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RESEARCH ARTICLE

MAMMAL DIVERSITY ASSOCIATED WITH FORMER SURFACE MINES IN THE VIRGINIA COALFIELDS

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ABSTRACT

Surface coal extraction and subsequent reclamation activities alter habitat availability for Appalachian wildlife, although broad surveys of mine-associated taxa are still largely lacking from the Virginia coalfields. We utilized game cameras to survey the mammal diversity of three habitat types – mined and reclaimed scrub/shrub habitat, mined and reclaimed scrub/shrub habitat associated with constructed wetlands, and unmined reference forests – at a reclaimed surface mine in Wise County, Virginia. We encountered 14 mammal species at this site, with the highest mammal diversity at mined wetlands and in unmined reference forests. Mammal diversity was substantially lower on reclaimed upland scrub-shrub habitats, echoing past findings for other taxa regarding decreased wildlife diversity on former surface mines. Our data provide a preliminary comparison of mammal diversity across three habitats associated with a former surface mine in the Virginia coalfields and highlight several key recommendations for land managers charged with maintaining wildlife diversity on formerly mined sites.

Keywords: Appalachia, biodiversity, coal, reclamation, wildlife.

INTRODUCTION

The southwestern Virginia coalfields contain one of eastern North America's most heavily impacted areas in terms of surface coal extraction. More than 5900 km^2 of this region have been impacted by surface mining to date, including older "strip" or contour mines and more recent mountaintop removal mining operations (Townsend et al., 2019; Pericak et al., 2018). Past work has found these activities and their ecological legacies to exert significant pressures on local wildlife populations, with mining both decreasing (Wickham et al., 2013; Maigret et al., 2019) and enhancing (Turner & Fowler, 1981; Lannoo et al., 2009; Hill & Smith, 2021) habitat suitability and quality for many wildlife species.

While the aforementioned work has highlighted clear impacts on wildlife from ongoing and recent surface mining across the central Appalachian coalfields, a consensus has not yet been reached on how best to manage mine-associated habitats for wildlife, particularly across former mines that have been exposed to varying reclamation strategies (Buehler & Percy, 2012; Lituma et al., 2020). Such former mines exist across the region in varying states of ecological health, with some older mines possessing second-growth forest cover created through volunteer hardwood establishment and younger mines being reclaimed using extensive grading and planting of non-native, invasive flora such as Sericea Lespedeza (*Lespedeza cuneata* Dumont de Courset, 1832) and Autumn Olive (*Elaeagnus umbellata* Thunberg, 1984; Zipper et al., 2011; Skousen & Zipper, 2020). Mining activities also have resulted in the creation of wetland habitat at many sites, including both constructed impoundments designed for stormwater management and shallow, incidental wetlands formed as a result of flattening local topography (Wieder, 1989; Atkinson & Cairns, 1994; Atkinson, 2010). Understanding how best to manage such mine-associated habitats will require both broad inventories of wildlife species using former surface mines and detailed studies of abundance and movement patterns across landscapes impacted by surface mining.

To date, work assessing wildlife use of older surface mines in the Virginia coalfields largely has been limited to focused studies of individual taxa such as amphibians, birds, or game populations of interest to state wildlife agencies (Sweeten & Ford, 2015; Hinkle et al., 2018; Virginia DWR, 2019; Hill & Smith, 2021; Hill et al., 2021). Studies of a broader taxonomic scope focused across a diversity of mine-associated habitat types are currently lacking in the literature, particularly for mammals across the coalfields of far southwest Virginia (Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise counties and the City of Norton). With increasing regional focus being put on repurposing former minelands for economic development activities and restoring other former surface mines for game populations (Zipper et al., 2020), information on associations of both game and non-game mammal species with mine-associated habitats is urgently needed to assess potential ecological risks from mineland redevelopment and guide the design of appropriate mineland reclamation strategies geared towards wildlife conservation.

We sought to address the aforementioned knowledge gaps through a preliminary comparison of mammal diversity across varying habitats associated with a former surface mine complex in Wise County, Virginia. This site contains an assortment of terrestrial and aquatic habitats created by varying eras of surface mining, ranging from reforested sites abandoned following industrial mining in the early 20th Century to more recent (circa 1990) surface mining reclaimed under existing federal guidelines. We specifically used automated game cameras to inventory mammal species and quantify diversity across three habitat types – mined and reclaimed scrub-shrub habitat, mined and reclaimed scrub-shrub habitat adjacent to constructed wetlands, and unmined reference forests – throughout 2021. Here we compare the results of these preliminary wildlife inventories, provide comparisons of wildlife diversity and use across various mine-associated habitats, and recommend future directions for hypothesis-driven work stemming from our results.

MATERIALS AND METHODS

Study Site

Our study site was located on a 120-ha surface mine encompassing the headwaters of Yellow Creek in Wise, Virginia (36.97766º N, 82.55741º W; Fig. 1). This site has seen near-continuous industrial coal extraction over the past century, ranging from early, small-scale surface mining in the early 1900s to larger surface mines abandoned prior to the establishment of federal reclamation guidelines in 1977 (Surface Mining Control and Reclamation Act of 1977; 30 U.S.C. §§1201-1211, 1231-1251, 1252-1328). More recent surface mining occurring after 1977 and reclaimed following federal guidelines was also undertaken across a large portion of the site in the 1980s and 1990s. No surface mining has taken place at this site since 2000, with several patches of unmined forests remaining on the site and experiencing no significant anthropogenic disturbance within at least the past 60 years.

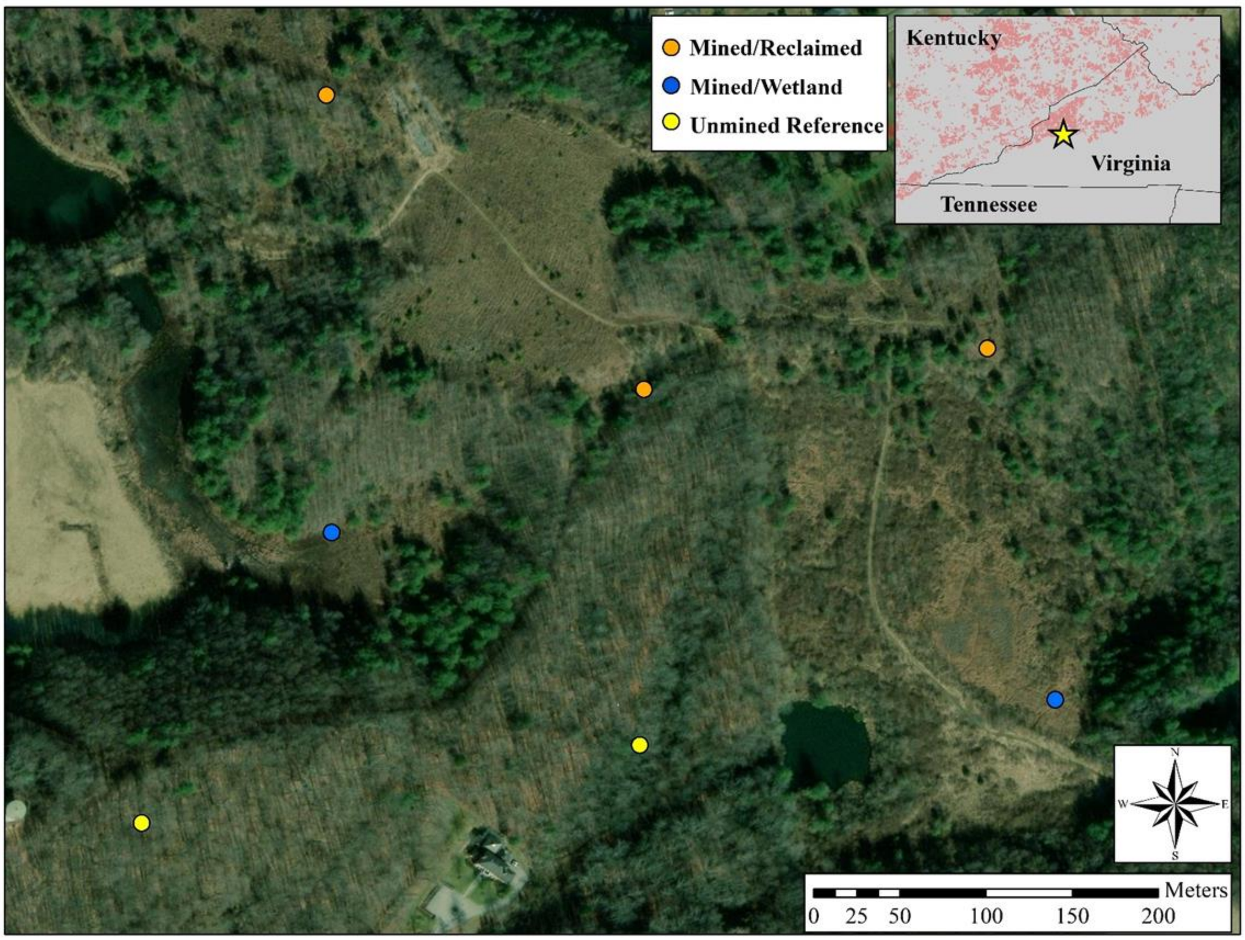

Figure 1. Location of seven game cameras, grouped by habitat type, installed on a former surface mine in Wise County, Virginia in 2021. Star in inset map denotes location of the study area, with red-shaded areas denoting the location of active and former surface mines in the surrounding central Appalachian region, as defined by Pericak et al. (2018).

Habitat features across the study site are variable and generally reflect the legacies of surface mining described above. These features include patches of intact, mature mixed mesophytic hardwood forests typical of the surrounding Cumberland Mountains physiographic province (Braun, 1942) in unmined areas, as well as mined and reclaimed scrub-shrub habitats that have been revegetated primarily with non-native Autumn Olive (*Elaeagnus umbellata*) and volunteer native hardwood establishment. The site additionally contains several wetland habitats nested within the aforementioned reclaimed surface mine which were either constructed for stormwater control during the reclamation process or formed incidentally as a result of the flattening of local topography.

Sampling Methods

We sought to examine mammal diversity across each of the aforementioned habitat types at our study site. Specifically, we inventoried mammal diversity across three habitat types: mined and reclaimed scrub-shrub upland habitats (hereafter "Mined/Reclaimed"), mined and reclaimed scrub-shrub habitat associated with constructed wetlands (hereafter "Mined/Wetland"), and unmined hardwood forests (hereafter "Unmined Reference") as reference sites. We installed a network of seven Bushnell Trophy Cam HD game cameras (Bushnell, Overland Park, Kansas) across the study site in August 2021, with one camera installed per habitat patch present at the site. We installed three cameras within Mined/Reclaimed habitat patches, two cameras at Mined/Wetland habitat patches, and two cameras in Unmined Reference forests (Fig. 1).

Cameras were installed as close to the center of each habitat patch as was possible given site constraints, with cameras also placed away from major access roads, trails, and similar linear corridors. We additionally followed protocols developed by Cove et al. (2021) for standardized game camera sampling, installing each camera at a height of 50 cm and at least 200 m away from the nearest camera. Wetland cameras were installed at the aforementioned height on the wetland margin, facing the wetland at a point that provided the maximum unobstructed view of adjacent terrestrial habitat along the wetland margin.

We armed all cameras on 31 August 2021, allowing cameras to run continuously through 18 November 2021 (79 total trap-nights per camera). This timeframe was chosen to capture both typical summer wildlife activity as well as the transition to overwintering periods for most wildlife species, which generally begin with the local onset of colder temperatures in late October and early November. Cameras were configured to capture images on default factory settings (normal camera sensitivity, 10 second delay interval, low night vision shutter speed). We visited each camera at 14-day intervals to check camera function and positioning, as well as to download captured images, throughout the sampling period.

Statistical Analyses

Following the completion of the sampling period, we viewed all images captured by our camera array and excluded all false positives (e.g., images with no wildlife visible) from further analyses. We then identified all captured wildlife images to the species level using visual assessments of each image. Visual assessments and species identification were performed by the coauthors in pairs, with both members of each pair confirming each species assignment. Images that could not be reliably identified to the species level due to poor image quality or having only a portion of the captured animal present in the image were coded as “unknown” and excluded from subsequent analyses.

We first compared species richness against sampling effort across each habitat type using individual-based rarefaction curves (Gotelli & Colwell, 2001). We then assembled wildlife inventories for each habitat type, including the species encountered during sampling and the total number of images captured for each species. To avoid falsely inflating our image counts, we counted series of multiple photos of the same species at a single camera as single, independent observations if at least ten minutes passed between photo series with no captures of that species (Kolowski & Forrester, 2017). This time interval was selected following an initial assessment of activity patterns within our overall dataset.

We calculated trap success for each habitat type as the number of identifiable photos for each encountered species per 100 trap-nights. We additionally calculated overall trap success, pooled across all species, for each habitat type. We also used Sorensen’s Coefficient of Similarity (Sorensen, 1948) to compare species shared between pairwise combinations of habitat types. Statistical comparisons and associated calculations were performed using R v.4.2.1 and the iNEXT package (Hsieh et al., 2016).

RESULTS

We encountered 14 mammal species across our camera array over 786 captured images with animals present (Table 1). Mined/Reclaimed habitats had the lowest overall trap success and species richness, with captures dominated by White-tailed Deer (*Odocoileus virginianus* Zimmerman, 1780). By contrast, Unmined Reference habitats and Mined/Wetland habitats had similar trap success rates and higher species richness. Rarefaction curves began to approach an asymptote for all habitat types, indicating a relatively thorough sampling effort within each habitat (Fig. 2).

Species inventories and per-species trap success were variable across habitat types and helped explain the aggregated patterns described above. White-tailed Deer were the most commonly detected species in our dataset, being detected by all cameras regardless of habitat type. Eastern Gray Squirrels (*Sciurus carolinensis* Gmelin, 1788), American Black Bears (*Ursus americanus* Pallas, 1780), Eastern Cottontails (*Sylvilagus floridanus* Allen, 1890) and Common Raccoons (*Procyon lotor* Linnaeus, 1758) were also detected and were abundant in all habitat types.

Other mammal taxa were less commonly encountered or were encountered only in particular habitat types. Bobcats (*Lynx rufus* Schreber, 1777) and Gray Foxes (*Urocyon cinereoargenteus* Schreber, 1775), for example, were encountered across all habitat types but were only present in low numbers at each site, with Bobcat trap success in Unmined Reference and Mined/Wetland sites being nearly double that of Mined/Reclaimed sites. Two species – American Beaver (*Castor canadensis* Kuhl, 1820) and Southern Flying Squirrel (*Glaucomys volans* Linnaeus, 1758) – were detected only at cameras associated with Mined/Wetland sites, with American Beavers being particularly abundant and observed foraging in family groups on numerous occasions. Sorensen’s Coefficients showed relatively high similarity in mammal assemblages across all habitat types, with a large proportion of species shared between pairwise habitat combinations (Table 2). Mined/Reclaimed and Mined/Wetland habitats, however, contained the most dissimilar species assemblages among pairwise combinations of habitat types.

Table 1. Trap success (events per 100 trap-nights) for 14 mammal species detected across game cameras installed in three habitat types associated with a former surface mine in Wise County, Virginia in 2021. Total trap success refers to trap success for each habitat type across all species.

		Habitat Type		
Species	**Common Name**	**Mined/ Reclaimed**	**Mined/ Wetland**	**Unmined Reference**
Canis lupus familiaris Linnaeus, 1758	Domestic Dog	—	—	3.16
Canis latrans Say, 1823	Coyote	0.84	2.53	0.63
Castor canadensis Kuhl, 1820	American Beaver	—	41.77	—
Didelphis virginiana Kerr, 1792	Virginia Opossum	—	10.13	9.49
Glaucomys volans Linnaeus, 1758	Southern Flying Squirrel	—	3.80	—
Lynx rufus Schreber, 1777	Bobcat	0.84	2.53	2.53
Odocoileus virginianus Zimmerman, 1780	White-tailed Deer	56.96	34.81	62.66
Peromyscus spp. Gloger, 1841	Deer Mice	—	0.63	—
Procyon lotor Linnaeus, 1758	Common Raccoon	0.42	9.49	12.66
Sciurus carolinensis Gmelin, 1788	Eastern Gray Squirrel	2.11	36.08	62.66
Sylvilagus floridanus Allen, 1890	Eastern Cottontail	3.38	15.82	4.43
Tamias striatus Linnaeus, 1758	Eastern Chipmunk	—	3.80	3.16
Urocyon cinereoargenteus Schreber, 1775	Gray Fox	0.42	0.63	4.43
Ursus americanus Pallas, 1780	American Black Bear	2.95	0.63	0.63
Total trap success		**67.93**	**162.65**	**166.44**
Species richness		**8**	**13**	**11**

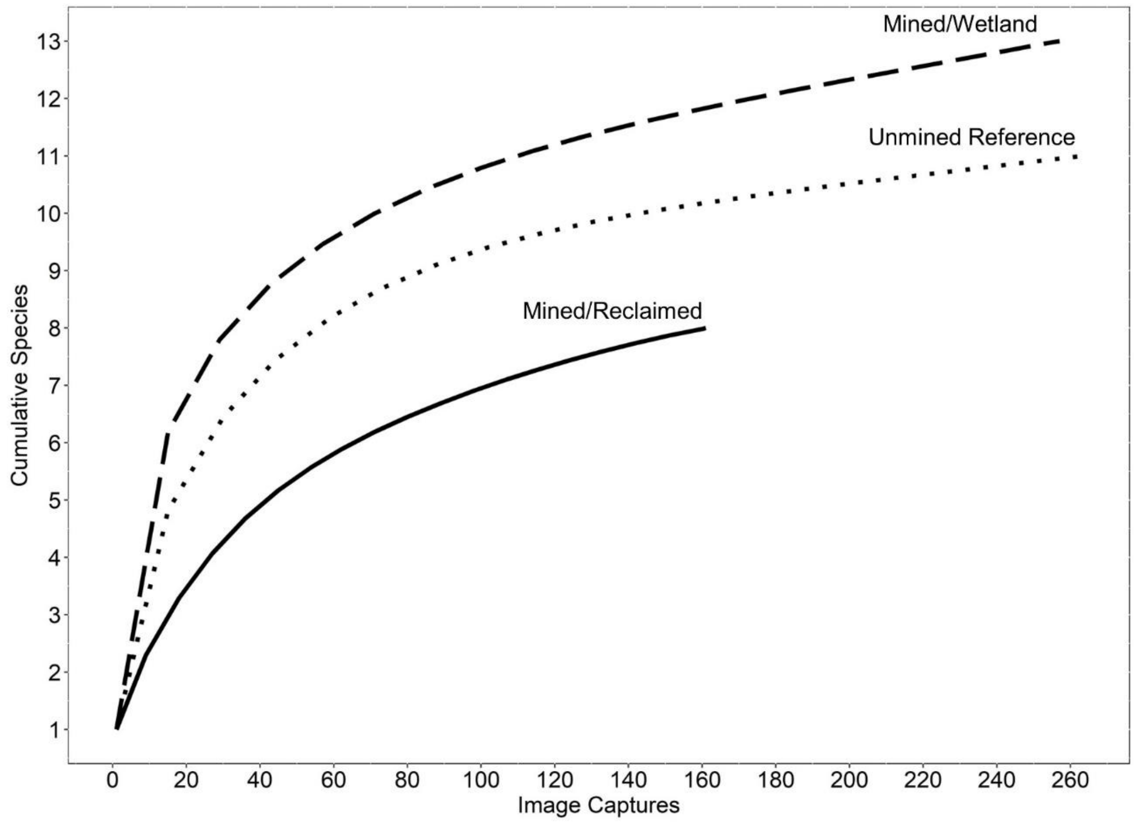

Figure 2. Rarefaction curves for mammal observations at game cameras installed on mined and reclaimed upland habitat (solid lines), mined habitat adjacent to wetlands (dashed lines), and unmined reference forests (dotted lines) at a former surface mine in Wise County, Virginia in 2021.

Table 2. Sorensen's Coefficients reflecting similarity of mammal assemblages at pairwise combinations of habitat types on a former surface mine in Wise County, Virginia in 2021. Coefficients range from 0 (no shared species) to 1 (identical species assemblages).

Habitat Type	Mined/Reclaimed	Mined/Wetland	Unmined Reference
Mined/Reclaimed			
Mined/Wetland	0.762		
Unmined Reference	0.842	0.833	

Discussion

Our sampling effort formed one of the first attempts to broadly inventory mammal diversity across habitats associated with surface mining in the Virginia coalfields. The wildlife diversity captured by our camera array encompassed regionally common and abundant taxa, including those associated with wetland habitats (e.g., American Beaver). Our results also found evidence of disparity in mammal diversity between habitat types reflecting varying legacies of surface coal extraction, despite the study area's relatively small overall size. Collectively, these results indicate that some former minelands across the Virginia coalfields, especially sites impacted by older mining activities, may harbor variable mammal assemblages.

We specifically found that mined and reclaimed upland habitats composed largely of non-native scrub-shrub vegetation possessed less speciose and less diverse mammal assemblages than nearby unmined upland hardwood forests. Captures at our mined and reclaimed habitats were dominated by a single heavily-abundant species (White-tailed Deer), with only isolated observations of other species that appeared to be either transient individuals moving through the habitat patch or visiting the habitat patch temporarily for foraging. These results are consistent with previous research showing that former surface mines converted into grassland or shrubland habitats often possess less speciose and less diverse species assemblages than those in nearby, undisturbed native hardwood forests (Brenner et al., 1982; Wickham et al., 2013; Williams et al., 2017). Our dataset supports this past work in suggesting that the legacies of surface mining and subsequent reclamation result in lowered species diversity in habitats impacted by surface mining in the central Appalachian coalfields.

We also found evidence of persistent use of mine-associated habitats, particularly scrub-shrub habitats, by American Black Bears. While past research has indicated that some former surface mines may be compatible with American Black Bears at the landscape scale (Unger, 2007), little empirical work has been performed to assess if and how American Black Bears are using formerly-mined habitats (Buehler & Percy, 2012). We found that American Black Bears may be using mined and reclaimed habitats during late summer and early fall when non-native species such as Autumn Olive (*E. umbellata*) are producing large amounts of soft mast, similar to reports by Lituma et al. (2020). The limited replication and temporal scope of our dataset did not allow for us to assess broader, landscape-scale movement patterns of bears between mined and unmined habitats, which could be important during winter months when largely unforested surface mines would lack hard mast and den trees – features that heavily influence American Black Bear habitat use (Vaughan, 2002; Ryan, 2009). More work, particularly studies encompassing a broader temporal scope across multiple seasons, is needed to understand the implications of surface mines and their ecological legacies on this species.

Cameras installed at wetland margins recorded similar species richness as those in unmined reference forests, despite each wetland occurring within the context of heavily disturbed mined and reclaimed scrub-shrub habitat. Many species recorded in unmined reference forests but not in reclaimed scrub-shrub habitat, for example, were detected at mined wetland sites, although it is unclear from our dataset if these species are permanent residents of habitat patches directly associated with these wetlands or if they are merely frequent visitors to wetlands from nearby forested and unmined patches for foraging or other behaviors. Our preliminary results nonetheless indicate that the construction or establishment of wetland habitats may substantially increase mammal diversity within otherwise heavily disturbed surface mines and that such wetlands are critical features within the larger landscape for even those mammal taxa that are not typically associated with former surface mines.

One limitation of our dataset is that we did not have wetland habitats available in unmined reference forests as part of our study site, which would have been a more appropriate reference comparison for mined wetlands than unmined upland forest habitat. It is possible, for example, that naturally-occurring wetlands in intact, mature forests could possess substantially higher mammal diversity than any of the habitat types included in this study. Similarly, wetland specialists would not be expected to regularly occur in the upland habitats surveyed through this study, which likely contributes to the overall higher mammal richness noted for wetland-associated sites in out dataset. Nonetheless, our results do show that constructed wetlands on former surface mines are capable of supporting populations of wetland specialists, such as American Beavers, and that mammal species more commonly associated with unmined hardwood forests at least periodically take advantage of such habitats as part of their home ranges. The use of constructed wetlands on former surface mines by American Beavers may be of special interest for the management of this species, given the relative lack of large wetland habitats across the steep terrain of the Cumberland Mountains in the absence of landscape alterations from surface mining (Thompson et al., 2007).

The temporal scope of our study and low replication of sampled habitat types precludes a more robust assessment of species abundance, movement patterns of mammals across heterogeneous landscapes containing a mixture of mined and unmined habitat patches, and associations of individual species with particular habitat variables that may be influenced by surface mining and subsequent reclamation activities. In addition, rarefaction curves indicated that several additional mammal species may have gone undetected in each habitat type, preventing us from exhaustively sampling all taxa across the study area. As a result, our data are best viewed as a preliminary inventory of mammal diversity associated with varying habitat types on former surface mines. Future, more intensive studies on individual species of interest may shed further light on associations with particular habitat variables influenced by surface mining and, especially, movement patterns of individual species between varying habitat patches found within mined landscapes. Enhanced survey approaches (e.g., multiple cameras per site, baited camera stations, and/or mammal trapping) may also facilitate more exhaustive surveys of mammal diversity on former surface mines.

Regardless, our results highlight several important management recommendations for maintaining mammal diversity on former surface mines. First, our data show a clear decrease in mammal diversity on upland portions of reclaimed surface mines planted with non-native vegetation, relative to nearby forested sites. Encouraging the re-establishment of native hardwood forests in previously-mined areas is therefore likely paramount for assisting in the recovery of mammal diversity following surface mining. Such reforestation efforts have recently been emphasized as critical steps in more broadly restoring ecosystem structure and function to mined landscapes in Appalachia (MacDonald et al., 2015), and our data underscore the potential value of this work for native wildlife species at the local scale. In a similar vein, efforts to redevelop former surface mines using industrial-scale energy or economic development projects (Zipper et al., 2020) will likely only further impede the recovery of such sites for native wildlife by retaining former surface mines in unforested, disturbed states. Land managers may therefore want to plan mineland redevelopment efforts carefully to enhance sites’ economic potential alongside habitat for native wildlife.

In addition, wetlands either constructed or formed incidentally on former surface mines appear to be critical embedded habitats for native mammal taxa in the Virginia coalfields, even when habitat immediately surrounding the wetland has been heavily disturbed. In our dataset, levels of mammal diversity in and around such wetlands matched those found within undisturbed, intact forest ecosystems. These results indicate that both constructed and incidental wetlands serve critical ecological roles on former surface mines, beyond their intended purposes of erosion and sediment control. Researchers and land managers should prioritize the protection of such habitats on formerly mined sites and use future work to explore management approaches that can maximize these habitats’ benefits for wildlife.

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