million, but only $4.2 million of that was added during the 2020 fiscal year. The remainder had been built up since the fund was initially created (KRGF 2020).

Another obstacle to sufficient and successful restoration is the lack of standardization of reclamation practices across Appalachia. The Appalachian Mountain Range covers multiple states, each of which has varying levels of enforcement regarding standards of reclamation. The study area for this project has been constrained to Eastern Kentucky, but a project such as this could be replicated in other areas where surface top mining has had a similar impact. Understanding the full impact of surface top mining and current reclamation practices on biodiversity has the potential to inform policy amendments that would serve to protect and enhance biodiversity and, therefore, the people that live within the entire Appalachian region.

Research Question

Although small-scale studies have shown detrimental impacts of mining on certain taxa (Lindberg et al. 2014; Madden and Fox 1997), no studies have examined mining effects at larger scales that span terrestrial and aquatic ecosystems in larger landscapes. Therefore, the central research question of this thesis project was: How do habitat change and pollution stemming from surface top mining and current reclamation practices affect biodiversity at large scales in Eastern Kentucky? The specific aims of this study were to: 1) investigate the influence of surface top mining and reclamation on biodiversity, with emphasis on the differential impacts to aquatic and terrestrial organisms; 2) synthesize existing research on reclamation effectiveness in the context of ecological and socio-economic impacts; and 3) propose policy recommendations that overcome existing impediments or barriers to effective reclamation and account for the historical disenfranchisement of Appalachian stakeholder perspectives. Current research suggests that of the two reclamation practices, the FRA is far more ecologically effective (Adams et al. 2017; Pericak et al. 2018; Williamson and Barton 2020). As such, the goal of this research was to propose amendments to current reclamation practices and mining policies using the results of this large-scale study on mining and biodiversity. The proposed amendments account for the issues stated above, help protect biodiversity, and ensure the return of the mined site back to its most natural state possible, consequently benefiting societal stakeholders in the region.

METHODS

Study Area

The study area for this project was Eastern Kentucky (Fig. 1), an area chosen primarily due to its geologic history, geographic location, and ecoregion. Coal in this region formed during the Carboniferous Period, between 360-299 million years ago (Kentucky Geological Survey 2023). Eastern Kentucky is rich in coal, primarily bituminous, that is characterized by moderate carbon content and potential heat energy. Bituminous coal is the most common form of coal mined in the United States and Kentucky (EIA 2022), which explains the large presence of mining in the region.

Eastern Kentucky lies in Ecoregion 69, the Central Appalachians Ecoregion, as designated by U.S. Environmental Protection Agency (EPA)(Fig. 2). Within Ecoregion 69, Ecoregions 69d and 69e were chosen as the areal extent in this study because of the similarity in topography, varying species diversity of the flora and fauna, and the prevalence of surface top mining within the regions.

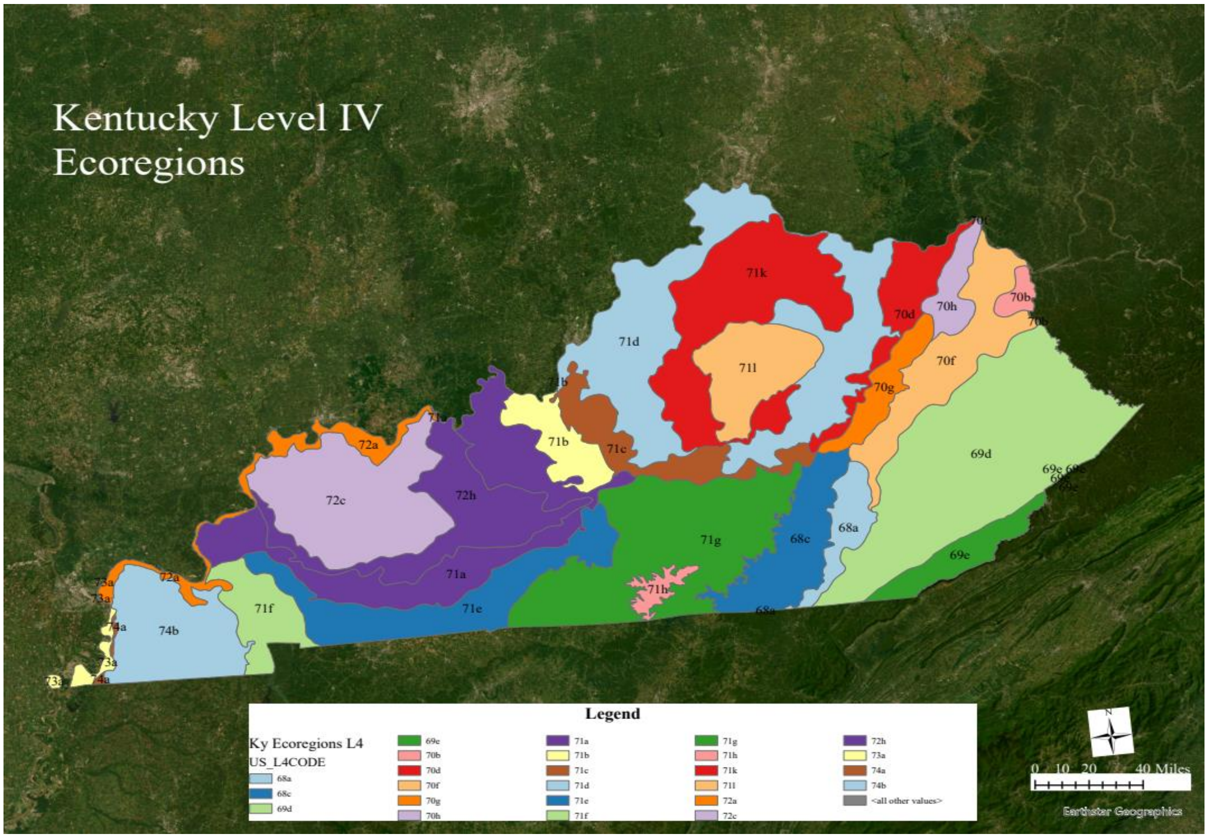

Figure 2. Level IV Ecoregions of Kentucky that show the study area for this project, 69d and 69e (EPA 2022).

Underlaid by shale, siltstone, and sandstone along with a high frequency of coal deposits, Ecoregion 69d, called the Dissected Appalachian Plateau, is characterized by narrow ridges and valleys, deep coves, and is extensively forested. Ecoregion 69e, called the Cumberland Mountain

Thrust Block, is characterized by high steep ridges, hills, and coves. It has the highest elevation in Kentucky and substantial topographic relief, giving rise to greater biodiversity in forest composition. While the underlying lithology is the same in 69d and 69e, the diversity in topography and habitat leads to a unique animal composition in relation to 69d, with less diverse fish populations in 69e. Both ecoregions have low nutrient and alkalinity levels (Woods et al. 2002).

Data Collection

To determine the extent to which mining impacts biodiversity within a defined region, the goal of the data collection and analysis was to compare percent of the area that was mined and the degree of biodiversity present within ecologically relevant boundaries. Publicly available datasets of surface mines, biodiversity, and land cover were analyzed in a Geographic Information System (GIS). Further statistical and graphical analyses then enabled the second set of goals, to determine differential impacts on terrestrial versus aquatic organisms and identify priority taxa subgroups that were especially impacted by mining. To accompany these results, a reclamation meta-analysis and interviews with government officials were conducted to determine the effectiveness of current reclamation policies. The quantitative analyses combined with the meta-analysis and interviews were used to identify potential intervention points that could serve to further improve the reclamation process such that biodiversity is better conserved, consequently enhancing benefits to society.

Percent Mined

Mine maps from the Kentucky Mine Mapping Information System (minemaps.ky.gov 2023) were overlain in ArcGIS Pro 10.3 to summarize data within ecologically relevant boundaries. Geospatial data were clipped by ecoregion (EPA 2022) and by subwatershed at the scale of the US Geological Survey Hydrologic Unit Code 12 (HUC12) resulting in 197 watersheds within the study area (USGS 2022). The geographic projection was North American Datum (NAD) 1983 (2011) StatePlane Kentucky FIPS 1600 (US Feet) projection. Watersheds clipped to the ecoregion boundaries resulted in edge artifacts in the dataset. Consequently, any watershed consisting of an area below 25km^2 was removed due to natural breaks in the data and inability to reliably compare the edge artifacts to full watersheds in the dataset. Surface mines were isolated from the entire dataset using the select by attribute and selecting for "S" under the Mine_Type column. All the surface mines isolated were either auger surface truck coal or surface truck coal. In some areas, mining companies came back to a previously mined-out area to extract more coal that was found further below ground. To avoid doubling the calculated mined-out area, overlapping boundaries of the mines were removed to create one large mine footprint. This was done using the pairwise union and dissolve tools, followed by a pairwise intersect tool within the HUC-12 watershed layer. This also effectively placed watershed boundaries over the mines such that any mine that crossed over a HUC-12 boundary was split between the two watersheds. Areas in km^2 were used to determine the percent of watershed occupied by surface mines by dividing the surface mine area by total watershed area to get percent mined of each watershed.

Biodiversity Data

In a similar process, latitude and longitude of species occurrence points from the Global Biodiversity Information Facility website (GBIF 2022) were imported into ArcGIS 10.3 using the add X,Y point data tool. The points were clipped to the ecoregions and HUC12 watersheds to summarize biodiversity data within the ecologically relevant boundaries using NAD 1983 (2011)

StatePlane Kentucky FIPS 1600 (US Feet) projection. This was followed by a pairwise intersection within the HUC12 watershed layer to confine the biodiversity metrics within ecologically relevant boundaries. The resulting attribute table from the intersection was then exported to Microsoft Excel.

In Microsoft Excel, a series of pivot tables were used to convert the species occurrence, or total number of observations in the dataset, to the desired diversity metric of species richness, or number of species, in each watershed. The species richness and percent mined value were paired by HUC12 ID, and duplicates were removed. Species richness was then plotted against percent mined using a stacked bar graph.

The taxonomic subgroups chosen for this study included Animalia, Plantae, Aves, Amphibia, Reptilia, Fish, Mammalia, Mollusca, Arthropoda, and Insecta. These subgroups were chosen to investigate if any groups were more negatively affected by mining than others such that they could be properly accounted for when proposing changes in reclamation practices. For example, arthropod density is sometimes used as a bioindicator of soil quality (Straalen and Verhoef 1997), which is why this group was included in the analysis of taxonomic subgroups. The same methods used to relate the full biodiversity data set and percent mined were used to relate these subgroups to the amount of surface top mining in each watershed.

Land Use Cover

Land cover data was downloaded from the National Land Cover Dataset (NLCD) (USGS 2019). In ArcGIS 10.3, the ecoregions, HUC-12 watersheds, and NLCD were reprojected into NAD 1983 State Plane to ensure similar area calculations. The layers were then overlain and clipped to each other. Tabulate area was run on the NLCD using the spatial analyst tool, calculating area in square feet. The resulting attribute table was exported to Microsoft Excel, where the units were converted from ft^2 to km^2. The land cover area was then divided by the total watershed area to yield the percent cover for all land cover classes within each watershed.

Statistical Analyses

Pearson Correlation tests were run in IBM SPSS version 28.0.0.0. Response variables included species richness of the full biodiversity dataset and the taxonomic subgroups, with the independent variables being percent mined and percent land cover in each NLCD class. The species richness was standardized on a per unit area basis (km^2) to address size differences between watersheds. Significance was evaluated at the alpha = 0.05 level of confidence, but values less than 0.1 were also considered due to the large and variable nature of the data set.

A stacked bar graph was used in graphical analysis for examining species richness in relation to percent mined in each watershed across five ranges (N=35) excluding watersheds with no mining that were separated into their own group (N=21). Ranges were determined by dividing the total amount of remaining watersheds in the dataset by five, after the removal of watersheds with no mining. The following taxa subgroups were examined: Animalia, Plantae, Aves, Amphibia, Reptilia, Fish, Mammalia, Mollusca, Arthropoda, and Insecta.

Reclamation Meta-Analysis and Interviews with Division of Abandoned Mined Lands

A meta-analysis of primary literature was compiled to summarize effectiveness of two reclamation options: Grassland Reclamation Approach and the Forestry Reclamation Approach. Interviews with the Kentucky Division of Abandoned Mined Lands (DAML) were conducted to investigate government policy, processes, and funding.

RESULTS

Impacts on Biodiversity and Reclamation Meta-Analysis

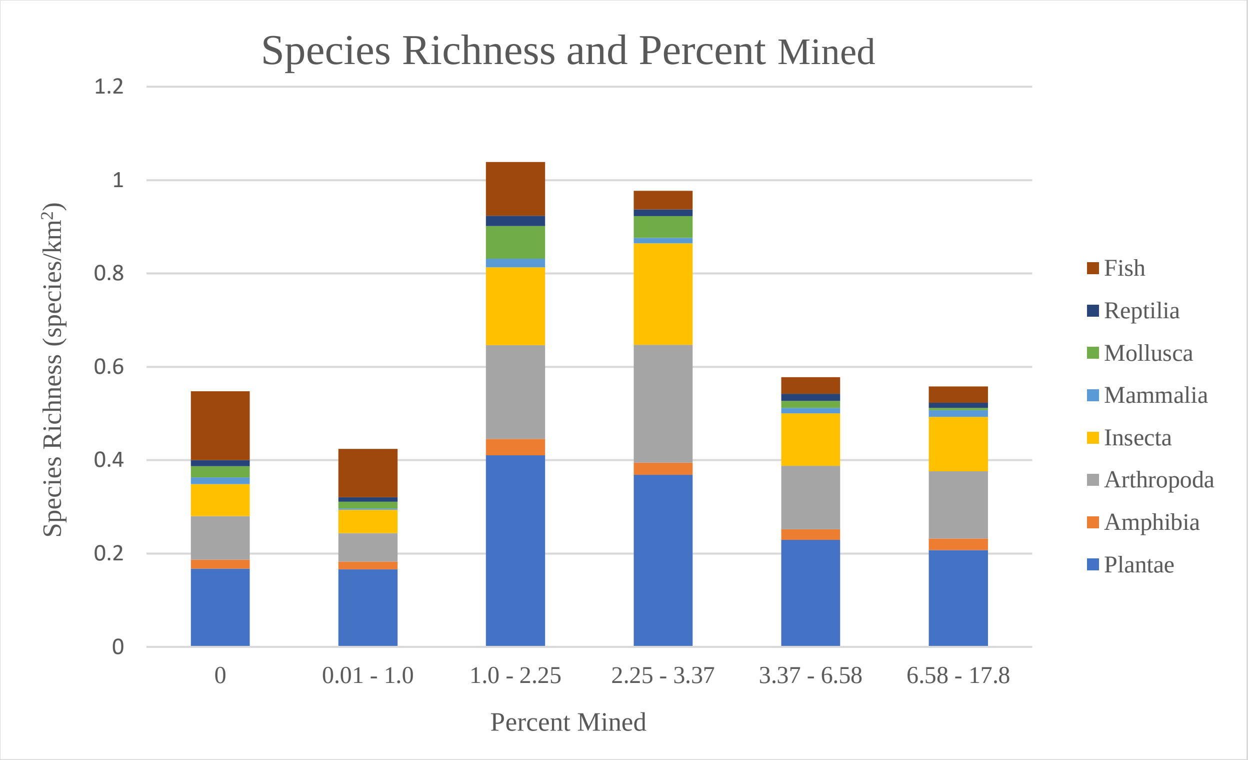

Figure 3. Relationship between species richness and percent mined within HUC12 watersheds showing differential impacts on various taxa subgroups (N =35 within each category). The first bar (N = 21) acts as a reference, representing an unmined landscape with resulting biodiversity.

All taxa subgroups showed a unimodal distribution in response to mining (Fig. 3). Whereas Amphibia maintained a relatively constant presence despite the increase in mining, a decline in species richness was observed at roughly three percent mined within a watershed for overall biodiversity and many of the subgroups, including Arthropoda and Insecta. Fish decreased in species richness more rapidly with increasing prevalence of mining in the watershed than other taxonomic groups (Fig. 3).

*Table 1. Selected significant Pearson correlations between percent mined, fish diversity, and various land cover variables. ($p < 0.05$ = **, $p < 0.10$ = *)*

Variable	**Percent Mined**	**Fish (richness/km^2)**	**Barren Land %**	**Deciduous Land %**	**Shrub/Scrub Land %**	**Herbaceous Land %**
Percent Mined	1	-0.208**	0.683**	-0.390**	0.643**	0.802**
Fish (richness/km^2)	-0.208**	1	-0.133	0.132	-0.198**	-0.176*
Barren Land %	0.683**	-0.133	1	-0.431**	0.383**	0.823**
Deciduous Land %	-0.390**	0.132	-0.431**	1	-0.357**	-0.490**
Shrub/Scrub Land %	0.643**	-0.198**	0.383**	0.357**	1	0.554**
Herbaceous Land %	0.802**	-0.176*	0.823**	-0.490**	0.554**	1

Significant correlations between biodiversity and percent mining in the watershed were observed for the Fish and Mollusca subgroups but not in the overall biodiversity or other subgroups (Table 2). Fish diversity significantly declined in the presence of surface top mining ($r = - 0.208$, $p = 0.003$). Mollusks were negatively impacted ($r = -0.140$, $p = 0.050$). The percent mined was also positively correlated with various types of land cover including herbaceous land cover ($r = 0.802$, $p = < 0.001$) and barren land cover (0.683, $p = <0.001$). A negative relationship between percent mined and deciduous forest land cover was observed ($r = -0.390$, $p = <0.001$).

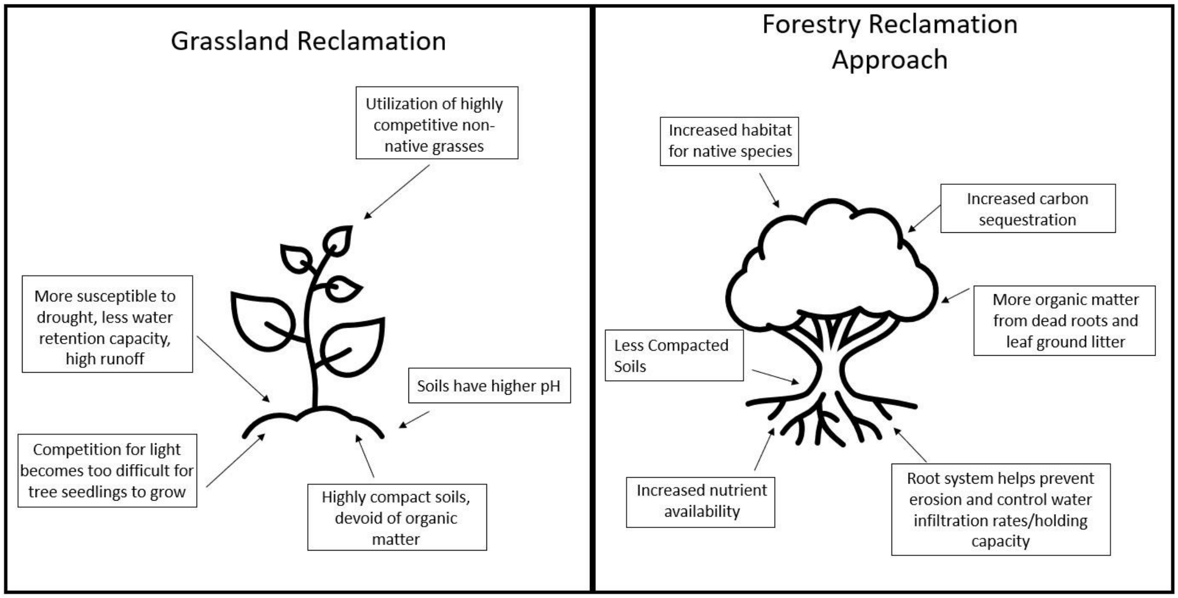

Figure 4. Differential environmental impacts of the grassland reclamation approach and Forestry Reclamation Approach (Franklin et al. 2012; Fox et al. 2020; Adams 2017; Bentham et al. 1992; Palmer et al. 2010)

Based on the literature reviewed for the meta-analysis, the differential impacts of the Forestry Reclamation Approach versus the grassland reclamation approach suggest that the FRA is substantially more ecologically beneficial and will create a better reclaimed environment that can foster the return of native biodiversity (Fig. 4). The Grassland Reclamation Approach utilizes highly competitive non-native species to initially colonize the site, which prevents native species from colonizing the area (Fig. 4). Invasive species are a well-known driver of biodiversity loss in general (Fagundez 2012), due to the highly competitive nature of these plants. Invasive plants dominate certain resources such as light availability and nutrient availability and have higher reproductive capabilities compared to native species. The Grassland Reclamation Approach method is also characterized by highly compact soils with less water retention capabilities (Fig. 4), leading to higher rates of runoff and increased risk of flooding. The soils also typically have a higher pH and are devoid of organic matter (Fig. 4), which impacts the native flora as some species, such as pines, are better equipped to thrive in slightly acidic soils.

The Forestry Reclamation Approach was created through collaboration among scientists, USDA, and OSMRE for the purpose of better reclamation of mine sites. This method utilizes native species for colonization, bringing added benefits of increased habitat for native fauna (Fig. 4). The use of native hardwoods and understory species provide better root systems that control erosion rates and maintain higher water infiltration rates (Fig. 4), thereby reducing water runoff rates and limiting flooding impacts of the magnitude in Eastern Kentucky in 2022. Due to the practices that must be utilized when enacting this approach (Adams et al. 2017), soils are typically less compact with more organic matter due to the presence of more leaf litter and dead roots (Fig. 4). Soils have higher nutrient availability as well (Fig. 4), which is beneficial to plant growth in general. For these reasons, the Forestry Reclamation Approach is more ecologically beneficial and creates a more suitable habitat for native biodiversity to return after mining has ceased.

Interviews with the Division of Abandoned Mined Lands for Kentucky

For Kentucky, all mining practices are enforced and monitored through the Kentucky Energy and Environment Cabinet (KEEC). Within the cabinet, under the Department of Natural Resources, there are four different divisions that deal with mining: Division of Mine Reclamation and Enforcement (DMRE), Division of Mine Permits, Division of Mine Safety, and Division of Abandoned Mine Lands (DAML). For the purposes of this research, both the DMRE and DAML are most applicable. In many states, the federal Office of Surface Mine Reclamation and Enforcement (OSMRE) oversees mine reclamation using the regulations and statutes laid out in SMCRA. However, Kentucky is a state that was granted primacy on May 18, 1982, allowing it to have its own independent regulatory authority (McGraw 1982). This gave the Kentucky state government the ability to create its own regulations for mining, including the amounts of bonds and permit processes (Fig. 5).

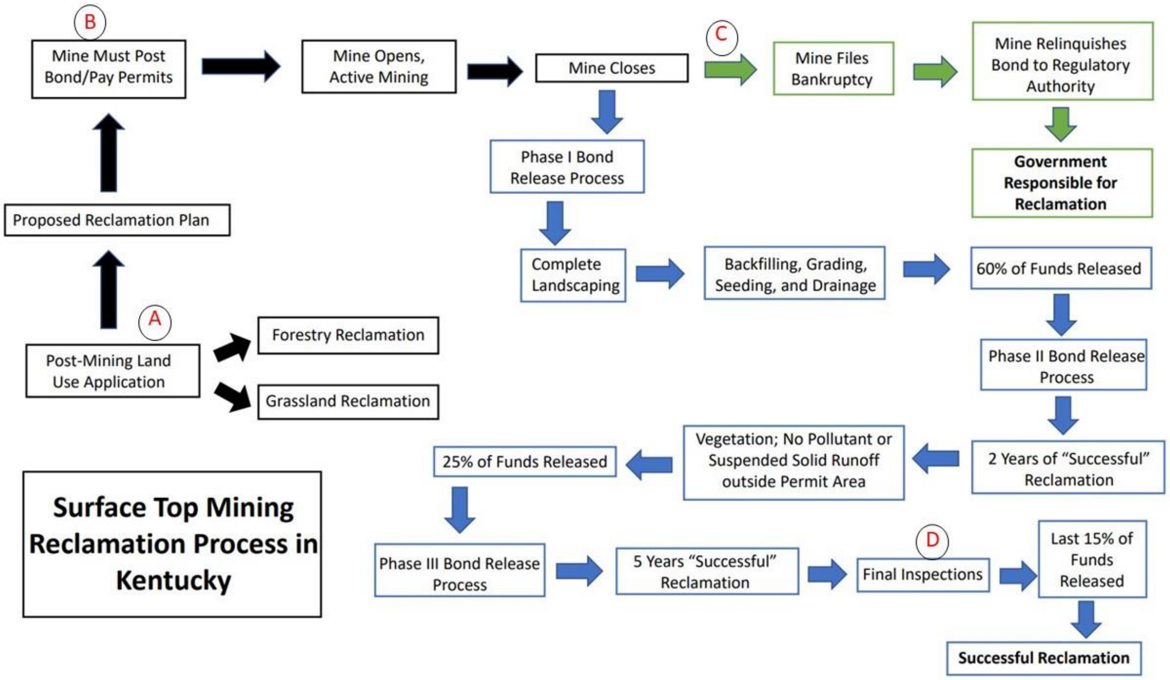

Figure 5. Process for reclamation pursuant to state level government statutes (KAR 405 10:040) with intervention points: A. creating a certain percentage of mines that must propose forestry reclamation as post-mining land use to support biodiversity, B. increase the amount that must be paid to reclamation gratuity fund and/or create new program to fund reintroduction efforts or further monitoring of animal diversity, C. create infrastructure in policy that holds mines accountable for reclamation and prevents filing for bankruptcy, D. have stricter enforcement of inspection regulations and/or monitor the return of animal diversity to the site

Figure 5 is a schematic outlining specific parts of the reclamation process pursuant to Kentucky statutes. Parts outlined in black refer to the pre-mining steps a mine must take before opening, including a post-mining land use application (KAR 405 016:210) and payment of all bonds (KAR 405 010:015), permits (KAR 405 008:030), and guaranty funding (KAR 405 010:070). After the mine closes, there are two potential avenues that a mine can take: filing for bankruptcy, outlined in green, or assuming responsibility for reclamation, outlined in blue. If a mine files for bankruptcy, the surety company holding the initial bond amount releases the bond back to the regulatory authority, the Kentucky state government (KAR 405 010:035), which then uses the fund for reclamation on the site. If a mine assumes responsibility for reclamation, there are three recognized phases of bond release that a mine must work through in order to receive the initial surety bond amount back (KAR 405 010:040). These steps include complete landscaping, vegetation, and final inspections.

Based on the information gained from the interviews, various issues such as reclamation funding and bankruptcy were identified as obstacles officials in the field are facing (T. Rader and L. Graham, pers. comm., 15 November 2022). Also, using the results from the meta-analysis and effects on biodiversity, various intervention points were identified to suggest ways that Kentucky could increase reclamation effectiveness (Fig. 5).

DAML oversees all mines considered “pre-law”, meaning all mines that went in before May 18, 1982 (T. Rader and L. Graham, pers. comm., 15 November 2022). This date is important because many of the mines that fall under the jurisdiction of DAML were created before SMCRA was passed by the legislature in 1977. The consequence is that many of these mines had little to no reclamation done on the site, which has drastic impacts on the surrounding environment. Funding for the DAML to do proper reclamation on a site that has been untouched for decades is also more difficult, as a result (T. Rader and L. Graham, pers. comm., 15 November 2022). DAML typically handles small scale mines that have forfeited their initial bonds or permits. DAML is also tasked with responding to citizen inquiries claiming that a problem with their property stems from a nearby mine. DAML will come out and investigate the inquired environmental issue, and if the issue stems from a nearby mine, DAML will then become responsible for fixing the issue (T. Rader and L. Graham, pers. comm., 15 November 2022). Within DAML, there are three groups. The role of the first group is to determine eligibility of citizen-based inquiries through mapping and site visits to the place of the inquiry to determine eligibility. If the issue on the property stems from a mine, the file gets passed to a different group that creates a remediation or treatment plan. Finally, the last group carries out the reclamation plan. There are several assistance programs that aid in the process, as well (T. Rader and L. Graham, pers. comm., 15 November 2022).

DMRE oversees “post-law" mining, also known as Title V mining. DMRE is responsible for typically large-scale surface mining operations and mines that file for bankruptcy. They utilize various regulations such as 405 KAR 16:200 Revegetation, 405 KAR 16:210 Post-Mining Land Use Capability, Reclamation Advisory Memorandum (RAM) #124, and Technical Reclamation Memoranda (TRM) #21 to outline and enforce proper reclamation of mines (E. Lawson, pers. comm., 15 November 2022). Mine bankruptcy and forfeiture are issues plaguing the system when it comes to proper reclamation (T. Rader and L. Graham, pers. comm., 15 November 2022). When a mine files for bankruptcy, DMRE can utilize the initial bond amount to fund reclamation (KAR 405 010:035).

DISCUSSION

Overall, biodiversity is being negatively affected by surface top mining in Eastern Kentucky, with aquatic organisms more detrimentally affected than terrestrial organisms. Effective reclamation policies such as the Forestry Reclamation Approach are not being sufficiently used such that both ecological and socio-economic issues are addressed. Reclamation policies are written under the assumption that if plant species can successfully colonize, animals will follow, which is supported by Castagneyrol and Jactel (2012). However, given the temporal aspect of rapid decline in ecosystem function following a loss in overall biodiversity (Cardinale et al. 2012), added steps might be necessary to ensure efficient return of animal diversity, as well, which could include reintroduction efforts.

The relationship between the amount of mining in a watershed and fish and mollusk biodiversity is likely due to aquatic organisms being confined to their habitat, whereas terrestrial organisms have motility to move through forests and away from the disturbed areas (Goss-Custard et al. 2006). Also, due to the nature of surface top mining, pollution and valley fill sites more directly affect aquatic organisms than terrestrial. For example, legacy mines have the potential to impact water quality within a watershed for years after reclamation has ceased, with detriments in particular to aquatic species through exposure to increased levels of selenium and strontium (Lindberg et al. 2014). For these reasons, it makes sense that fish would be more significantly affected by the mining in the region than other taxonomic groups. Similar reasoning can be applied to mollusks due to their dependence on aquatic ecosystems. Valley fill sites are permanent in that there is no possibility of reclamation after the site has been created. This extreme loss of habitat prevents organisms from adapting or forming resilience against future disturbances.

The results of this study support the idea that biodiversity increases up to a certain amount of disturbance (~ 3% mined), after which biodiversity decreases, and only certain taxa such as birds are able to maintain greater diversity. The mobile nature of birds could explain the decreased impacts felt by this taxon. For example, Goss-Custard et al. (2006) showed that disturbances cause bird movement away from the affected location. The unimodal trend in the taxonomic response of biodiversity to increasing prevalence of mining in the watershed could be explained by the Intermediate Disturbance Hypothesis (IDH) (Connell 1979). The hypothesis requires a repeated local disturbance that creates isolated “patches” where new species are able to colonize, creating a more mixed population. The IDH also requires that the disturbance be frequent enough that competitive exclusion does not occur and both colonizing species and climax species are present (Wilson 1994). Low levels of disturbance allow the competitive species to monopolize. However, if the disturbance were to occur too frequently, or too severely, species are not able to recolonize and coexist, leaving only resistant species. The process of surface top mining in Eastern Kentucky fits these parameters.

Two mechanisms associated with the IDH, between-patch and within-patch mechanisms, could be influencing the response of biodiversity to mining. The primary difference between these two mechanisms is that the former focuses on spatial relationships, whereas the latter is more temporal based. Between-patch mechanisms require disturbances that create “patches” in the landscape and a trade-off that allows competition between species to occur. Within-patch mechanisms state that the intermediate disturbance is felt by all organisms such that the only thing left to influence coexistence is the temporal variability in which organisms’ access and use resources (Roxburgh et al. 2004).

If done correctly, reclamation of these mines could create the conditions in which new species could colonize and thrive in early successional conditions, supporting both mechanisms of IDH. Surface top mining creates the patches, but certain reclamation methods inhibit the colonization of the native early successional species. For instance, the methods utilized in the grassland reclamation approach have been found to outcompete some of the native early successional species that are staples in Mesophytic Appalachian forests (Franklin et al. 2012). In highly disturbed areas, typically only early colonizing species adapted to rapid growth are able to colonize, giving rise to low species richness. Effective reclamation methods present an opportunity to create suitable habitats for native colonizing species that are typically outcompeted by non-natives or highly competitive species utilized to initially vegetate the site.

Disturbances affect many different aspects of an ecological community, including mortality rates, birth rates, and carrying capacity. Researchers found that a change in carrying capacity due to limitations in resource availability following a disturbance had overwhelming control over consequences on ecosystem function compared to disturbance caused changes in mortality and birth rates (Dornelas 2010). Regarding the IDH, models suggested that following increased mortality and decreased birth rates, carrying capacity can increase, which then correlates to an increase in total abundance and species richness. This could mean that a different factor, besides carrying capacity, is maintaining primary effects on biodiversity; or a mix of the mortality rates, birth rates, and changes in carrying capacity are working in tandem with each other. In the context of surface top mining, these external factors could include effects from pollution or soil compaction from mining and certain reclamation practices.

Another aspect of the data that must be mentioned is the nature of the biodiversity occurrence data. The Global Biodiversity Information Facility (GBIF) is a large collection of data that includes species occurrences with geolocations, among other information, and is the only publicly available data source for species occurrences on a scale that a project like this requires. GBIF is a global network of data holding institutions, such as nature research facilities and universities, that have agreed to a certain set of parameters upon which they can input their data (GBIF). Based the distribution of species occurrences, some discrepancies in the sampling of the data are apparent. Many of the species occurrence points were centered around the cities of Eastern Kentucky (Fig. 7). Many of the research facilities and universities lie around the cities, Cumberland for example, which causes a higher percentage of occurrences to be found around cities simply because that is where people are looking. Reaching the remote areas within the selected study area is more difficult, and fewer sampling studies are being done in these more remote regions. This is evident through both the distribution of the data (Fig. 7), the significant positive correlation between developed areas and biodiversity, and the negative correlation between biodiversity and deciduous forest cover (Appendix A). The negative correlation could only be explained through the fact that there is less sampling going on in those heavily forested areas, which leads to a lower representation of the biodiversity in those areas.

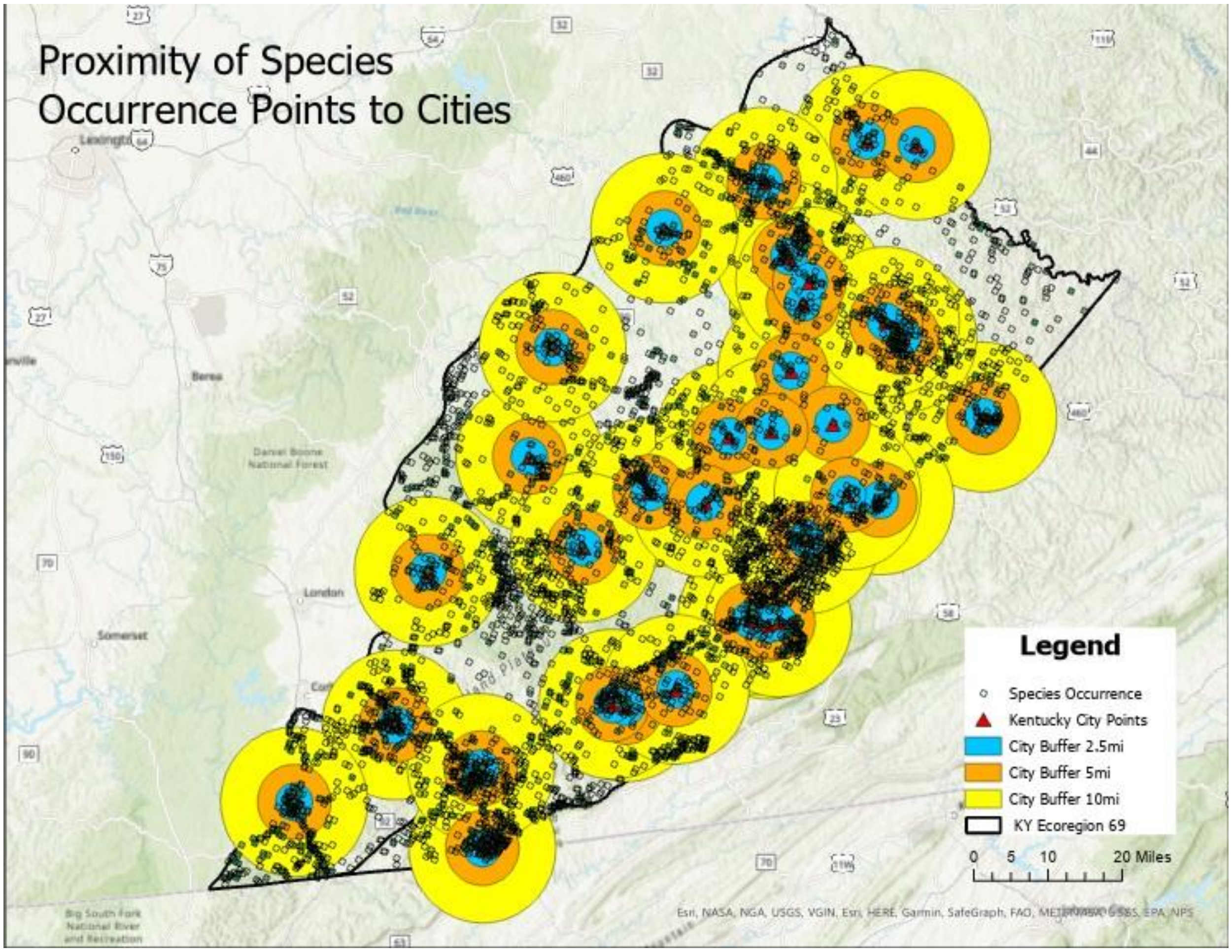

Figure 4. Proximity of biodiversity occurrence points to cities within the study area. Buffer regions around the city center extend to 10 mile diameters.

The only group that diverged from the overall patterns expressed by the data (e.g., positive correlations with increased development) was fish. This is further evidence that fish were not as affected by a geographic sampling bias. The full biodiversity data set had a significant positive correlation with open water, but the full biodiversity data set excluding Aves found no significant relationship. This could be explained by the fact that many bird species are considered aquatic, also made evident through the significant positive correlation between Aves and open water coverage (Appendix A). Nonetheless, despite these limitations to the dataset, the effect of mining on biodiversity is clear and largely unaffected by the sampling bias.

The Forestry Reclamation Approach has been proven to be more effective in maintaining and restoring biodiversity on mined lands than the Grassland Reclamation Approach (Adams et al. 2017; Angel et al. 2005), but the analysis of land cover data in this study supports the conclusion that improper reclamation is being utilized in the region. The extent of mining in the watershed and herbaceous, shrub/scrub, and barren land cover were positively correlated, suggesting that the grassland reclamation approach is more prevalent in Eastern Kentucky. The significant relationship between mining and deforestation also supports the argument that there is improper reclamation being utilized in the region. If the forestry reclamation approach were being utilized on the scale that this study proposes, the deciduous land cover/mixed forests correlations would be less significant.

Mixed forests were positively correlated with most of the biodiversity groups. Mixed forests consist of coniferous and deciduous trees in the eastern portion of the United States, typically located at higher elevations. Biodiversity is expected to increase in correlation with deciduous forests, but the opposite was observed in this study. There are multiple different explanations for why mixed forests show an increase in biodiversity. One example could be that there have been more studies and therefore higher sampling density in higher elevations just as a focal point for studies in the region due to the unique mountainous terrain. This would inadvertently cause there to be higher percentages of biodiversity in the higher elevations as opposed to the lower. This explanation is confounded by the distribution of the data (Fig. 7). Besides being clustered around city centers and universities, many points are located along park boundaries or geographic boundaries of particular interest. For example, there are clusters of data at the border between the Cumberland thrust block and surrounding lowland areas, along the higher elevation border.

If effectively implemented, reclamation has the potential to reduce the negative consequences that come with a loss in biodiversity. Current policies regarding the utilization of the forestry reclamation approach are in general sufficiently written. They effectively outline what constitutes a conducive environment for bringing back mixed mesophytic forests, but also the practices that should be utilized to receive such outcomes (Adams et al. 2017). Despite effective policies, the current reclamation practices actively being utilized on these mines do not meet these standards. Instead, the more commonly applied grassland reclamation approach contributes to biodiversity loss using highly competitive non-native grasses and through the deterioration of soil conditions. As previously discussed, at higher elevations, plant diversity tends to become more heavily influenced by competitive exclusion and niche partitioning (Bryant et al. 2008). The grassland reclamation approach completely overpowers natural competitive relationships that drive native successional patterns and community structure, leading to a monoculture of invasive grasses that inhibit the colonization of native plant communities. In contrast, the Forestry Reclamation Approach attempts to create the conditions that foster a natural successional process for the region, allowing return of native colonizing species that transition to a native climax community comprised of mainly late successional species.

Policy Recommendations and Intervention Points

There are three points regarding policy change that could have a positive impact on ecosystem resiliency and biodiversity recovery: amending federal policies such as the Surface Mining Control and Reclamation Act (SMCRA) and the Clean Water Act (CWA), amending state-level laws, and adding more specific reclamation criterion under the Forestry Reclamation Approach. Regarding feasibility, amending federal laws as substantive as SMCRA and CWA would take too long and receive far too much resistance politically to achieve any real progress. Due to the aforementioned sense of urgency regarding these amendments, both in terms of conserving biodiversity and managing the future of a dying industry, this proposal will address state-level regulations and statutes.

When considering how to change current reclamation policies, two perspectives must be considered: 1) what can be done pre-mining to make reclamation easier when the time comes and 2) what can be done during the reclamation process to provide the best results. For example, mine companies are required to preemptively save the topsoil portion of the overburden to make reclamation easier (KAR 405 016:050). Topsoil typically has much better organic matter levels and has better water retention capabilities (Sheoran et al. 2010). The topsoil layer typically is not saved to avoid additional expense and is instead combined in valley fill sites with the rest of the overburden. Further, even if this topsoil is saved pre-mining, it sits for sometimes years while the mine is active. During this time, the topsoil loses organic matter and becomes nutritionally deficient (Kundu and Ghose, 1997). To alleviate the loss of organic matter, the topsoil would have to continually be treated while sitting. While pre-mining actions are important, post-mining policy amendments may have broader effects due to existing mines that have been abandoned or undergone improper reclamation.

The observation that many of these statutes are effectively written but the resulting reclamation efforts are not producing the necessary results to foster a return to a healthy ecosystem point to shortfalls of implementation and oversight. Based on the regulations, the post-mining land use must be approved by the cabinet. Despite requiring prior land use approval, there are no requirements for any certain number of mines to return the land to forests as a proactive step towards biodiversity conservation. Policies also do not require the monitoring of the return of animal species, nor mention reintroduction efforts that could expedite the process. Creating a specified number of mines that must be reclaimed as forestry utilizing the FRA could foster the conditions under which natural succession can occur and biodiversity can be introduced (Fig. 5A). Of course, this would also require strict enforcement until completion to ensure that the benefits of implementing this system would be felt by the region.

Mines could be selected to use the Forestry Reclamation Approach through either a lottery system or based on funds available from the mine. Small scale mines typically do not have the monetary resources to complete more costly methods of reclamation, so they utilize approaches such as the grassland reclamation approach. Forcing mines to complete costly reclamation practices could force them to file for bankruptcy, which would only further the stress placed on state resources. Another important aspect to consider when determining which mines should use the Forestry Reclamation Approach is the native diversity of the permit area and how much surface top mining is occurring nearby. Using the results of this study, watersheds could be ranked based on the amount of biodiversity and amount of surface top mining consequently showing which areas would most benefit from the Forestry Reclamation Approach such that biodiversity restoration can occur in the areas most severely impacted.

The next intervention point comes when a mine must post reclamation bonds (Fig. 5B). If approved for forestry post-mining land use, the regulations that outline that process for reclamation are written thoroughly and effectively. However, they do not mention the introduction of any species besides plants, nor do they monitor the return of species other than plants during their observation periods after initial reclamation efforts are completed. As previously mentioned, mines also must pay into the Reclamation Guaranty Fund, which is large pool that the government utilizes to reclaim mines that have filed for bankruptcy thereby relinquishing responsibility for reclamation. A new fund could be created that covers a multitude of extra expenditures that would hasten the return of native fauna. These funds could support the reintroduction of specific early successional animal species to accelerate the return of animal diversity. For example, reintroduction efforts of elk have been attempted in the Great Smoky Mountains National Park (NPS 2015) and have largely been successful. Elk populations were decimated in the region due to over-hunting, leading various conservation groups to be concerned about the possibility of extinction for the species entirely. Elk have a direct impact on vegetation through herbivory and seed dispersal, while also acting as prey for larger predators and carrion for other species (USDA 2021). Funding could also pay for longer periods of monitoring that account for the return of native fauna (Fig. 5D). These added methods that account for non-plant biodiversity could enhance the overall ecosystem function of the area and enhance the definition of “successful” reclamation. Further research would be required to determine which native species would be most beneficial in terms of reintroduction efforts.

An increase in the surety bond amount and the amount that must be paid into the Reclamation Guaranty Fund would further promote more comprehensive reclamation. The surety bond acts as insurance policy that allows mines to receive money back in phases during the reclamation process (KAR 405 010:015). Like many insurance policies, these amounts range based on the payment and reclamation history of the mine. Frequently, the bond amounts are too little to cover the cost of reclamation should the mine file for bankruptcy (T. Rader and L. Graham, pers. comm., 15 November 2022). They are also insufficient to where the mine would rather forego getting that money back, as opposed to completing reclamation. Raising this surety bond amount for all mines would make it harder for them to file bankruptcy and lose that money completely. Further, if bankruptcy is still filed, the government has more funds to implement better reclamation methods as opposed to being forced to go with the quickest and cheapest option, grassland reclamation.

A common issue throughout this project is the common practice of mine bankruptcy (T. Rader and L. Graham, pers. comm., 15 November 2022; Mistich 2022; Bruggers 2022), which leads to another point of intervention (Fig. 5C). Currently, there are little to no deterrents to prevent a mine from filing for bankruptcy and only structures in place outlining the process after which a mine does file for bankruptcy and how that must be done (KAR 405 010:050). Adding disincentives to bankruptcy would be difficult to implement due to the politicized nature of the issue. More research would be needed to determine what the anti-bankruptcy legislation would like and its anticipated impacts on the economy and industry as whole. Even so, stricter background checks on mines during the permitting and bonding process could help filter out mines that have a higher likely-hood of filing, thereby decreasing the chances of bankruptcy. Or creating more stringent fiscal checks on how mines plan to pay for everything along with frequent fiscal reports to ensure the mines are maintaining the money that must be utilized for reclamation.

Finally, based on the anticipated positive benefits one would expect from the utilization of the Forestry Reclamation Approach from the literature (Adams et al. 2017; Angel et al. 2015; Williamson and Barton 2020) and the effectiveness of policy written for forestry reclamation (Adams et al. 2017; KAR 405 016:200), lack of enforcement could be a potential issue leading to the adverse effects seen in biodiversity, correlations in various land use, and the flooding of Eastern Kentucky. More stringent final inspections could be beneficial in ensuring the mine is actually successfully reclaimed (Fig. 5D). Also with this step, the definition of "successful" reclamation should be altered such that it includes the return of native animal diversity, as well (Fig. 5D). This could be achieved through extended monitoring time of the mine to ensure animal diversity is returning in such a way that is natural to the native successional patterns. Another benefit that would come from extending monitoring time of the mine is that it would ensure no pollutant runoff stemming from damage caused to the initial infrastructure put in by the mine from either acid mine drainage or natural causes.

Based on the interviews with officials from the Division of Abandoned Mined Lands, funding and staffing are clear issues for reclamation efforts (T. Rader and L. Graham, pers. comm., 15 November 2022). However, as a part of the bipartisan Infrastructure Investment and Jobs Act passed by Congress in 2021 during the Biden Administration, DAML will receive roughly $75 million in funding to use for reclamation and funding of various programs (Rogers 2022). This, in combination with increasing funding from implementing various interventions (Fig. 5), would enhance the ability of the Kentucky state government to conduct effective reclamation practices to better biodiversity conservation in Appalachia.

Along with amending current reclamation practices and policies, biodiversity offsets should be considered to help fund reclamation. Biodiversity offsets are “measurable conservation outcomes resulting from actions designed to compensate for residual adverse impacts on biodiversity arising from project development, accordance with the mitigation hierarchy” (Githiru et al. 2015). The idea behind biodiversity offsets is that no development project, in this case a mining project, can fully eliminate biodiversity impacts/loss, so these offsets will provide a way to compensate for those losses. Offsets can come in a variety of different forms. Girthiru et al. (2015) explored the monetary form of offsets where companies would pay a fee that covers the monetary amount lost through biodiversity loss and various ecosystem services. Costanza et al. (1997) estimated that the global revenue created from ecosystem services is roughly $33 trillion per year (Costanza et al. 1997), so the potential for money to be made through these offsets is clear. However, issues could arise through placing a monetary value on various ecosystem services, and how that amount is being calculated. Despite this, placing monetary offsets on mining practices could create funding for better reclamation practices that the mines or the government could use. There are some issues associated with enacting biodiversity offsets regarding corruption and improper implementation (Girthiru et al. 2015), but should proper safeguards be enacted, biodiversity offsets can be useful in funding further reclamation sites.

This study showed that aquatic diversity is more detrimentally affected than terrestrial, and as such, minimizing impacts to aquatic ecosystems should be better accounted for during the reclamation process, but valley fill sites destroy headwater streams (Williamson and Barton, 2020; EPA 2010). When an environment is completely buried by up to 250m of overburden (Ross et al. 2016), reclamation or rehabilitation can no longer occur. However, something that could be done is a form of offset where the mine could reclaim adversely affected aquatic ecosystems in other places. This might not influence aquatic biodiversity at the specific mine site, but it would better biodiversity for the region in general. For example, if a mine destroyed 3km of headwater streams from the valley fill process, they could be forced to reclaim 3km of streams somewhere else where reclamation and rehabilitation is possible. This method has the potential to positively impact aquatic diversity in the region as a whole.

As previously mentioned, the Grassland Reclamation Approach is the easier and cheaper method compared to Forestry Reclamation. Based on this lower cost and the sheer number of mines that need to be reclaimed, the grassland reclamation approach almost seems like the only viable option as it does help with certain aspects such as erosion control. However, the biodiversity and natural beauty of the region bolster the society that lives there. In a region whose economy relies drastically on industry or has been monopolized by the extraction of natural resources, bringing in alternative industries to boost the economy is difficult. The region instead could utilize the vast natural areas and immense potential for biodiversity to increase ecotourism as another industry to help the economy. Eastern Kentucky is largely undeveloped in terms of infrastructure compared to other areas of Kentucky and the country. Many natural areas remain in-tact, and the FRA can be utilized to bolster the regions that have been negatively impacted by surface mines. Despite the added upfront cost, the benefits reaped from increasing the amount of FRA utilization in the region, along with adding more recreational infrastructure, have the potential to increase profit in the region while also reducing flood risk and other negative environmental consequences.

Ecotourism is generally considered a positive method to stimulating local economies while also conservating natural areas (Taylor et al. 2003). However, there are several aspects that must be considered in order to ensure that the economic profit of the industry goes to local residents to minimize negative consequences. Private companies and third party organizations only serve to divert revenue generated from the industry away from the stakeholders in the region (Taylor et al. 2003; Bookbinder et al. 1998). This, in combination with the added development of the area in the forms of hotels and other tourist-related infrastructure, could impact biodiversity, just in a different form than the previous extractive industries. However, in other areas of Kentucky, ecotourism has played an important role. For example, Mammoth Cave National Park near Bowling Green, Kentucky, has created many positive impacts for local communities and local economies. Visitors to Mammoth Cave National Park spent roughly $47 million in nearby communities, creating and supporting hundreds of jobs, and benefiting the local economy by roughly $60 million in 2021 alone (NPS 2022). However, much of the revenue generated came from the lodging and restaurants sectors (NPS 2022), which are issues highlighted by Taylor et al. (2003) and Bookbinder et al. (1998). This represents a delicate trade-off between stimulating local economies through ecotourism, which could increase the standard of living, while also maintaining protected natural areas, with the added detriments brought on by increased development in the surrounding area.

Given the historical disenfranchisement of Appalachian stakeholders previously discussed (e.g., Evans and Freeman 2016), integrating stakeholders into the conversation on conserving biodiversity in the region, and what methods should be implemented to achieve such a goal, is paramount. Altering reclamation practices, permitting, and bonding processes in Kentucky could have negative consequences for the mining industry in general (T. Rader and L. Graham, pers. comm., 15 November 2022), which would further exacerbate issues with healthcare and job security. Presenting alternatives such as ecotourism that have the potential to stimulate local economies and livelihoods while also preserving biodiversity might open the region up to change. More research is needed to model the potential impacts of implementing various intervention points, along with estimates of potential revenue generated from ecotourism before any physical action is taken.

The goal of these recommendations is to provide a framework that is both environmentally and economically feasible. The best-case scenario is one that allows natural succession to occur, potentially at an accelerated rate, such that a minimal amount of money is required to achieve proper reclamation while maintaining minimal concessions to the environment. As previously mentioned, funding is a primary consideration for the entities tasked with reclamation, so allowing a natural succession to unfold after initial reclamation will be the most cost-effective outcome, provided the implementation plan was supported by the stakeholders of the region.

CONCLUSION

Surface top mining has a vast array of impacts on the society and environment in Eastern Kentucky. Despite the benefits brought to the economy and job opportunities, there is a loss of culturally valuable environmental relationships (Pudup 1990), along with several adverse health effects such as Black Lung disease (Castranova and Vallyathan 2000). Environmental consequences include added pollution and extreme habitat change (Ross et al. 2016), and soils lacking proper hydrology (Gyawali et al. 2022) and nutrient content (Asensio et al. 2011; Sheoran et al. 2010; Gaiero et al. 2013). Given the historical disenfranchisement of Appalachian stakeholders (Evans and Freeman 2016), there is much to be done to better protect the region from these negative impacts. Biodiversity plays a key role in how humans interact with and benefit from the environment (Cardinale et al. 2012; Costanza et al. 2017; Millennium Ecosystem Assessment 2005). As such, it should be properly tended to after mining ceases.

Reclamation has the potential to mitigate these negative impacts should it be done so quickly and efficiently. Impediments to effective reclamation include issues with bankruptcy and forfeiture (T. Rader and L. Graham, pers. comm., 15 November 2022) and ineffective methods being utilized such as the grassland reclamation approach (Pericak et al. 2018).

Biodiversity is being negatively affected in Eastern Kentucky by surface top mining at a large scale. Further, aquatic diversity is being more detrimentally affected than terrestrial. Correlations between percent mined and various land cover types indicate a dominant use of the grassland reclamation approach as a primary method of reclamation in the region despite the associated negative impacts to the environment. Interviews with the division of abandoned mined lands identified various obstacles to reclamation (T. Rader and L. Graham, pers. comm., 15 November 2022), which must be addressed when considering how to better Kentucky reclamation practices to better biodiversity conservation. Based on the quantitative and qualitative analysis of this study, various intervention points were identified for how to better reclamation practices in Kentucky, along with identifying various programs that if implemented, could either fund better reclamation or better conserve biodiversity in the region. However, more research is needed to model the anticipated effects of these proposed changes on the economy, industry, biodiversity, and stakeholders in the region.

Future Research

Studying how mortality rates, birth rates, and carrying capacity change following a disturbance can be important in determining how biodiversity will change in response to stresses in the environment (Dornelas 2010). Determining the effects of surface top mining on these specific factors could help predict how biodiversity will respond in future scenarios, and to what magnitude the decline could be. Based on that, adequate conservation methods can be utilized to counteract the potential losses. Next steps would be to enact these policies and track the results on biodiversity. The issue that enacting new policy would face is that biodiversity takes years to regenerate, the native flora and fauna need time to revegetate following the intense amount of environmental degradation. The time it would take to do field studies on multiple sites using the proposed reclamation changes would take years to complete. The issue of improper reclamation and lasting effects of surface top mining is having negative effects at present and needs active attention. However, before enacting any policy recommendations, an economic analysis of the grassland reclamation approach versus the Forestry Reclamation Approach should be conducted such that the implementation of the FRA as a primary method of reclamation is feasible for the government and mining corporations. Analysis of other variables, such as change in elevation, invasive species, habitat fragmentation, and pollution, in conjunction with the amount of mining could inform the relationships between biodiversity taxa subgroups and percent mined.

Biodiversity plays a crucial role in the way that people rely on and interact with the environment. It creates an environment that provides important recreational relationships such as hunting and fishing (Todd et al. 2010, Li et al. 2018), while also providing society with things such as clean air and clean water (Millennium Ecosystem Assessment 2005). The Appalachian mountain range is one of the most biodiverse areas in the world and is home to hundreds of endangered and endemic species (Woodward 2012). As such, it provides the people of Appalachia unique benefits and native cultural traditions such as harvesting ginseng. Understanding the impacts of surface top mining and current reclamation practices on biodiversity in Eastern Kentucky can better inform biodiversity conservation efforts in the region and maintain beneficial relationships between nature and society.

REFERENCES

Adams, Mary Beth, ed. 2017. The Forestry Reclamation Approach: guide to successful reforestation of mined lands. Gen. Tech. Rep. NRS-169. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 128 p. https://doi.org/10.2737/NRSGTR-169.

Angel, P; Davis, V; Burger, J; Graves, D; Zipper, C. 2017. Chapter 1: The Appalachian regional reforestation initiative. In: Adams, Mary Beth, ed. The Forestry Reclamation Approach: guide to successful reforestation of mined lands. Gen. Tech. Rep. NRS-169. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 1-1 1-4.

Asensio V., Vega FA., Andrade-Couce ML., Covelo E. 2011. Tree vegetation to improve physico-chemical properties in bare mine soils. Fresenius Environmental Bulletin. 20(12):3295-3303.

Cardinale BJ., Duffy JE., Gonzalez A., Hooper D., Perrings C., Venail P., Narwani A., Mace G., Tilman D., Wardle D., Kinzig A., Daily G., Loreau M., Grace J., Larigauderie A., Srivastava D., Naeem S. 2012. Biodiversity Loss and its impact on humanity. Nature. 486: 59–67 doi:10.1038/nature11148.

Reyers B., Polasky S., Tallis H., Mooney HA., Larigauderie A. 2012. Finding Common Ground for Biodiversity and Ecosystem Services. BioScience, 62(5): 503–507 Doi: 10.1525/bio.2012.62.5.12

Belcik M., Lenda M., Amano T., Skora P. 2020. “Different Response of the Taxonomic, Phylogenetic, and Functional Diversity of Birds to Forest Fragmentation.” Scientific Reports. 10(1).

Bentham H., Harris JA, Birch P, Short KC. 1992. Habitat Classification and Soil Restoration Assessment Using Analysis of Soil Microbiological and Physico-chemical Characteristics. J Appl Ecol. 29(3):711–718. doi: 10.2307/2404480

Beyfuss R. 1999. American Ginseng Production in Woodlots. Lincoln, Nebraska: National Agroforestry Center. https://digitalcommons.unl.edu/agroforestnotes/14/.

Bookbinder MP., Dinerstein E., Rijal A., Cauley H., Rajouria A. 19981. Ecotourism's Support of Biodiversity Conservation. Conservation Biology. 12(6): 1399–1404. http://www.jstor.org/stable/2989859

Boudou, A., Ribeyre, F. 1997. Aquatic Ecotoxicology: From the Ecosystem to the Cellular and Molecular Levels. Environmental Health Perspectives. 105: 21–35. https://doi.org/10.2307/3433395

Bruggers BJ. "Out of control": Sinking coal industry swamps Kentucky with "zombie" mine violations. The Courier-Journal. [accessed 2022 Dec 1]. https://www.courier-journal.com/story/news/local/2022/04/18/sagging-coal-industrys-zombie-mine-violations-swamp-kentucky-agency/7341572001/.

Bruggers BJ. 2022. Strip mining aided deadly Kentucky flooding, ex-regulators say. They want an investigation. The Courier-Journal. https://www.courier-journal.com/story/news/local/2022/08/08/strip-mining-contributed-to-deadly-kentucky-flooding-ex-regulators-say/65394273007/.

Bruggers BJ. How coal companies walked away from their "absolutely massive" environmental catastrophes. The Courier-Journal. [accessed 2022 Dec 1]. https://www.courier-journal.com/story/money/2022/01/05/legacy-coal-absolutely-massive-environmental-catastrophe/6420523001/.

Bryant, J. A., Lamanna, C., Morlon, H., Kerkhoff, A. J., Enquist, B. J., & Green, J. L. (2008). Microbes on Mountainsides: Contrasting Elevational Patterns of Bacterial and Plant Diversity. *Proceedings of the National Academy of Sciences of the United States of America, 105,* 11505–11511. http://www.jstor.org/stable/25463370

Cardinale BJ., Matulich K., Hooper D., Byrnes J., Duffy E., Gamfeldt L., Balvanera P., O'Connor M., Gonzalez A. 2011. The functional role of producer diversity in ecosystems. Am. J. Bot. 98:572–592. doi: 10.3732/ajb.1000364

Castagneyrol, B., Jactel, H. 2012. Unraveling plant—animal diversity relationships: a meta-regression analysis. Ecology. 93(9): 2115–2124. http://www.jstor.org/stable/41739269

Castranova, V., Vallyathan, V. 2000. Silicosis and Coal Workers' Pneumoconiosis. Environmental Health Perspectives. 108: 675–684. https://doi.org/10.2307/3454404

Cataldo DA, Wildung RE. 1978. Soil and Plant Factors Influencing the Accumulation of Heavy Metals by Plants. Environ Health Perspect. 27:149–159. doi: 10.2307/3428874

Chakravarty, S., K., S., P., C., N., A., & Shukl, G. 2012. Deforestation: Causes, Effects and Control Strategies. Global Perspectives on Sustainable Forest Management. https://doi.org/10.5772/33342.

Coal explained - U.S. Energy Information Administration (EIA). wwweiagov. https://www.eia.gov/energyexplained/coal/#:~:text=Coal%20is%20classified%20into%20four.

Connell JH. 1979. Intermediate-Disturbance Hypothesis. Science. 204(4399):1345–1345. doi:https://doi.org/10.1126/science.204.4399.1345.

Costanza, R., d'Arge R., de Groot R., Farber S., Grasso M., Hannon B., Limburg K., Naeem S., O'Neill R., Paruelo J., Raskin R., Sutton P., Van Den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature. 387: 253–260. https://doi.org/10.1038/387253a0

Dykeman W. 2019. Appalachian Mountains - Geology. In: Encyclopædia Britannica. https://www.britannica.com/place/Appalachian-Mountains/Geology.

Dornelas, M. 2010. Disturbance and change in biodiversity. Philosophical Transactions: Biological Sciences. 365(1558): 3719–3727. http://www.jstor.org/stable/20789185

Economo, E.P., Narula N., Friedman N.R. Weiser M., Guenard B. 2018. Macroecology and macroevolution of the latitudinal diversity gradient in ants. Nat Commun. 9:1778. https://doi.org/10.1038/s41467-018-04218-4

Elk Country. 2021 Jun 22. Biological and Physical Resources. [accessed 2023 Apr 30]. https://www.fs.usda.gov/biology/wildlife/elk

Elk. 2015 Jul 15. Great Smoky Mountains. [accessed 2023 Apr 30]. https://www.nps.gov/grsm/learn/nature/elk

Evans MC, Freeman J. (Directors). (2016). *Blood on the Mountain* [Film]. Virgil Films.

Fox J., Campbell J., Acton P. 2020. Carbon Sequestration by Reforesting Legacy Grasslands on Coal Mining Sites. Energies. 13(23): 6340.

Franklin J, Zipper C, Burger J, Skousen J, Jacobs D. 2012. Influence of herbaceous ground cover on forest restoration of eastern US coal surface mines. New For. 43:905-924. doi:10.1007/s11056-012-9342-8

Gaiero, JR., McCall CA., Thompson KA., Day NJ., Best AS., Dunfield KE. 2013. Inside the root microbiome: Bacterial root endophytes and plant growth promotion. American Journal of Botany. 100(9):1738–1750. http://www.jstor.org/stable/23596206

Geng S., Shi P., Song M., Zong N., Zu J., Zhu W. 2019. Diversity of vegetation composition enhances ecosystem stability along elevational gradients in the Taihang Mountains, China. Ecological Indicators. 104: 594– 603 doi:10.1016/j.ecolind.2019.05.038.

Geology of Rocky Mountain National Park. U.S. Geological Survey. https://www.usgs.gov/geology-and-ecology-of-national-parks/geology-rocky-mountain-national-park

Gerson JR. et al. 2020. Mercury and Selenium Loading in Mountaintop Mining Impacted Alkaline Streams and Riparian Food Webs. Biogeochemistry. 150(1): 109–122.

Gerwing TG, Hawkes VC., Gann GD., Murphy SD. 2021. Restoration, reclamation, and rehabilitation: On the need for, and positing a definition of, ecological reclamation. Restoration Ecology. doi:10.1111/rec.13461.

Githiru M, King MW, Bauche P, Simon C, Boles J, Rindt C, Victurine R. 2015. Should biodiversity offsets help finance underfunded Protected Areas? Biological Conservation. 191:819–826. doi:https://doi.org/10.1016/j.biocon.2015.07.033.

Greenberg CH., McLeod DE., Loftis DL. 1997. An Old-Growth Definition for Western and Mixed Mesophytic Forests. Gen. Tech. Rep. SRS-16. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 21 p.

Goss-Custard JD, Triplet P, Sueur F, West AD. 2006. Critical thresholds of disturbance by people and raptors in foraging wading birds. Biological Conservation. 127(1):88–97. doi.org/10.1016/j.biocon.2005.07.015.

Gyawali B, Shrestha S, Bhatta A, Pokhrel B, Cristan R, Antonious G, Banerjee S, Paudel KP. 2022. Assessing the Effect of Land-Use and Land-Cover Changes on Discharge and Sediment Yield in a Rural Coal-Mine Dominated Watershed in Kentucky, USA. Water. 14(4):516. https://doi.org/10.3390/w14040516

Harfoot MBJ., Tittensor D., Knight S., Arnell A., Blyth S., Brooks S., Butchart S., Hutton J., Jones M., Kapos V., Scharlemann J., Burgess N. 2018. Present and Future Biodiversity Risks from Fossil Fuel Exploitation." Conservation Letters. 11(4): 1.

Hedman CW., van Lear DH. 1995. Vegetative Structure and Composition of Southern Appalachian Riparian Forests. Bulletin of the Torrey Botanical Club. 122(2): 134–144. https://doi.org/10.2307/2996452

Hennen J. 2008. Introduction to the New Edition In: Harlan Miners Speak: Report on Terrorism in the Kentucky Coal Fields Prepared by Members of the National Committee for the Defense of Political Prisoners. The University Press of Kentucky. Accessed 5 May 2023. ISBN: 978-0-8131-9187-4

Fagúndez J. 2012. Heathlands Confronting Global Change: Drivers of Biodiversity Loss from past to future scenarios. Annals of Botany. 111:151–172 doi:10.1093/aob/mcs257.

Jenny H. 1941. Factors of soil formation. New York: Mcgraw-Hill Book Co.

Kentucky Energy and Environment Cabinet. (2022). Quarterly Coal Dashboard. Retrieved March 28, 2023, from https://eec.ky.gov/Energy/News-Publications/Pages/quarterly-coal-dashboard.aspx.

KENTUCKY RECLAMATION GUARANTY FUND 2020 STATE FISCAL YEAR ANNUAL REPORT. 2020. Frankfort, Kentucky: Kentucky Energy and Environment Cabinet. https://apps.legislature.ky.gov/CommitteeDocuments/262/12922/Nov%2018%202020%20KY%20Reclamation%20Guaranty%20Fund%202020%20State%20Fiscal%20Year%20Annual%20Report.pdf.

Kopple B. (Director). (1976). *Harlan County, USA* [Film]. Cabin Creek Films.

Korner C., Ohsawa M., … Watanabe T. (2005) Chapter 24: Mountains In: Millennium Ecosystem Assessment Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

Kundu Nk., Ghose MK. 1997. Shelf life of stock-piled topsoil of an opencast coal mine. Environmental Conservation. 24(1): 24–30. http://www.jstor.org/stable/44519238

Learn About Silicosis. 2022 Nov 17. American Lung Association. [accessed 2023 May 4]. https://www.lung.org/lung-health-diseases/lung-disease-lookup/silicosis/learn-about-silicosis.

Li X., Stainback G., Barton C., Yang J. 2018. Valuing the environmental benefits from reforestation on reclaimed surface mines in Appalachia. J. Am. Soc. Min. Reclam, 7: 1-29.

Lindberg TT, Arnold MC, Liu YT, Porter KA, Hsu-Kim H, Hinton DE, Di Giulio RT. 2014. Bioaccumulation and speciation of selenium in fish and insects collected from a mountaintop removal coal mining-impacted stream in West Virginia. Ecotoxicology. 23(5):929-38. doi: 10.1007/s10646-014-1236-4.

Lovan D. 2015. No union mines left in Kentucky, where union wars once raged. The Washington Post. https://www.washingtonpost.com/business/economy/closure-of-kentuckys-last-unionized-coal-mine-may-be-ironic-sign-of-success/2015/09/05/8c1a1a42-5417-11e5-8c19-0b6825aa4a3a_story.html.

Macdonald SE., Landhäusser SM., Skousen J., Franklin J., Frouz J., Hall S., ... & Quideau, S. 2015. Forest restoration following surface mining disturbance: challenges and solutions. *New* Forests. 46:703-732.

Mace GM, Norris K, Fitter AH. 2012. Biodiversity and ecosystem services: A multilayered relationship. Trends in Ecology & Evolution. 27:19–26. doi:10.1016/j.tree.2011.08.006.

Madden KE., Fox BJ. 1997. Arthropods as Indicators of the Effects of Fluoride Pollution on the Succession Following Sand Mining. Journal of Applied Ecology. 34(5): 1239–1256. https://doi.org/10.2307/2405235

McGraw MP. 1982. Surface Mining Primacy for Kentucky: The Legal Implications. Kentucky Law Journal. 71(1), Article 4. https://uknowledge.uky.edu/klj/vol71/iss1/4

Mehana ESED. 2014. Impact of water pollution with heavy metals on fish health: Overview and updates. Global Veterinaria. 12(2):219-231.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC

Mistich D. 2022. Coal companies use bankruptcy and asset transfers to shed obligations. NPR. [accessed 2023 Apr 25]. https://www.npr.org/2022/10/17/1128354266/coal-companies-use-bankruptcy-and-asset-transfers-to-shed-obligations.

Montrie, C. 2000. Expedient Environmentalism: Opposition to Coal Surface Mining in Appalachia and the United Mine Workers of America, 1945-1975. Environmental History. 5(1): 75–98. https://doi.org/10.2307/3985536

Mummey DL., Stahl PD., Buyer JS. 2002. Soil microbiological properties 20 years after surface mine reclamation: spatial analysis of reclaimed and undisturbed sites. Soil Biology and Biochemistry. 34*(*11): 1717-1725.

National Institute for Occupational Safety and Health. 2011. Coal Mine Dust Exposures and Associated Health Outcomes A Review of Information Published Since 1995.

Palmer MA, Bernhardt ES, Schlesinger WH, Eshleman KN, Foufoula-Georgiou E, Hendryx MS, Lemly AD, Likens GE, Loucks OL, Power ME, White PS, Wilcock PR. 2010. Mountaintop Mining Consequences. Science, 327(5962):148–149. http://www.jstor.org/stable/40508802

Pericak AA, Thomas CJ, Kroodsma DA, Wasson MF, Ross MRV, Clinton NE, et al.. 2018. Mapping the yearly extent of surface coal mining in Central Appalachia using Landsat and Google Earth Engine. PLoS ONE. 13(7): e0197758. doi:10.1371/journal.pone.0197758

Pudup MB. 1990. The Limits of Subsistence: Agriculture and Industry in Central Appalachia. Agricultural History. 64(1): 61–89. http://www.jstor.org/stable/3743183

Rader T., Graham L. Personnel Communication. 15 November 2023.

Coal Profile Analysis. 2022. US Energy Information Administration. https://www.eia.gov/state/analysis.php?sid=KY#:~:text=Coal%20was%20mined%20in%20Kentucky,been%20mined%20in%20the%20state.

Regulating Active Coal Mines | Office of Surface Mining Reclamation and Enforcement. wwwosmregov. https://www.osmre.gov/programs/regulating-active-coal-mines.

Rogers S. 2022. Kentucky to get $74 million for mine reclamation, clean up hazardous sites. abc36. [accessed 2023 May 1]. https://www.wtvq.com/kentucky-to-get-75-million-for-mine-reclamation-clean-up-hazardous-sites

Ross M, McGlynn B, Bernhardt E. 2016. Deep Impact: Effects of Mountaintop Mining on Surface Topography, Bedrock Structure, and Downstream Waters. Environ Sci Technol. 50(4):2064-2074. doi:10.1021/acs.est.5b04532

Roxburgh SH., Shea K., Wilson JB. 2004. The Intermediate Disturbance Hypothesis: Patch Dynamics and Mechanisms of Species Coexistence. Ecology. 85(2): 359–371. http://www.jstor.org/stable/3450202

Savage E. 2021. Repairing the Damage: The costs of delaying reclamation at modern-era mines. Appalachian Voices. https://appvoices.org/resources/RepairingTheDamage_ReclamationAtModernMines.pdf.

Scherber C, Eisenhauer N, Weisser WW, Schmid B, Voigt W, Fischer M, Schulze ED, Roscher C, Weigelt A, Allan E, Bessler H, Bonkowski M, Buchmann N, Buscot F, … Tscharntke T. 2010 Bottom-up effects of plant diversity on multitrophic interactions in a biodiversity experiment. Nature. 468(7323):553-6. doi: 10.1038/nature09492.

Sen. Mitch McConnell - Kentucky. OpenSecrets. (2023). Retrieved March 28, 2023, Available from https://www.opensecrets.org/members-of-congress/mitch-mcconnell/industries

Sheoran V.; Sheoran AS.; Poonia P. 2010. Soil Reclamation of Abandoned Mine Land by Revegetation: A Review. International Journal of Soil, Sediment and Water. 3(2) Article 13.

Sundqvist MK., Sanders NJ., Wardle DA. 2013. Community and Ecosystem Responses to Elevational Gradients: Processes, Mechanisms, and Insights for Global Change. Annual Review of Ecology, Evolution, and Systematics. 44:261–280. http://www.jstor.org/stable/43049604

Suding KN, Lavorel S, Chapin FS, Cornelissen JHC, Díaz S, Garnier E, et al. 2008. Scaling environmental change through the community-level: a trait-based response-and-effect framework for plants. Glob. Change Biol. 14:1125–1140

Taylor JE., Dyer GA., Stewart M., Yunez-Naude A., Ardila S. 2003. The Economics of Ecotourism: A Galápagos Islands Economy-Wide Perspective. Economic Development and Cultural Change. 51(4): 977–997. https://doi.org/10.1086/377065

Tilman D., Reich PB., Knops J., Wedin D., Mielke T., Lehman C. 2001. Diversity and Productivity in a Long-Term Grassland Experiment. Science. 294(5543): 843–845. Doi:

Todd J., Doshi S., McInnis A. 2010. Beyond coal: A resilient new economy for Appalachia. Solutions. 1(4): 45-52.

Tourism to Mammoth Cave National Park generates $69.2 million in Economic Benefits. 2022 Jun 4. National Park Service. [accessed 2023 May 1]. https://www.nps.gov/maca/learn/news/tourism-to-mammoth-cave-national-park-creates-69-2-million-in-economic-benefits.htm.

U.S. Energy Information Administration. 2022. Kentucky State Energy Profile. Retrieved March 20, 2023. Available from https://www.eia.gov/state/print.php?sid=KY

Violle C, Navas ML, Vile D, Kazakou E, Fortunel C, Hummel I, et al. 2007. Let the concept of trait be functional! Oikos. 116:882–892

When did Kentucky's coal form? 2023 Jan 5. Kentucky Geological Survey . [accessed 2023 May 2]. https://www.uky.edu/KGS/coal/coal-ky-info-when-coal-form

Williamson T, Barton C. 2020. Hydrologic Modeling to Examine the Influence of the Forestry Reclamation Approach and Climate Change on Mineland Hydrology. Science of the Total Environment. 743. p. N.PAG.

Wilson AA, Ditmer MA, Barber JR, Carter NH, Miller ET, Tyrrell LP, Francis CD. 2021. Artificial night light and anthropogenic noise interact to influence bird abundance over a continental scale. Global Change Biology. 27(17):3987–4004. doi:10.1111/gcb.15663.

Wilson JB. 1994. THE "INTERMEDIATE DISTURBANCE HYPOTHESIS" OF SPECIES COEXISTENCE IS BASED ON PATCH DYNAMICS. N Z J Ecol. 18(2):176–181. http://www.jstor.org/stable/24066772

Woods AJ., Omernik JM., Martin WH., Pond GJ., Andrews WM., Call SM, Comstock JA., Taylor DD. 2002. Ecoregions of Kentucky (color poster with map, descriptive text, summary tables, and photographs). Reston, VA., U.S. Geological Survey (map scale 1:1,000,000).

Woodward, SL. 2012. Temperate Broadleaf Deciduous Forest. Biomes of the World. Retrieved March 20, 2023. Available from https://php.radford.edu/~swoodwar/biomes/?page_id=94

World Wildlife Fund. Global 200. Published: 2012, August 1. Retrieved March 19, 2023. Available from https://www.worldwildlife.org/publications/global-200

Y. Hautier et al.. 2015 Anthropogenic environmental changes affect ecosystem stability via biodiversity. Science. 348: 336–340. doi:10.1126/science.aaa1788.

Yüksek F., Altun L., Karaöz O., Şengönül K., Yüksek T., Küçük M. 2013. The effect of altitude on soil properties and leaf traits in wild Vaccinium arctostaphylos L. populations in the forest understory in Fırtına River basin. In Proceedings book from international Caucasian forestry symposium. 24-26.

Kentucky State Regulations

Postmining land use capability. 405 KAR 16:210.(2021). https://apps.legislature.ky.gov/law/kar/titles/405/016/210/

General bonding provisions. 405 KAR 10:015.(2021). https://apps.legislature.ky.gov/law/kar/titles/405/010/015/

Surface coal mining permits. 405 KAR 8:030.(2021). https://apps.legislature.ky.gov/law/kar/titles/405/008/030/

Kentucky reclamation guaranty fund. 405 KAR 10:070.(2021). https://apps.legislature.ky.gov/law/kar/titles/405/010/070/

Procedures, criteria and hearing requirements for cancellation of surety bonds after notice of noncompliance issued for failure to maintain contemporaneous reclamation. 405 KAR 10:035.(2021). https://apps.legislature.ky.gov/law/kar/titles/405/010/035/

Topsoil. 405 KAR 16:050.(2021). Procedures, criteria and schedule for release of performance bond. 405 KAR 10:040.(2021). https://apps.legislature.ky.gov/law/kar/titles/405/010/040/

Reforestation Initiative. Reclamation Advisory Memorandum 124. Department for Surface Mining Reclamation and Enforcement.(2009). https://eec.ky.gov/Natural-Resources/Mining/Mine-Permits/RAMS/RAM124.pdf

Plant species, distribution patterns, seeding rates, and planting arrangements for revegetation of mined lands. Technical Reclamation Memorandum 21. Kentucky Department of Fish and Wildlife Resources.(1995). https://eec.ky.gov/Natural-Resources/Mining/MinePermits/TRMs/TRM21.pdf

ArcGIS and Biodiversity Data

Appalachian Regional Commission (ARC), 1965 – Mapping Appalachia. [Data Set]. https://mapappalachia.geography.vt.edu/about/arc/.

Environmental Protection Agency. (2022). Ecoregion Download Files by State – Region 4. [Data Set]. https://www.epa.gov/eco-research/ecoregion-download-files-state-region-4#pane-15

GBIF.org (24 October 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.4g7jcs.

Kentucky Energy and Environmental Cabinet . (2023). MinedOutAreas [Data Set]. http://minemaps.ky.gov/Maps/GisData

U.S. Geological Survey. (2019). NLCDlandcover_2019_release [Data Set]. https://www.usgs.gov/centers/eros/science/national-land-cover-database

U.S. Geological Survey. (n.d.). NHD_Kentucky_State [Data Set]. https://www.usgs.gov/national-hydrography/access-national-hydrography-products

APPENDIX A

Variable	(Arthropoda (occ/kn	Insecta (occ/km2)	Mammalia (occ/km2)	Mollusca (occ/km2)	Reptilia (occ/km2)	Fish (occ/km2)	OPEN_WATER (%)	DEVELOPED_(%)
Percent Mined	0.024	0.02	0.029	0.14	-0.03	-0.208**	-0.026	0.177**
Full Biodiversity (occ/km2)	0.667**	0.649**	0.382**	0.514**	0.627**	0.273**	0.298**	0.416**
Full Biodiversity (No Aves occ/km2)	0.769**	0.745**	0.443))	0.532**	0.648**	0.316**	0.133	0.437**
Animalia (occ/km2)	0.680**	0.667**	0.376**	0.505**	0.626**	0.302**	0.319**	0.452**
Plantae (occ/km2)	0.424**	0.401**	0.269**	0.364**	0.423**	0.126	0.160*	0.208**
Aves (occ/km2)	0.310**	0.304**	0.174*	0.323**	0.394**	0.125	0.431**	0.376**
Amphibia (occ/km2)	0.528**	0.496**	0.315**	0.304**	0.542**	0.168**	-0.105	0.160*
(Arthropoda (occ/km2)	1	0.994**	0.443**	0.311**	0.655**	0.053	0.056	0.274**
Insecta (occ/km2)	0.994**	1	0.418**	0.309**	0.642**	0.031	0.06	0.251**
Mammalia (occ/km2)	0.443**	0.418**	1	0.194**	0.360**	0.159**	0.008	0.03
Mollusca (occ/km2)	0.311*	0.309**	0.194**	1	0.303**	0.122	0.095	0.179*
Reptilia (occ/km2)	0.665**	0.642**	0.360**	0.303**	1	0.09	0.088	0.376**
Fish (occ/km2)	0.053	0.031	0.159*	0.122	0.09	1	-0.008	0.197**
OPEN_WATER (%)	0.056	0.06	0.008	0.095	0.088	-0.008	1	-0.009
DEVELOPED_(%)	0.274**	0.251**	0.03	0.179*	0.376**	0.197**	-0.009	1
DEVELOPED1(%)	0.284**	0.273**	0.104	0.176*	0.354**	-0.140*	0.048	0.586**
DEVELOPE_1(%)	0.384**	0.373**	0.181*	0.222**	0.409**	-0.132	0.082	0.481**
DEVELOPE_2(%)	0.435**	0.427**	0.132	0.199**	0.418**	-0.127	0.106	0.388**
BAREEN_LAND(%)	0.001	0.002	0.053	-0.054	-0.007	-0.133	-0.026	-0.165*
DECIDUOUS_(%)	-0.264**	-0.247**	-0.126	-0.13	-0.320**	0.132	-0.063	-0.254**
EVERGREEN_(%)	-0.086	-0.083	-0.061	0.011	-0.021	-0.009	0.081	-0.288**
MIXED_FOREST(%)	0.259**	0.228**	-0.185**	0.175*	0.248**	-0.01	-0.046	-0.039
SHRUB_SCRU(%)	-0.052	-0.048	-0.024	-0.083	-0.018	-0.198**	-0.045	-0.248**
HERBACEOUS(%)	-0.007	-0.01	0.005	-0.092	0.001	-0.176*	-0.018	-0.222**
HAY_PASTURE(%)	-0.051	-0.035	-0.068	-0.023	0.013	0.04	-0.013	0.300**
CULTIVATED(%)	-0.035	-0.031	-0.015	0.021	0.004	0.018	-0.012	-0.117
WOODY_WETL(%)	0.005	0.003	0.032	0.021	0.181*	-0.044	0.012	0.237**
EMERGENT_H(%)	0.008	0.006	0.092	-0.016	0.079	-0.035	0.066	0.057

Variable	DEVELOPED1(%)	DEVELOPE_1(%)	DEVELOPE_2(%)	BAREEN_LAND(%)	DECIDUOUS_(%)	EVERGREEN_(	MIXED_FOREST(%)
Percent Mined	0.046	0.063	0.059	0.683**	-0.390**	0.13	-0.002
Full Biodiversity (occ/km2)	0.374**	0.428**	0.400**	-0.018	0.281**	0.026	0.230**
Full Biodiversity (No Aves occ/km2)	0.277**	0.378**	0.372**	-0.034	-0.240**	0.019	0.308**
Animalia (occ/km2)	0.367**	0.431**	0.412**	-0.024	-0.283**	-0.017	0.162*
Plantae (occ/km2)	0.194**	0.282**	0.247**	0	-0.187**	0.101	0.287**
Aves (occ/km2)	0.332**	0.359**	0.310**	0.009	-0.248**	0.027	0.046**
Amphibia (occ/km2)	0.105	0.145*	0.166*	-0.012	-0.113	0.025	0.257**
(Arthropoda (occ/km2)	0.284**	0.384**	0.435**	0.001	-0.264**	-0.086	0.259**
Insecta (occ/km2)	0.273**	0.373**	0.427**	0.002	-0.247**	-0.083	0.228**
Mammalia (occ/km2)	0.104	0.181*	0.132	0.053	-0.126**	-0.061	0.185**
Mollusca (occ/km2)	0.176*	0.222**	0.199**	-0.054	-0.13	0.011	0.175*
Reptilia (occ/km2)	0.354**	0.409**	0.418**	-0.007	-0.320**	-0.021	0.248**
Fish (occ/km2)	-0.140*	-0.132	-0.127	-0.133	0.132	-0.009	-0.01
OPEN_WATER (%)	0.048	0.082	0.106	-0.026	-0.063	0.081	-0.046
DEVELOPED_(%)	0.586**	0.481**	0.388**	-0.165*	-0.254**	-0.288**	-0.039
DEVELOPED1(%)	1	0.921**	0.794**	0.04	-0.475**	0.043	-0.135
DEVELOPE_1(%)	0.921**	1	0.915**	0.096	-0.430**	0.097	-0.094
DEVELOPE_2(%)	0.794**	0.915**	1	0.109	-0.341**	0.093	-0.123
BAREEN_LAND(%)	0.040**	0.096	0.109	1	-0.431**	0.098	0.015
DECIDUOUS_(%)	-0.475**	-0.430**	-0.341**	-0.431	1	-0.173*	-0.492**
EVERGREEN_(%)	0.043	0.097	0.093	0.098	-0.173*	1	0.012
MIXED_FOREST(%)	-0.135	-0.094	-0.123	0.015	-0.492**	0.12	1
SHRUB_SCRU(%)	0.018	0.004	0.008	0.383**	-0.357**	0.317**	-0.122
HERBACEOUS(%)	0.044	0.086	0.087	0.823**	-0.490**	0.256**	-0.01
HAY_PASTURE(%)	0.263**	0.086	0.007	-0.233**	-0.419**	-0.138	-0.02
CULTIVATED(%)	-0.044	0.003	-0.062	-0.069	-0.286**	0.170*	0.318**
WOODY_WETL(%)	0.306**	0.170*	0.084	-0.063	-0.398**	0.002	0.074
EMERGENT_H(%)	0.156*	0.135	0.055	-0.018	-0.428**	0.214	0.297**

Variable	SHRUB_SCRU(%)	HERBACEOUS(%)	HAY_PASTURE(%)	CULTIVATED(%)	WOODY_WETL(	EMERGENT_H(
Percent Mined	0.643**	0.802**	-0.288**	-0.101	-0.072	-0.045
Full Biodiversity (occ/km2)	-0.109	-0.029	-0.06	-0.032	0.094	0.039
Full Biodiversity (No Aves occ/km2)	-0.127	-0.067	-0.108	-0.039	0.031	0.003
Animalia (occ/km2)	-0.101	-0.028	0.002	-0.019	0.109	0.053
Plantae (occ/km2)	-0.089	-0.023	-0.163*	-0.048	0.032	0
Aves (occ/km2)	-0.048	0.044	0.025	-0.012	0.151*	0.076
Amphibia (occ/km2)	-0.021	-0.065	-0.135	-0.034	0.04	0
(Arthropoda (occ/km2)	-0.052	-0.007	-0.051	-0.035	0.005	0.008
Insecta (occ/km2)	-0.048	-0.01	-0.035	-0.031	0.003	0.006
Mammalia (occ/km2)	-0.024	0.005	-0.068	-0.015	0.032	0.2
Mollusca (occ/km2)	-0.083	-0.092	-0.023	0.021	0.021	-0.016
Reptilia (occ/km2)	-0.081	0.001	0.014	0.004	0.181*	0.079
Fish (occ/km2)	-0.198**	-0.176*	0.04	0.018	-0.044	-0.035
OPEN_WATER (%)	-0.045	-0.018	-0.013**	-0.012	0.012	0.066
DEVELOPED_(%)	-0.248**	-0.222**	0.300**	-0.117	0.237**	0.057
DEVELOPED1(%)	0.018	0.044	0.264**	-0.044	0.306**	0.156*
DEVELOPE_1(%)	0.004	0.086	0.086	0.003	0.170*	0.135
DEVELOPE_2(%)	0.008	0.087	0.007	-0.062	0.084	0.055
BAREEN_LAND(%)	0.383**	0.823**	-0.223**	-0.069	-0.063	-0.018
DECIDUOUS_(%)	-0.375**	-0.490**	-0.419**	-0.286**	-0.398**	-0.428**
EVERGREEN_(%)	0.317**	0.256	-0.138	0.170*	0.002	0.214**
MIXED_FOREST(%)	-0.122	-0.01	-0.02	0.318**	0.074	0.297**
SHRUB_SCRU(%)	1	0.554**	-0.078	-0.069	0.032	-0.036
HERBACEOUS(%)	0.544**	1	-0.230**	-0.058	-0.039	-0.014
HAY_PASTURE(%)	-0.078	-0.230**	1	0.322**	0.524**	0.393**
CULTIVATED(%)	-0.069	-0.058	0.322**	1	0.279**	0.696**
WOODY_WETL(%)	0.032	-0.039	0.524**	0.279**	1	0.650**
EMERGENT_H(%)	-0.036	-0.014	0.393**	0.696**	0.650**	1