Received: 3 June 2025 | Revised: 19 July 2025 | Accepted: 28 July 2025

DOI: 10.1002/ecs2.70423

ECOSPHERE
AN ESA OPEN ACCESS JOURNAL

ARTICLE
Animal Ecology

Initial responses of songbird communities to forest reclamation on legacy surface mines

Rebecca N. Davenport[1] | **Christopher Barton**[1] | **John Cox**[1] | **Jacquelyn C. Guzy**[2] | **Lauren Sherman**[1] | **Jeffery L. Larkin**[3] | **Todd Fearer**[4,5] | **Steven J. Price**[1]

[1]Department of Forestry and Natural Resources, University of Kentucky, Lexington, Kentucky, USA

[2]Wetland and Aquatic Research Center, U.S. Geological Survey, Davie, Florida, USA

[3]Department of Biology, Indiana University of Pennsylvania, Indiana, Pennsylvania, USA

[4]American Bird Conservancy, The Plains, Virginia, USA

[5]Appalachian Mountains Joint Venture, Blacksburg, Virginia, USA

Correspondence
Steven J. Price
Email: steven.price@uky.edu

Present address
Rebecca N. Davenport, Stantec, Fresno, California, USA.

Funding information
American Ornithological Society; US Forest Service; The Wildlife Society; Wilson Ornithological Society; McIntire Stennis Capacity Grant Program, Grant/Award Number: KY009040; Karri Casner Environmental Sciences Fellowship; Office of Surface Mining Reclamation and Enforcement Applied Science Grant Program, Grant/Award Number: S21AC10048; Department of Forestry and Natural Resources at the University of Kentucky; Richards Graduate Student Research Activity Award

Handling Editor: Evan P. Tanner

Abstract

Surface coal mining and subsequent reclamation efforts in the Appalachian Mountains, USA, transform the ecological characteristics of natural landscapes. The Forestry Reclamation Approach (FRA) is a mine reclamation method that emphasizes best management practices in forestry. FRA practices have demonstrated success in establishing native forests and accelerating natural succession on coal mines; however, no studies have empirically examined the effects of the FRA on bird communities. Our study aimed to assess the avian community composition within young forests reclaimed using the FRA after one decade of forest growth. Whereas traditional reclamation practices often support grassland avian guilds, we expected that the FRA would provide habitat for shrubland and young forest avian guilds. Moreover, we sought to determine whether FRA forests would contain known avian indicator species of the native forest land cover. In June 2022, we conducted point count surveys in high-elevation, red spruce-northern hardwood (RS-NH) forests in the Appalachian Mountains of eastern West Virginia, USA. Using Bayesian multispecies occupancy models, we assessed avian guild occupancy and species richness within two FRA forest age classes (2–5 years and 8–11 years). We also examined avian community composition within two older RS-NH reference age classes to predict the future avian composition within FRA forests if reclamation succeeds. We found that the FRA breeding bird community included all of the avian indicator species expected to inhabit a young RS-NH forest. These results suggest that after approximately one decade, legacy mines reclaimed using the FRA are progressing toward a native RS-NH forest that supports associated forest bird communities.

KEYWORDS
Appalachians, avian communities, breeding forest birds, coal mine reclamation, Forestry Reclamation Approach, indicator species, nesting guilds, occupancy, red spruce-northern hardwood, species richness

INTRODUCTION

Human disturbance can dramatically transform natural landscapes, often resulting in habitat fragmentation (Fischer & Lindenmayer, 2007; Wilson et al., 2016), reductions in habitat quality and complexity (Caviedes & Ibarra, 2017; Pike et al., 2010; Vásquez-Grandón et al., 2018), and changes in biodiversity (Barlow et al., 2016; Cardinale & Palmer, 2002; Dornelas, 2010). Surface coal mining is a large-scale human disturbance that has impacted over 607,000 ha of land across the Central Appalachian Mountains region of eastern North America since the 1970s (Pericak et al., 2018). Coal mining can disturb ecosystems by altering the landscape's natural topography, reducing forest cover, and changing natural hydrology and soil properties (Wickham et al., 2013). Consequently, mining and other forms of resource extraction often impact various biotic communities, leading to long-term shifts in community composition (Schuler et al., 2002). Efforts to restore coal-mined land can mitigate the downstream effects of disturbance on local taxa.

Surface mine reclamation aims to reduce the adverse environmental consequences of landscape change. Mine reclamation can generally be classified into two approaches: traditional reclamation into grassland and the Forestry Reclamation Approach (FRA), developed in 2005 (Burger et al., 2005). Under the Surface Mining Control and Reclamation Act (SMCRA) of 1977, coal mining companies are required to revegetate the landscape and restore the area to its approximate original contour to prevent soil erosion and landslides post-mining (Bulluck & Buehler, 2006; Burger et al., 2005; Lambert et al., 2021). Traditional reclamation practices in the Appalachians typically involve soil compaction by heavy equipment and the planting of aggressive, non-native grasses and forbs to form grasslands (Angel et al., 2015). Despite the legislative intentions, traditional reclamation frequently results in poor hydrological function, limited root growth, loss of topographic complexity, forest loss, and loss of biodiversity (Angel et al., 2015; Wickham et al., 2013; Williamson & Barton, 2020). Moreover, traditionally reclaimed minelands often remain in a state of arrested succession, thus inhibiting successful reforestation of native trees for decades (Bulluck & Buehler, 2006; Burger et al., 2013; Zipper et al., 2011).

Contrary to traditional reclamation, the FRA aims to more quickly restore ecosystem function and native forest vegetation to minelands (Burger et al., 2005; Zipper et al., 2011). This approach was developed after extensive reclamation research and involves a detailed five-step process for reclaiming active minelands to forest under SMCRA (Burger et al., 2005). Specifically, the FRA recommends methods for creating a suitable rooting medium, loosely grading topsoil, using native vegetation for erosion control ground-cover, and planting native tree species using proper planting techniques (Burger et al., 2005). Minelands reclaimed using the FRA have been observed to undergo a more accelerated natural succession compared to traditional methods that establish grasslands (Groninger et al., 2007). Consequently, the FRA may ultimately create conditions that maintain somewhat similar ecological communities to those of native Appalachian forests.

A modified form of the FRA was developed for "legacy mines," or surface mines that were originally reclaimed to grassland or shrubland (Burger et al., 2013). Contrary to the FRA practices used on active mines, legacy mine FRA emphasizes soil decompaction, non-native species removal, native tree and shrub planting, woody debris loading, and vernal pool creation (Burger et al., 2013). Despite their different applications, both forms of the FRA are expected to encourage the rapid succession of native forest and habitat provisioning for biotic communities. In particular, the FRA may benefit Appalachian forest-obligate bird species, many of which depend on contiguous multiaged forest across their breeding range (Fiss et al., 2021; Schlossberg et al., 2018; Vitz & Rodewald, 2006).

The FRA may differ from traditional reclamation practices in its capacity to support diverse forest bird communities, including many species experiencing dramatic population declines (Rosenberg et al., 2019). Theoretically, the FRA should benefit forest bird communities by initially providing a mix of herbaceous, shrub, and sapling cover known to be important to many forest birds during nesting and post-fledgling periods (Anders et al., 1998; Goguen, 2019; King et al., 2006), and later providing habitat for mature forest species after several decades of succession (Groninger et al., 2007). Given the accelerated natural succession of FRA forests (Groninger et al., 2007), we should also expect FRA sites to begin providing habitat conditions for forest birds associated with closed-canopy (or older) forests faster than naturally regenerated forests post-mining. Nevertheless, no studies have verified these expectations by examining the avian community within forests reclaimed using the FRA (Lituma et al., 2021; Zipper et al., 2011). This is a critical research gap, as FRA implementation could potentially contribute to avian conservation efforts across hundreds of thousands of hectares of land in the Appalachians, where the recovery of forest bird species is a regional priority (Franzreb & Phillips, 1996; Franzreb & Rosenberg, 1997).

One way to discern whether reclaimed landscapes are providing habitat for breeding forest birds is by comparing breeding season bird communities on reclaimed mines to those within native reference forests. At high elevations (>1000 m) in the Central Appalachians, the

native land cover has historically consisted of red spruce (*Picea rubens*)-dominated forests. Due to surface coal mining, exploitative timber harvest, and wildfire damage, red spruce populations in the Central Appalachians have been significantly reduced and replaced by even-aged, northern hardwoods (Hopkins, 1899; Schuler et al., 2002; Trani, 2002). A recent study identified 11 bird species that are strong indicators of red spruce-northern hardwood (RS-NH) forests in the Central Appalachians (Clipp et al., 2022). The presence/absence of these indicator species on FRA minelands can therefore inform reclamation success for breeding bird communities.

We conducted a preliminary assessment of forest bird communities within legacy mines reclaimed using the FRA. To evaluate the current status of avian communities within young FRA forests, our study had two main questions: First, do FRA forests support shrubland and young forest avian guilds after only one decade of forest growth? Second, are there specifically young RS-NH avian indicator species present within both FRA forest classes? To answer these questions, we assessed the composition of breeding bird communities across two age classes of young FRA forest (2–5 years and 8–11 years). We also examined avian communities within two reference age classes for older RS-NH forest: (1) >40 years old naturally regenerated forest on mineland, and (2) >100 years unmined mature forest. Our references established a framework for tracking the progression of FRA forest bird communities toward native forest bird communities over time. Due to the forest management guidelines inherent in the FRA, we hypothesized that FRA forests would already host young forest bird species, including those that are strongly associated with RS-NH forests.

METHODS

Study area

Our study occurred in the Monongahela National Forest (MNF), located in the Allegheny Mountains of eastern West Virginia (USA) (Figure 1). The MNF covers over 371,906 ha across 10 counties in the West Virginia highlands, with elevations ranging from around 305 to 1482 m above sea level (USDA Forest Service, n.d.). Common hardwood species include American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and black cherry (*Prunus serotina*) (Clipp et al., 2022). Above 1000 m, red spruce is often the dominant tree species in the region (Rentch et al., 2007; Stephenson & Clovis, 1983).

Within the MNF, we focused on legacy minelands at the Mower Tract and Sharp Knob, located in Randolph and Pocahontas counties, West Virginia, respectively. The Mower Tract is a 16,187-ha, high-elevation area of the MNF located on Cheat Mountain (1478 m), and was purchased from the Mower Land and Lumber Company in the early 1980s (Green Forests Work, 2020). In addition to intensive logging from the late 1800s until the early 1970s, approximately 809 ha of the Mower Tract were surface mined for coal in the late 1970s and early 1980s and reclaimed to grasslands, further contributing to the loss of native RS-NH forests (Green Forests Work, 2020). Red spruce-northern hardwood forests were similarly degraded at Sharp Knob (1382 m), a mountain peak where coal mining continued across 280 ha of land through the early 1970s, followed by traditional reclamation into grassland.

In 2008, the US Forest Service partnered with Green Forests Work and the Appalachian Regional Reforestation Initiative to begin implementing ecological restoration on legacy minelands in the MNF. From 2011 to 2021, Green Forests Work planted over 566,000 native trees across 450 ha of the Mower Tract (Green Forests Work, 2023). In addition to recommended FRA practices used on active mine sites (Burger et al., 2005), Green Forests Work used modified FRA techniques that pertain specifically to legacy mine sites (Burger et al., 2013), including non-native species removal and soil de-compaction using a deep ripping shank. Green Forests Work also created vernal pools and loaded woody debris within project areas on the Mower Tract to enhance structural complexity, provide wildlife habitat, slow surface runoff of water, and enhance depressional water storage on-site (Branduzzi et al., 2020). These same FRA practices were also implemented on legacy mines at Sharp Knob. From 2018 to 2021, Green Forests Work planted over 92,000 native trees and shrubs across 68 ha of Sharp Knob (Green Forests Work, 2023).

Forest age classes

To assess avian breeding community response to mine reclamation, we selected 32 sites within the MNF (29 in the Mower Tract and 3 at Sharp Knob) (Figure 1). Sites were divided equally among four forest age classes: (1) younger FRA (YFRA), (2) older FRA (OFRA), (3) naturally regenerated forest on mineland (REGEN), and (4) unmined, mature forest (MAT) (Figure 2). Younger FRA sites were reclaimed between 2017 and 2020, or 2–5 years prior to data collection in 2022. These sites were planted with a seedling mix of red spruce and 12 hardwood species, including aspen (*Populus* sp.), black cherry, mountain ash (*Sorbus americana*), sugar maple, and serviceberry (*Amelanchier arborea*). In 2021, red spruce seedlings at YFRA sites had a mean height of 0.36 m (Rhodes, 2022). At the time of data collection in

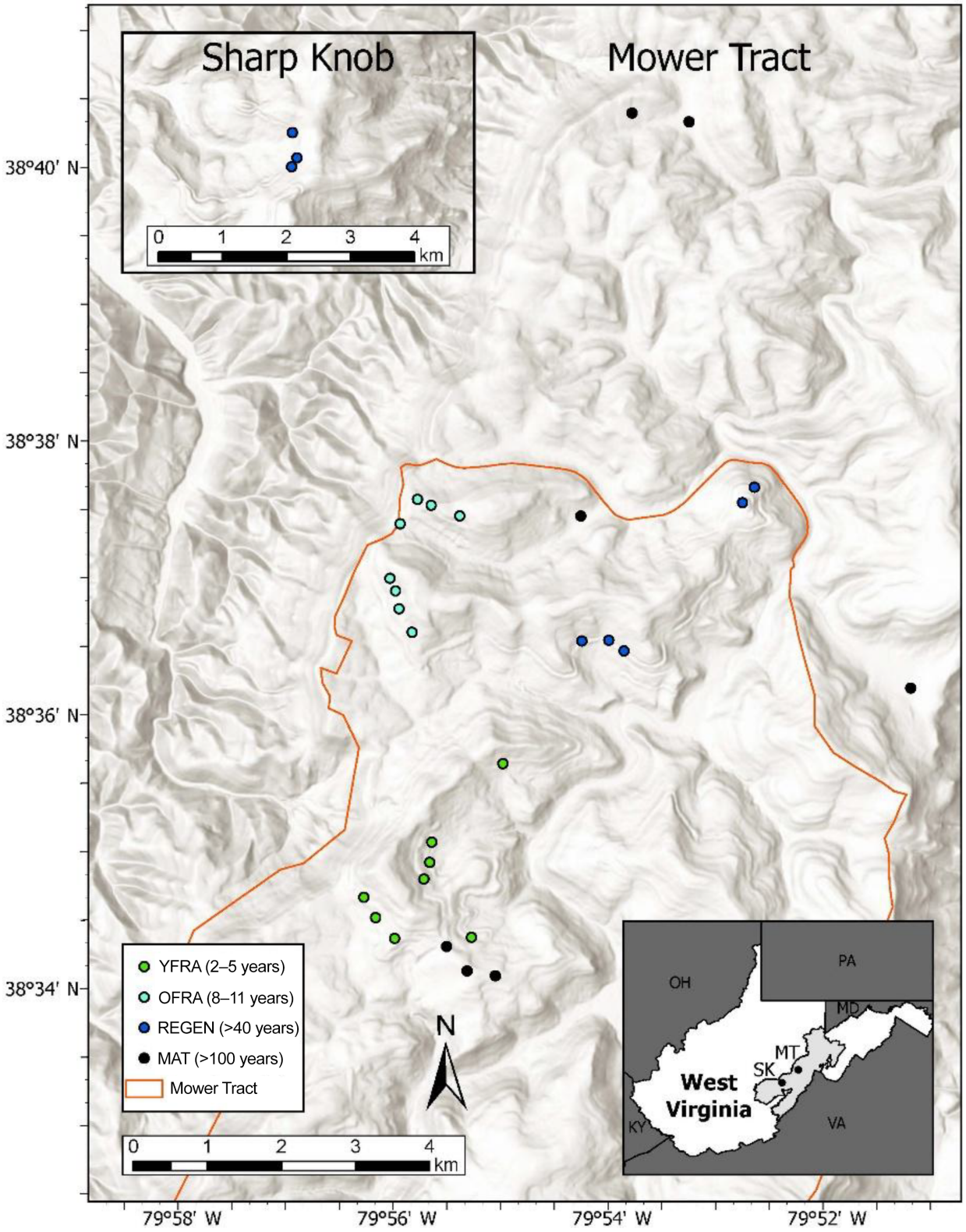

FIGURE 1 Map of 32 sites selected in 2022 across the Monongahela National Forest (West Virginia, USA), each belonging to one of four forest age classes. Green sites are younger Forestry Reclamation Approach (FRA) sites that were reclaimed between 2 and 5 years ago (YFRA). Light blue sites represent older FRA sites that were reclaimed between 8 and 11 years ago (OFRA). Dark blue sites represent naturally regenerated forests that were mined >40 years ago (REGEN). Black sites indicate unmined, mature forest sites that were logged >100 years ago (MAT). Twenty-nine sites fall within the Mower Tract orange boundary, while 3 sites are positioned within Sharp Knob. Inset map shows locations of the Mower Tract (MT) and Sharp Knob (SK) within West Virginia.

FIGURE 2 Four age classes of red spruce-northern hardwood forest in the Monongahela National Forest, West Virginia: (A) younger Forestry Reclamation Approach (FRA) (YFRA; 2–5 years), (B) older FRA (OFRA; 8–11 years), (C) naturally regenerated forest on mineland (REGEN; >40 years), and (D) unmined, mature forest (MAT; >100 years). Photo credit: Rebecca N. Davenport.

2022, planted trees and shrubs averaged <1 m in height. Generally, YFRA sites were characterized by extensive herbaceous groundcover, including species from the original mine reclamation mix and naturally colonized species that emerged after ripping (Branduzzi, 2020). Older FRA sites were reclaimed between 2011 and 2014, or 8–11 years before data collection. During site preparation, OFRA sites were initially planted with a seedling mix of red spruce and three hardwood species—aspen, black cherry, and serviceberry. In 2021, red spruce seedlings at OFRA sites had an average height of 2.01 m (Rhodes, 2022). At the time of data collection in 2022, planted trees and shrubs had reached approximately 2–4 m in height. Based on the planting of herbaceous cover as well as early tree and shrub growth, both YFRA and OFRA sites were classified as young successional forest. Coal mining at REGEN sites occurred prior to 1977, or over 40 years prior to our study. Given that these sites were mined before SMCRA was passed, the land was not restored to its original contour, and all REGEN sites were adjacent to an exposed rock face, or highwall. All of the REGEN benches (i.e., narrow, horizontal strips of land cut into the side of open-pit mines) were initially reclaimed as grasslands, and all of these sites were planted with non-native conifers such as Norway spruce (*Picea abies*). The long and narrow mine benches were surrounded, above and below, by native forest which could have provided a seed source for natural succession; however, the compacted nature of the soils and the inability of Norway spruce to facilitate regeneration of other species have slowed succession (Branduzzi, 2020). Regardless, the lengthy time since reclamation and narrowness of the mine benches at REGEN sites contributed to moderate recolonization and natural regeneration of red spruce and other native plants, resulting in a mosaic of native and exotic tree species with varying age classes

amidst patches of grassland. We categorized REGEN sites as a mixture of herbaceous, small-diameter woody stems, and maturing forest. REGEN sites functioned as our first reference for older RS-NH forest. Finally, MAT sites were unmined patches of second-growth, RS-NH forest, harvested during the early 1900s. They were predominantly composed of red spruce, beech, yellow birch (*Betula alleghaniensis*), and red maple (*Acer rubrum*). Although MAT sites have a history of disturbance, they were not surface mined and therefore represented a least disturbed reference for evaluating the trajectory of FRA forest recovery. We did not collect vegetation height data for either reference age class during the study period. However, both older forest age classes had nearly 100% canopy cover within a 100-m radius (Davenport, 2023).

Initially, we hoped to include an additional reference category for unmined, early successional RS-NH forest. This would have allowed us to directly compare avian communities in FRA forests to those within the same forest age class, giving us a better assessment of FRA progress. However, we were unable to locate sufficient site replicates within the Mower Tract and Sharp Knob to include an early successional reference category. Although we did not expect the REGEN and MAT forests to contain similar bird communities to FRA forests at the present time, we hoped that they would foreshadow older FRA forest conditions. Therefore, REGEN and MAT forests still functioned as informative references for older RS-NH forests.

Each site was centered around either a created or natural vernal pool. This study was part of a large-scale assessment of wildlife response to the FRA that included birds, amphibians, bats, and other mammals. Given the close association between vernal pools and many of the target species, vernal pools were a necessary feature for site selection and were the centralized location for all wildlife surveying. Vernal pools ranged in total area from 5 to 233 m^2. Considering the relatively small size of these vernal pools, we were not concerned that vernal pool presence would influence the overall composition of site-specific bird communities. Point count surveys detected birds up to a 100-m radius (see *Point count surveys*), while vernal pools spanned a maximum radius of ~8.61 m. All selected vernal pools were positioned at least 200 m apart to facilitate spatial independence between avian surveys.

Point count surveys

From June 1 through June 23, 2022, we surveyed breeding bird communities using 10-min, 100-m radius, stationary point count surveys located at the edge of each site's vernal pool. Each site was sampled on three occasions during the study period, with a 7-day interval between consecutive surveys. The duration of the study was one breeding season, and we assumed closure during the 3-week sampling period. We performed point counts in the absence of rain and strong winds, starting no earlier than 15 min before sunrise, and ending no later than 10:00 am EST. Prior to each point count, we recorded day of year, time of survey, air temperature, wind speed, and cloud cover to include as survey covariates in our analyses. Cloud cover and wind speed were estimated using the Okta scale (Stull, 2015) and Beaufort wind force scale (World Meteorological Organization, 1970), respectively. Each survey was conducted simultaneously by two observers, both of whom were trained and tested to minimize bias and confirm accuracy. Observers recorded all species seen or heard during the survey, excluding all flyovers. If there were discrepancies between the two reports, we adjusted the data record to include all species confidently detected by either observer during the survey. If a species was only detected by one observer, we referred back to an audio recording taken during the 10-min survey on the mobile application software, Merlin (The Cornell Lab, 2014), to either confirm or deny the presence of the species. Audio recordings were only used to cross-reference species that had already been detected by human observers during the point count and did not otherwise supplement survey data.

Multispecies Bayesian community occupancy model

To assess the effect of reclamation approach and survey covariates on avian communities, we constructed a Bayesian hierarchical multispecies community occupancy model (MacKenzie et al., 2017; Zipkin et al., 2009). This model incorporates site and survey covariates to provide species-specific estimates of occupancy and detection probability, and to estimate the mean community response (Dorazio & Royle, 2005). Specifically, we estimated avian community response to categorical site-specific covariates of forest age class (i.e., YFRA, OFRA, REGEN, or MAT). We also tested for meaningful associations between detection probability and five survey-level covariates: day of year (DOY), time of day (Time), estimated cloud cover (Cloud), estimated wind speed (Wind), and air temperature (Temp). We did not include vernal pool area as a site covariate given that vernal pool size and other site characteristics (i.e., distance to road and proportion of forest cover) did not have a meaningful relationship with avian occupancy (Davenport, 2023). This is likely because vernal pool area was negligible compared to surveyed forest area,

and the proportion of forest cover was collineated with forest age class. Mean proportion of forest cover within a 100-m radius for YFRA (mean ± SE) (0.81 ± 0.26) and OFRA (0.63 ± 0.26) was less than REGEN (1.00 ± 0.00) and MAT (0.99 ± 0.04) (Davenport, 2023).

Our community modeling approach combined single species estimates with the average parameter estimate for the entire community. This approach reduces bias and improves the precision of parameter estimates for species with few detections, or "data-poor" species, by borrowing information from species with higher detections, or "data-rich" species (Pacifici et al., 2014; Sauer & Link, 2002). Therefore, we separated species into three distinct nesting habitat guilds: (1) mature forest, (2) young forest, and (3) generalist, based on previous classifications of their breeding biology (Appendix S1: Table S1; Byers et al., 2010; Canterbury et al., 2000). Both young forest and mature forest habitat guilds of birds have strongly positive within-group correlations, or similar population responses to environmental variation (Canterbury et al., 2000). Consequently, it is crucial that the community consists of species with either ecological, functional, or behavioral relatedness (Pacifici et al., 2014). By separating our pool of species into these functional groups (i.e., nesting guilds), we ensured that the models would only borrow data from species with shared nesting habitat requirements.

We formatted our data into a matrix (i,j,k), where species i was detected at site j on sampling occasion k. Occupancy probability, Ψ_{ij}, represented the probability of species i occurring at site j, modeled as a function of covariate parameters on α. Detection probability, p_{ijk}, represented the probability of detecting species i at site j on sampling occasion k, modeled as a function of covariate parameters on β. We modeled multispecies occupancy for each guild with the following equation, applied to three models (i.e., mature forest, young forest, and generalist guilds):

$$\text{logit}(\Psi_{ij}) = u_i + \alpha_{1i}\text{YFRA}_j + \alpha_{2i}\text{OFRA}_j + \alpha_{3i}\text{REGEN}_j.$$

We modeled detection probability for each guild with the following equation applied to three models (i.e., mature forest, young forest, and generalist guilds):

$$\text{logit}\left(p_{ijk}\right) = v_i + \beta_{1i}\text{DOY}_{jk} + \beta_{2i}\text{Time}_{jk} + \beta_{3i}\text{Cloud}_{jk} + \beta_{4i}\text{Wind}_{jk} + \beta_{5i}\text{Temp}_j.$$

Each model contained a total of eight parameters: α_{1i}, α_{2i}, α_{3i}, β_{1i}, β_{2i}, β_{3i}, β_{4i}, and β_{5i}. Parameters α_1, α_2, and α_3 were effects of the categorical variable of forest age class, with "MAT" as the reference category. The remaining parameters were continuous covariates, standardized to have mean of zero.

We estimated species richness (SpR) at sampled sites by summing indicator variables for occupancy for each species at each site for each model iteration to generate a posterior predictive distribution for species richness in each age class. More specifically, at each iteration, the model estimated a latent state variable (occupied or unoccupied) for species i at site j, which we summarized across all species (within the guild) at a given site for that iteration. We then calculated the mean species richness per forest age class for each guild.

We used a Bayesian framework with Markov chain Monte Carlo sampling (Link et al., 2002). We used a uniform distribution and uninformative priors with a mean of −3 and precision of 3 (i.e., $U(-3, 3)$ for α, β, and community-level parameters, and $U(0, 5)$ for all SD [σ] parameters). The model was run with three parallel chains, which were checked for convergence using the Gelman–Rubin statistic; for all monitored parameters in this study, this value was at or below 1.02, indicating convergence (Gelman & Rubin, 1992). Each chain was run for 70,000 iterations with a 20,000-sample burn-in and a thinning rate of 3. We thus retained 50,000 samples from the posterior distribution and approximated posterior summary statistics for each parameter, including mean, SD, and 95% Bayesian credible intervals (CIs). The CIs were defined by the 2.5 and 97.5% percentiles of the distribution. Parameter estimates with CIs that did not contain zero were interpreted as biologically meaningful covariates for occupancy and/or detection probability. We used the R package R2WinBUGS (Sturtz et al., 2005) in R version 4.0.3 to export data into WinBUGS version 1.4.3 and perform the Bayesian analysis. R and WinBUGS code were developed by Guzy (2024).

RESULTS

Point count surveys

We detected 49 species during avian point count surveys (Appendix S1: Table S1). In total, we detected 35, 32, 30, and 36 species in the YFRA, OFRA, REGEN, and MAT forest age classes, respectively. Within the nesting habitat guilds, we detected 26 mature forest species, 16 young forest species, and 7 habitat generalist species (Appendix S1: Table S1). Across all forest age classes, we detected 15 avian indicator species of RS-NH forests (Clipp et al., 2022). The number of detected indicator species in the YFRA, OFRA, REGEN, and MAT forests was 11, 13, 13, and 12, respectively (Appendix S1: Table S1). Eleven indicator species belonged to the mature forest

guild, three belonged to the young forest guild, and one belonged to the habitat generalist guild. Detection of young forest guild species was negatively associated with day of year ($\beta_1 = -0.51$; 95% CI = −0.99 to −0.08). Remaining survey covariates did not have meaningful associations with avian nesting habitat guild detection (Appendix S1: Table S2).

Species richness and occupancy estimates

Younger (2–5 years) FRA forest

Mean species richness estimates for the mature forest, young forest, and habitat generalist guilds were 10.47 (95% CI = 6.63–15.88), 11.86 (95% CI = 8.75–15.13), and 4.40 (95% CI = 3.25–5.63), respectively (Figure 3). Mean occupancy estimates for the mature forest, young forest, and habitat generalist guilds were 0.36 (95% CI = 0.15–0.65), 0.79 (95% CI = 0.54–0.94), and 0.76 (95% CI = 0.32–0.97), respectively (Figure 4). Estimated mean occupancy of the mature forest guild was negatively associated with YFRA sites, whereas occupancy of the young forest and habitat generalist guilds was both positively associated with YFRA sites (Figure 5; Appendix S1: Table S3). Of the 15 avian indicator species of RS-NH forests detected in our study (Clipp et al., 2022), occupancy estimates for 10 species were negatively associated with YFRA sites, and four species were positively associated with YFRA sites (Table 1).

Older (9–20 years) FRA forest

Mean species richness estimates for the mature forest, young forest, and habitat generalist guilds were 10.22 (95% CI = 6.88–15.13), 10.40 (95% CI = 7.13–14.38), and 2.48 (95% CI = 1.88–3.88), respectively (Figure 3). Mean occupancy estimates for the mature forest, young forest, and habitat generalist guilds were 0.36 (95% CI = 0.15–0.62), 0.69 (95% CI = 0.37–0.92), and 0.38 (95% CI = 0.05–0.86), respectively (Figure 4). Estimated mean occupancy of the mature forest guild was negatively associated with OFRA sites, whereas occupancy of the young forest guild was positively associated with OFRA sites (Figure 5; Appendix S1: Table S3). Estimated mean occupancy of the habitat generalist guild did not show a meaningful association with OFRA sites. Of the 15 avian indicator species of RS-NH forests detected in our study (Clipp et al., 2022), occupancy estimates for five species were negatively associated with OFRA sites, and

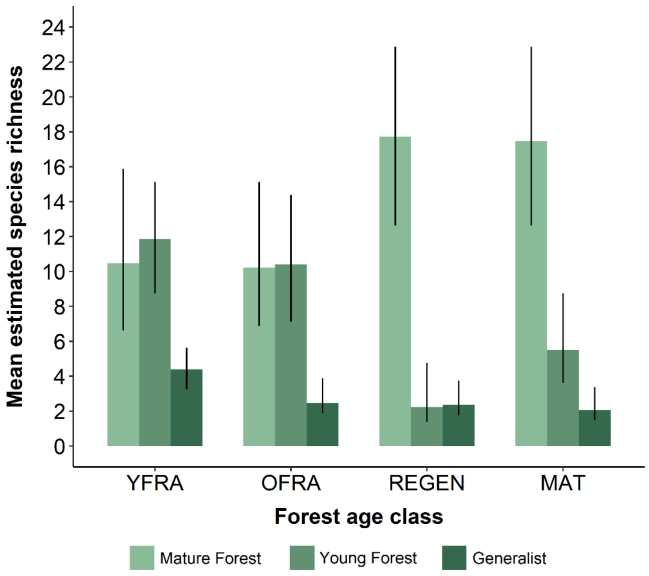

FIGURE 3 Mean estimated species richness of three avian nesting habitat guilds (i.e., mature forest, young forest, and generalist) across four forest age classes (i.e., younger Forestry Reclamation Approach [FRA] [YFRA], older FRA [OFRA], naturally regenerated forest on mineland [REGEN], and unmined mature forest [MAT]). Solid black lines indicate 95% credible intervals for richness estimates. Species richness estimates are derived from avian point count surveys conducted in the Monongahela National Forest, West Virginia, in June 2022.

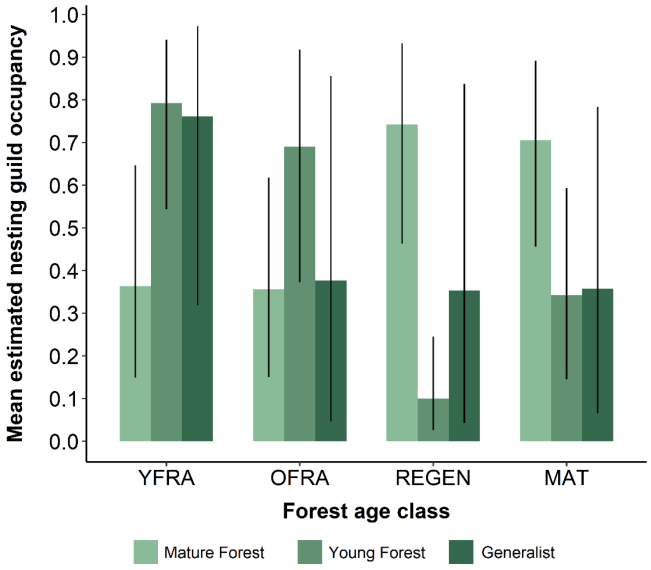

FIGURE 4 Mean estimated occupancy of three avian nesting habitat guilds (i.e., mature forest, young forest, and generalist) across four forest age classes (i.e., younger Forestry Reclamation Approach [FRA] [YFRA], older FRA [OFRA], naturally regenerated forest on mineland [REGEN], and unmined mature forest [MAT]). Solid black lines indicate 95% credible intervals for occupancy estimates. Occupancy estimates are derived from avian point count surveys conducted in the Monongahela National Forest, West Virginia, in June 2022.

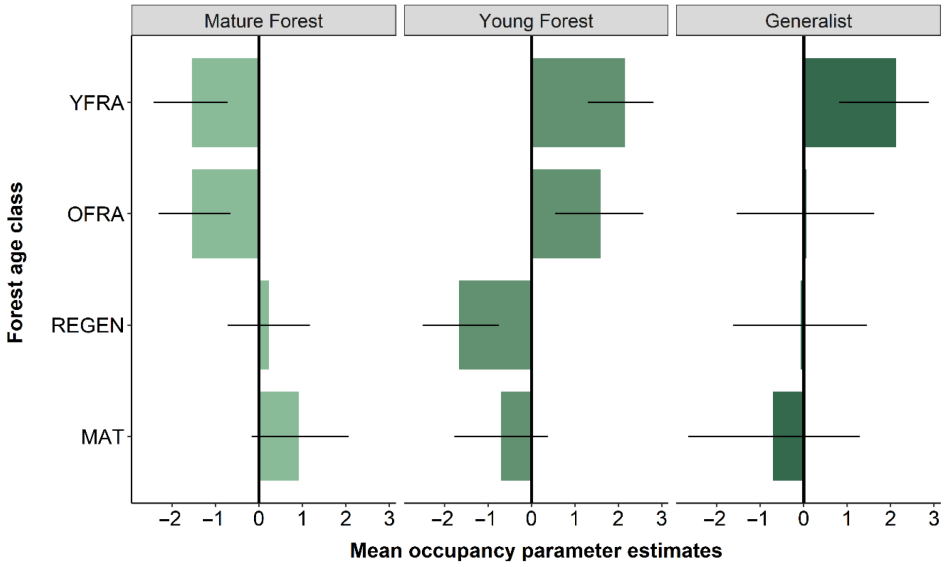

FIGURE 5 Mean parameter estimates for occupancy of three avian nesting habitat guilds (i.e., mature forest, young forest, and generalist). Green bars to the right of 0.0 indicate a positive relationship between guild occupancy and forest age class, whereas bars to the left of 0.0 indicate a negative relationship. Solid black lines indicate 95% credible intervals (95% CIs) for parameter estimates. Estimates are considered meaningful if the 95% CIs do not contain zero. Parameter estimates are derived from avian point count surveys conducted in the Monongahela National Forest, West Virginia, in June 2022. MAT, unmined mature forest; OFRA, older Forestry Reclamation Approach; REGEN, naturally regenerated forest on mineland; YFRA, younger Forestry Reclamation Approach.

three species were positively associated with OFRA sites (Table 1).

Naturally regenerated forest (>40 years)

Mean species richness estimates for the mature forest, young forest, and habitat generalist guilds were 17.73 (95% CI = 12.63–22.88), 2.25 (95% CI = 1.38–4.75), and 2.36 (95% CI = 1.75–3.75), respectively (Figure 3). Mean occupancy estimates for the mature forest, young forest, and habitat generalist guilds were 0.74 (95% CI = 0.46–0.93), 0.10 (95% CI = 0.03–0.25), and 0.35 (95% CI = 0.04–0.84), respectively (Figure 4). Estimated mean occupancy of the young forest guild was negatively associated with REGEN sites, whereas mean occupancy estimates for both the mature forest and habitat generalist guilds did not show a meaningful association with REGEN sites (Figure 5; Appendix S1: Table S3). Of the 15 avian indicator species of RS-NH forests detected in our study (Clipp et al., 2022), occupancy estimates for two species were negatively associated with REGEN sites, and none were positively associated with REGEN sites (Table 1).

Unmined mature forest (>100 years)

Mean species richness estimates for the mature forest, young forest, and habitat generalist guilds were 17.48 (95% CI = 12.63–22.88), 5.50 (95% CI = 3.63–8.75), and 2.07 (95% CI = 1.50–3.38), respectively (Figure 3). Mean occupancy estimates for the mature forest, young forest, and habitat generalist guilds were 0.71 (95% CI = 0.46–0.89), 0.34 (95% CI = 0.15–0.59), and 0.36 (95% CI = 0.07–0.78), respectively (Figure 4). Mean occupancy estimates for the mature forest, young forest, and habitat generalist guilds did not show a meaningful association with MAT sites (Figure 5; Appendix S1: Table S3). Of the 15 avian indicator species of RS-NH forests detected in our study (Clipp et al., 2022), none were negatively associated with MAT sites, and seven species were positively associated with MAT sites (Table 1).

DISCUSSION

The primary objective of our study was to assess the bird community composition within young FRA forests. As expected, forests established using the FRA were dominated by avian species that breed in shrubland and young forests, including forests only 2–5 years post-reclamation. Species detected widely across younger and older FRA forests included the American Goldfinch (*Spinus tristis*), Chipping Sparrow (*Spizella passerina*), Common Yellowthroat (*Geothlypis trichas*), Dark-eyed Junco (*Junco hyemalis*), Eastern Towhee (*Pipilo erythrophthalmus*), Field Sparrow (*Spizella pusilla*), and Indigo Bunting (*Passerina cyanea*). Other studies have found similar bird species to be

TABLE 1 Mean parameter estimates (α) and 95% credible intervals (95% CIs in parentheses) for occupancy of red spruce-northern hardwood forest avian indicator species, separated by avian nesting habitat guild (i.e., mature forest, young forest, and generalist), where parameter estimates are derived from avian point count surveys conducted in the Monongahela National Forest in June 2022.

Guild	Species	α_{YFRA}	α_{OFRA}	α_{REGEN}	α_{MAT}
Mature forest	Blackburnian Warbler (*Setophaga fusca*)	**−1.86** (**−2.85** to **−0.82**)	**−1.68** (**−2.68** to **−0.42**)	0.54 (−0.98 to 2.36)	2.16 (−0.04 to 4.55)
	Black-throated Green Warbler (*Setophaga virens*)	**−1.57** (**−2.60** to **−0.32**)	−1.40 (−2.53 to 0.32)	0.45 (−1.26 to 2.36)	**4.12** (**1.66–6.76**)
	Blue-headed Vireo (*Vireo solitarius*)	**−1.61** (**−2.64** to **−0.38**)	**−1.57** (**−2.62** to **−0.11**)	0.35 (−1.36 to 2.28)	**3.08** (**0.74–5.79**)
	Golden-crowned Kinglet (*Regulus satrapa*)	**−1.52** (**−2.53** to **−0.30**)	**−1.91** (**−2.85** to **−0.85**)	0.89 (−0.59 to 2.66)	**2.21** (**0.00–4.57**)
	Hermit Thrush (*Catharus guttatus*)	**−1.69** (**−2.74** to **−0.48**)	−1.35 (−2.50 to 0.42)	0.22 (−1.62 to 2.18)	**3.21** (**0.72–6.22**)
	Magnolia Warbler (*Setophaga magnolia*)	**−1.63** (**−2.66** to **−0.41**)	−1.36 (−2.50 to 0.41)	0.30 (−1.52 to 2.26)	**4.01** (**1.57–6.69**)
	Red-breasted Nuthatch (*Sitta canadensis*)	**−1.59** (**−2.65** to **−0.26**)	−1.31 (−2.50 to 0.60)	0.34 (−1.47 to 2.29)	**3.51** (**0.76–6.64**)
	Rose-breasted Grosbeak (*Pheucticus ludovicianus*)	**−1.56** (**−2.65** to **−0.17**)	**−1.60** (**−2.70** to **−0.01**)	0.38 (−1.43 to 2.30)	0.37 (−3.45 to 5.05)
	Swainson's Thrush (*Catharus ustulatus*)	**−1.39** (**−2.43** to **−0.02**)	**−2.06** (**−2.91** to **−1.04**)	0.49 (−1.03 to 2.30)	2.20 (−0.01 to 4.53)
	Winter Wren (*Troglodytes hiemalis*)	**−1.68** (**−2.74** to **−0.47**)	−1.40 (−2.55 to 0.31)	0.41 (−1.27 to 2.29)	1.75 (−1.10 to 5.32)
	Yellow-rumped Warbler (*Setophaga coronata*)	−1.37 (−2.45 to 0.19)	−1.47 (−2.58 to 0.25)	0.11 (−1.90 to 2.14)	**3.78** (**1.13–6.70**)
Young forest	Chestnut-sided Warbler (*Setophaga pensylvanica*)	**2.15** (**1.03–2.88**)	**1.77** (**0.46–2.83**)	**−1.74** (**−2.78** to **0.43**)	−1.72 (−4.00 to 0.61)
	Dark-eyed Junco (*Junco hyemalis*)	**2.17** (**1.01–2.89**)	**1.69** (**0.16–2.81**)	−1.37 (−2.55 to 0.32)	1.11 (−1.32 to 3.67)
	Mourning Warbler (*Geothlypis philadelphia*)	**2.00** (**0.31–2.87**)	**1.92** (**0.67–2.89**)	**−1.66** (**−2.76** to **0.12**)	−2.54 (−5.65 to 1.09)
Generalist	Northern Flicker (*Colaptes auratus*)	**2.06** (**0.33–2.92**)	0.52 (−1.36 to 2.54)	−0.04 (−1.99 to 1.89)	−2.06 (−6.08 to 3.63)

Note: Alpha (α) values indicate the strength and direction of the relationship between species occupancy and forest age class (i.e., younger FRA [YFRA; 2–5 years], older FRA [OFRA; 8–11 years], naturally regenerated forest on mineland [REGEN; >40 years], and unmined mature forest [MAT; >100 years]). Parameter estimates in boldface indicate meaningful relationships between species occupancy and the given forest age class (i.e., 95% CIs did not contain zero).

associated with Appalachian minelands reclaimed as shrubland (e.g., Margenau et al., 2019). Considering the prominence of young trees and shrubs and herbaceous groundcover within our FRA forests, we expected that associated breeding bird communities would belong to shrubland and young forest guilds.

We also predicted that bird communities in FRA forests might be distinguished from those within traditionally reclaimed grasslands, in part due to the native planting of trees and shrubs at FRA sites. Although our study did not directly compare young FRA forests to traditionally reclaimed grasslands, several studies have documented grassland species such as the Dickcissel (*Spiza americana*), Eastern Meadowlark (*Sturnella magna*), Grasshopper Sparrow (*Ammodramus savannarum*), Henslow's Sparrow (*Centronyx henslowii*), and Horned Lark (*Eremophila alpestris*) within reclaimed grasslands in the Appalachians (e.g., Margenau et al., 2019; Wood & Ammer, 2015). Although a direct comparison between high-elevation Appalachian reclaimed grasslands and FRA forests is needed to validate differences in bird communities, none of these grassland bird species occurred within FRA forests. Our preliminary observations may suggest that FRA practices removed the effects of non-native grasses on the avian community and established early successional shrubland and forest cover for associated bird communities.

Beyond determining the overall bird community composition within FRA forests, we were especially interested in whether FRA management practices established habitat for birds associated with native RS-NH forest cover. Of the 11 bird species identified as strong indicators of RS-NH forests in the Central Appalachians (Clipp et al., 2022), three species would be expected to nest in early successional RS-NH forest based on their breeding biology—the Chestnut-sided Warbler (*Setophaga pensylvanica*), Dark-eyed Junco, and Mourning Warbler (*Geothlypis philadelphia*) (Byers et al., 2010; Canterbury et al., 2000). All three of these species had occupancy estimates positively associated with both FRA forest age classes. This finding suggests that the FRA forests we monitored are already providing native habitat for breeding birds after only one decade of growth post-reclamation. Furthermore, we found that most of the indicator species expected to nest in mature RS-NH forest were negatively associated with FRA forests. This was anticipated given the absence of mature forest cover across our FRA sites. However, the number of negative species associations dropped from 10 to 5 between the younger and older FRA forest age classes, perhaps due to the taller vegetation and denser RS-NH tree cover within older FRA forests. Collectively, these findings suggest that breeding bird communities occupying FRA sites include species indicative of RS-NH reference systems, and that given additional time to successionally advance, FRA forests may support more of the bird species that are indicators of mature RS-NH forest.

Assessing forest restoration can be challenging because of the timeframe necessary for the ecosystem to fully develop. Studies assessing restoration projects must be sensitive to early changes in community development and predict future conditions. In this study, we applied a variation of the EPA's Wetland Research Program (WRP) (Kentula et al., 1992; Kolka et al., 2002) approach to assess avian community composition within FRA forests. The WRP approach includes the use of a reference system, which is a least disturbed example, or target ecosystem that the restored system should succeed to over time. The reference system approach has been defined as a standard used to measure the following: (1) the variability of natural conditions in an ecosystem (Kaufmann et al., 1994, 1998); (2) the change in an ecosystem (Kaufmann et al., 1998; Morgan et al., 1994); and (3) the success of ecological restoration or management objectives (Christensen et al., 1996; Moore et al., 1999). Although we understand the temporal and structural limitations that are inherent in comparing communities in early successional systems to older ones, we have shown it as a valuable method for understanding the restoration response of bats (Snyder et al., 2024) and amphibians (Price et al., 2024; Sherman et al., 2024) in the same restoration area as this study. Considering that we are examining forests that were restored at different times, we can also use this approach to examine how species composition may change over time as the structural complexity of the restored landscape changes.

As expected, avian communities within our older RS-NH reference forests were primarily composed of birds that breed in mature forest rather than shrubland and young forest. Species detected across naturally regenerated forest on mineland and unmined mature forest included the Blackburnian Warbler (*Setophaga fusca*), Black-throated Green Warbler (*Setophaga virens*), Blue-headed Vireo (*Vireo solitarius*), Golden-crowned Kinglet (*Regulus satrapa*), Magnolia Warbler (*Setophaga magnolia*), and Swainson's Thrush (*Catharus ustulatus*). Given the older age of our naturally regenerated forests and unmined forests (i.e., >40 years and >100 years, respectively), we expected that these reference forests may foreshadow habitat availability for breeding birds within FRA forests.

We had also anticipated that reference forests would host all or most of the 11 RS-NH indicator species known to breed in mature forests, including the Blackburnian Warbler, Black-throated Green Warbler, Blue-headed Vireo, Golden-crowned Kinglet, Hermit Thrush (*Catharus guttatus*), Magnolia Warbler, Red-breasted Nuthatch (*Sitta canadensis*), Rose-breasted Grosbeak (*Pheucticus ludovicianus*), Swainson's Thrush, Winter Wren (*Troglodytes hiemalis*), and Yellow-rumped Warbler (*Setophaga coronata*). Although all 11 of these indicator species were detected in naturally regenerated forests, none of the species had occupancy estimates positively associated with this reference age class. In this regard, naturally regenerated forests on mineland substantially differed from forests established using the FRA and unmined mature forests, both of which supported the indicator species corresponding to their successional stage. Even though naturally regenerated forests and unmined forests were estimated to host a similar overall richness of mature forest species (i.e., ~18 species; Figure 3), naturally regenerated forests are not providing conditions that support bird communities expected within the pre-mining RS-NH forest type (Clipp et al., 2022). The presence of mature forest species yet the dearth of RS-NH indicator species within forests that naturally regenerated on mineland may point to limitations of RS-NH recolonization via passive seed recruitment (Rhodes, 2022).

Associations with RS-NH indicator species occupancy suggest that forests established using the FRA may ultimately surpass naturally regenerated forests in providing habitat for RS-NH-dependent bird species. This is likely because forests resulting from the FRA were intentionally managed for growing conditions that facilitate RS-NH forest establishment and growth, while the growth of

naturally regenerated forests on previously mined lands was inhibited by heavy soil compaction and exotic species planting (Green Forests Work, 2020). After more than four decades since reclamation, naturally regenerated forests do appear to have succeeded to a more mature forest stage. Still, remnants of the original reclamation remain in the form of open grassland areas and exotic tree and shrub species. The narrowness of the mine benches and exposure to seed rain from the adjacent forest have aided their overall transition. Successful regeneration would be even less likely to occur on large surface mines reclaimed under SMCRA, where soil compaction is more severe, and the distance to seed sources is substantially greater (Angel et al., 2015; Hall et al., 2010).

Considering the apparent limitations in natural regeneration on legacy mines, our unmined mature forest age class may be a more accurate reference for future forest conditions and associated bird communities within FRA forests. If the implementation of the FRA was successful at our sites, they should eventually mature to RS-NH forest with sufficient cover for songbirds and other Appalachian wildlife. Therefore, future studies should continue to track forest succession and wildlife communities within our study sites, using our preliminary observations and unmined mature forests as a framework for evaluation. Repeated monitoring will be valuable for adaptively modifying FRA protocols to best achieve desired reclamation outcomes.

Due to the limited temporal and spatial scale of this study, we considered our observations to be a preliminary assessment of avian community composition within FRA forests. Nevertheless, even with only one breeding season of point count data across 32 sites, we observed clear associations between young FRA forests and young forest avian habitat guilds. Additional surveys could determine whether there is annual variation in breeding bird occupancy across these forest types, and strengthen our understanding of avian guild associations with forests reclaimed using the FRA. Finally, we understand that our forest age classes could be conflated with proportion canopy cover and other forest attributes, but we interpreted associations between avian occupancy and forest age class as a representation of general patterns shared across sites within each age class category. Future studies could test additional site covariates on occupancy (e.g., average vegetation height, shrub density, tree species composition, and other vegetation characteristics) to identify specific features of the FRA that are influencing bird communities.

CONCLUSION

Mountaintop removal mines and expansive area mines that are heavily compacted and converted to homogenous grassland or shrubland often remain in a state of arrested succession for several decades (Ingold & Dooley, 2013; Margenau et al., 2019; Wood & Ammer, 2015). Not only could the FRA become a viable alternative to traditional reclamation that establishes grassland on active mines, but it could be more widely used to convert legacy mines into native forests (Burger et al., 2013). In order to maintain herbaceous, shrub, and sapling cover for birds associated with young forest habitat, land managers may consider staggering implementation of the FRA across legacy mines so that young forests are continuously established proximate to mature forests. Dynamic forest structures consisting of multiaged forest patches will sustain the habitat needs of declining young forest bird communities (Sauer et al., 2017). Additionally, several mature forest bird species have been documented using young forests during post-fledgling periods, as long as such forest is proximate to their mature forest nesting habitat (Anders et al., 1998; King et al., 2006; Vitz & Rodewald, 2006). Therefore, understanding the timing of FRA forest succession may allow land managers to implement the FRA in a way that satisfies the spatiotemporal breeding habitat use patterns of forest bird species.

AUTHOR CONTRIBUTIONS

Rebecca N. Davenport, Christopher Barton, John Cox, Jeffery L. Larkin, Todd Fearer, and Steven J. Price conceived the research objectives. Rebecca N. Davenport, Christopher Barton, John Cox, Jacquelyn C. Guzy, Lauren Sherman, Jeffery L. Larkin, and Steven J. Price designed the methodology. Rebecca N. Davenport, Christopher Barton, Lauren Sherman, and Steven J. Price performed the fieldwork. Rebecca N. Davenport and Jacquelyn C. Guzy analyzed the data and prepared figures and/or tables. Rebecca N. Davenport wrote the manuscript. Rebecca N. Davenport, Christopher Barton, John Cox, Jacquelyn C. Guzy, Lauren Sherman, Jeffery L. Larkin, and Steven J. Price edited the manuscript.

ACKNOWLEDGMENTS

This project was funded through the Office of Surface Mining Reclamation and Enforcement Applied Science Grant Program (grant number S21AC10048), the McIntire Stennis Capacity Grant Program (grant number KY009040), and the Department of Forestry and Natural Resources at the University of Kentucky. In addition, we would like to acknowledge support from the Karri Casner Environmental Sciences Fellowship, Richards Graduate Student Research Activity Award, Kentucky Chapter of The Wildlife Society, Wilson Ornithological Society, and American Ornithological Society. Victoria Burgess, Madoline Varias, Andrea Drayer, and Jill Newman assisted with fieldwork. Additionally, we thank

Anna Branduzzi (Green Forests Work) and Todd Kuntz (US Forest Service) for assisting with study site selection and fieldwork.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data and code (Davenport et al., 2025) are available on Figshare: https://doi.org/10.6084/m9.figshare.29577476.v1. Code (Guzy, 2024) is available on Figshare: https://doi.org/10.6084/m9.figshare.25017743.v1.

ORCID

Jacquelyn C. Guzy https://orcid.org/0000-0003-2648-398X
Steven J. Price https://orcid.org/0000-0002-2388-0579

REFERENCES

Anders, A. D., J. Faaborg, and F. R. Thompson. 1998. "Postfledging Dispersal, Habitat Use, and Home-Range Size of Juvenile Wood Thrushes." *The Auk* 115(2): 349–358. https://doi.org/10.2307/4089193.

Angel, H. Z., C. D. Barton, M. French, and P. N. Angel. 2015. "The Appalachian Regional Reforestation Initiative and Green Forests Work: Bringing Back the Forest on Surface Coal Mines in Appalachia." *Journal of the American Society of Mining and Reclamation* 4(2): 91–101. https://doi.org/10.21000/JASMR15020091.

Barlow, J., G. D. Lennox, J. Ferreira, E. Berenguer, A. C. Lees, R. M. Nally, J. R. Thomson, et al. 2016. "Anthropogenic Disturbance in Tropical Forests Can Double Biodiversity Loss from Deforestation." *Nature* 535(7610): 144–47. https://doi.org/10.1038/nature18326.

Branduzzi, A. 2020. "Enhancing Native Plant Diversity on Legacy Minelands." MS thesis, University of Kentucky. https://uknowledge.uky.edu/forestry_etds/59/.

Branduzzi, A. M., C. D. Barton, and A. Lovell. 2020. "First-Year Survival of Native Wetland Plants in Created Vernal Pools on an Appalachian Surface Mine." *Ecological Restoration* 38(2): 70–73.

Bulluck, L. P., and D. A. Buehler. 2006. "Avian Use of Early Successional Habitats: Are Regenerating Forests, Utility Right-of-Ways and Reclaimed Surface Mines the Same?" *Forest Ecology and Management* 236(1): 76–84. https://doi.org/10.1016/j.foreco.2006.08.337.

Burger, J., C. E. Zipper, P. N. Angel, N. Hall, J. G. Skousen, C. D. Barton, and S. Eggerud. 2013. *Establishing Native Trees on Legacy Surface Mines*. Forest Reclamation Advisory No. 10. Washington, DC: Appalachian Regional Reforestation Initiative, US Office of Surface Mining.

Burger, J., D. Graves, P. Angel, V. Davis, and C. Zipper. 2005. *The Forestry Reclamation Approach*. Forest Reclamation Advisory No. 2. Washington, DC: Appalachian Regional Reforestation Initiative, US Office of Surface Mining.

Byers, E. A., J. P. Vanderhorst, and B. P. Streets. 2010. *Classification and Conservation Assessment of Upland Red Spruce Communities in West Virginia*. Elkins, WV: West Virginia Natural Heritage Program.

Canterbury, G. E., T. E. Martin, D. R. Petit, L. J. Petit, and D. F. Bradford. 2000. "Bird Communities and Habitat as Ecological Indicators of Forest Condition in Regional Monitoring." *Conservation Biology* 14(2): 544–558. https://doi.org/10.1046/j.1523-1739.2000.98235.x.

Cardinale, B. J., and M. A. Palmer. 2002. "Disturbance Moderates Biodiversity-Ecosystem Function Relationships: Experimental Evidence from Caddisflies in Stream Mesocosms." *Ecology* 83(7): 1915–27. https://doi.org/10.2307/3071774.

Caviedes, J., and J. T. Ibarra. 2017. "Influence of Anthropogenic Disturbances on Stand Structural Complexity in Andean Temperate Forests: Implications for Managing Key Habitat for Biodiversity." *PLoS One* 12(1): e0169450. https://doi.org/10.1371/journal.pone.0169450.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, et al. 1996. "The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management." *Ecological Applications* 6(3): 665–691. https://doi.org/10.2307/2269460.

Clipp, H. L., D. J. Brown, C. T. Rota, and P. B. Wood. 2022. "Distinct Forest Bird Communities Are Strongly Associated with Red Spruce-Northern Hardwood Ecosystems in Central Appalachia, USA." *Ecological Indicators* 135: 108568. https://doi.org/10.1016/j.ecolind.2022.108568.

Davenport, R. 2023. "Effects of Forest Reclamation and Landscape Features on Avian Occupancy, Species Richness, and Abundance in Appalachia." MS thesis, University of Kentucky. https://uknowledge.uky.edu/forestry_etds/70.

Davenport, R., C. Barton, J. Cox, J. Guzy, L. Sherman, J. L. Larkin, and S. Price. 2025. "Davenport et al. Initial Responses of Songbird Communities to Forest Reclamation on Legacy Surface Mines." figshare. Dataset. https://doi.org/10.6084/m9.figshare.29577476.v2.

Dorazio, R. M., and J. A. Royle. 2005. "Estimating Size and Composition of Biological Communities by Modeling the Occurrence of Species." *Journal of the American Statistical Association* 100(470): 389–398. https://doi.org/10.1198/016214505000000015.

Dornelas, M. 2010. "Disturbance and Change in Biodiversity." *Philosophical Transactions of the Royal Society, B: Biological Sciences* 365(1558): 3719–27. https://doi.org/10.1098/rstb.2010.0295.

Fischer, J., and D. B. Lindenmayer. 2007. "Landscape Modification and Habitat Fragmentation: A Synthesis." *Global Ecology and Biogeography* 16(3): 265–280. https://doi.org/10.1111/j.1466-8238.2007.00287.x.

Fiss, C., D. McNeil, A. Rodewald, D. Heggenstaller, and J. Larkin. 2021. "Cross-Scale Habitat Selection Reveals within-Stand Structural Requirements for Fledgling Golden-Winged Warblers." *Avian Conservation and Ecology* 16(1): 16. https://doi.org/10.5751/ACE-01807-160116.

Franzreb, K. E., and K. V. Rosenberg. 1997. "Are Forest Songbirds Declining? Status Assessment from the Southern Appalachians and Northeastern Forests." Transactions of the 62nd North American Wildlife and Natural Resources Conference. https://www.fs.usda.gov/research/treesearch/560.

Franzreb, K. E., and R. A. Phillips. 1996. *Neotropical Migratory Birds of the Southern Appalachians*. Asheville, NC: U.S.

Department of Agriculture, Forest Service, Southern Research Station.

Gelman, A., and D. B. Rubin. 1992. "Inference from Iterative Simulation Using Multiple Sequences." *Statistical Science* 7(4): 457–472. https://doi.org/10.1214/ss/1177011136.

Goguen, C. B. 2019. "Survival, Movements, and Habitat Use of Fledgling Veeries (*Catharus fuscescens*) in Northeastern Pennsylvania." *The American Midland Naturalist* 181(1): 18–28. https://doi.org/10.1674/0003-0031-181.1.18.

Green Forests Work. 2020. "Mined Land Restoration in the Monongahela National Forest 2010–2020." Greenforestswork.Org.

Green Forests Work. 2023. "Ecological Restoration on the Monongahela National Forest 2023 Report." Greenforestswork.Org.

Groninger, J., J. Skousen, P. Angel, C. Barton, J. Burger, and C. Zipper. 2007. *Mine Reclamation Practices to Enhance Forest Development through Natural Succession*. Forest Reclamation Advisory. Newtown Square, PA: Appalachian Regional Reforestation Initiative, US Office of Surface Mining.

Guzy, J. 2024. "Data/Code for Guzy Et Al_2019_influence of Riparian Buffers and Habitat Characteristics on Salamander Assemblages in Headwater Streams within Managed Forests." https://doi.org/10.6084/m9.figshare.25017743.v1.

Hall, S. L., C. D. Barton, and C. C. Baskin. 2010. "Topsoil Seed Bank of an Oak–Hickory Forest in Eastern Kentucky as a Restoration Tool on Surface Mines." *Restoration Ecology* 18(6): 834–842. https://doi.org/10.1111/j.1526-100X.2008.00509.x.

Hopkins, A. 1899. "Report on Investigations to Determine the Cause of Unhealthy Conditions of the Spruce and Pine from 1880–1893." *West Virginia Agricultural and Forestry Experiment Station Bulletins* 56: 197–254. https://doi.org/10.33915/agnic.56.

Ingold, D. J., and J. L. Dooley. 2013. "Nesting Success of Grassland and Shrub-Nesting Birds on the Wilds, an Ohio Reclaimed Surface Mine." *The Ohio Journal of Science* 111(2): 37–41.

Kaufmann, M. R., L. S. Huckaby, C. M. Regan, and J. Popp. 1998. *Forest Reference Conditions for Ecosystem Management in the Sacramento Mountains, New Mexico*. General Technical Report RMRS-GTR-19. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 87 p. 19. https://doi.org/10.2737/RMRS-GTR-19.

Kaufmann, M. R., R. T. Graham, D. A. Boyce, Jr., W. H. Moir, L. Perry, R. T. Reynolds, R. L. Bassett, et al. 1994. *An Ecological Basis for Ecosystem Management*. General Technical Report RM 246. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p. 246. https://doi.org/10.2737/RM-GTR-246.

Kentula, M., R. P. Brooks, S. E. Gwin, C. C. Holland, A. D. Sherman, and J. C. Sifneos. 1992. *An Approach to Improving Decision Making in Wetland Restoration and Creation*, 1st ed. Washington, DC: Island Press.

King, D., R. Degraaf, M.-L. Smith, and J. Buonaccorsi. 2006. "Habitat Selection and Habitat-Specific Survival of Fledgling Ovenbirds (*Seiurus aurocapilla*)." *Journal of Zoology* 269(4): 414–421. https://doi.org/10.1111/j.1469-7998.2006.00158.x.

Kolka, R. K., C. C. Trettin, E. A. Nelson, C. D. Barton, and D. E. Fletcher. 2002. "Application of the EPA Wetland Research Program Approach to a Floodplain Wetland Restoration Assessment." *Journal of Environmental Monitoring and Restoration* 1(1): 37–51.

Lambert, M., A. N. Drayer, W. Leuenberger, S. J. Price, and C. Barton. 2021. "Evaluation of Created Wetlands as Amphibian Habitat on a Reforested Surface Mine." *Ecological Engineering* 171: 106386. https://doi.org/10.1016/j.ecoleng.2021.106386.

Link, W. A., E. Cam, J. D. Nichols, and E. G. Cooch. 2002. "Of Bugs and Birds: Markov Chain Monte Carlo for Hierarchical Modeling in Wildlife Research." *The Journal of Wildlife Management* 66(2): 277–291. https://doi.org/10.2307/3803160.

Lituma, C. M., J. J. Cox, S. F. Spear, J. W. Edwards, J. L. De La Cruz, L. I. Muller, and W. M. Ford. 2021. "Terrestrial Wildlife in the Post-Mined Appalachian Landscape: Status and Opportunities." In *Appalachia's Coal-Mined Landscapes: Resources and Communities in a New Energy Era*, edited by C. E. Zipper and J. Skousen, 135–166. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-57780-3_6.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2017. *Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence*. Burlington, MA: Elsevier.

Margenau, E. L., P. B. Wood, C. A. Weakland, and D. J. Brown. 2019. "Trade-Offs Relating to Grassland and Forest Mine Reclamation Approaches in the Central Appalachian Region and Implications for the Songbird Community." *Avian Conservation and Ecology* 14(1): art2. https://doi.org/10.5751/ACE-01304-140102.

Moore, M. M., W. W. Covington, and P. Z. Fulé. 1999. "Reference Conditions and Ecological Restoration: A Southwestern Ponderosa Pine Perspective." *Ecological Applications* 9(4): 1266–77. https://doi.org/10.2307/2641395.

Morgan, P., G. H. Aplet, J. B. Haufler, H. C. Humphries, M. M. Moore, and W. D. Wilson. 1994. "Historical Range of Variability: A Useful Tool for Evaluating Ecosystem Change." *Journal of Sustainable Forestry* 2(1–2): 87–111. https://doi.org/10.1300/J091v02n01_04.

Pacifici, K., E. F. Zipkin, J. A. Collazo, J. I. Irizarry, and A. DeWan. 2014. "Guidelines for a Priori Grouping of Species in Hierarchical Community Models." *Ecology and Evolution* 4(7): 877–888. https://doi.org/10.1002/ece3.976.

Pericak, A. A., C. J. Thomas, D. A. Kroodsma, M. F. Wasson, M. R. V. Ross, N. E. Clinton, D. J. Campagna, Y. Franklin, E. S. Bernhardt, and J. F. Amos. 2018. "Mapping the Yearly Extent of Surface Coal Mining in Central Appalachia Using Landsat and Google Earth Engine." *PLoS One* 13(7): e0197758. https://doi.org/10.1371/journal.pone.0197758.

Pike, D. A., B. M. Croak, J. K. Webb, and R. Shine. 2010. "Subtle – but Easily Reversible – Anthropogenic Disturbance Seriously Degrades Habitat Quality for Rock-Dwelling Reptiles: Habitat Disturbance and Rock-Dwelling Reptiles." *Animal Conservation* 13(4): 411–18. https://doi.org/10.1111/j.1469-1795.2010.00356.x.

Price, S. J., R. N. Davenport, L. Sherman, J. L. Larkin, J. Cox, J. C. Newman, and C. Barton. 2024. "Response of Red-Backed Salamanders (*Plethodon cinereus*) to the Forestry Reclamation Approach on Legacy Surface Mines in the Monongahela National Forest (West Virginia)." *Ecological Restoration* 42(2): 105–7.

Rentch, J. S., T. M. Schuler, W. M. Ford, and G. J. Nowacki. 2007. "Red Spruce Stand Dynamics, Simulations, and Restoration Opportunities in the Central Appalachians." *Restoration Ecology* 15(3): 440–452. https://doi.org/10.1111/j.1526-100X.2007.00240.x.

Rhodes, B. 2022. "Evaluating Restoration Outcomes: Red Spruce Reforestation in the West Virginia Highlands." MS thesis,

University of Kentucky. https://uknowledge.uky.edu/forestry_etds/63/.

Rosenberg, K. V., A. M. Dokter, P. J. Blancher, J. R. Sauer, A. C. Smith, P. A. Smith, J. C. Stanton, et al. 2019. "Decline of the North American Avifauna." *Science* 366(6461): 120–24. https://doi.org/10.1126/science.aaw1313.

Sauer, J. R., and W. A. Link. 2002. "Hierarchical Modeling of Population Stability and Species Group Attributes from Survey Data." *Ecology* 83(6): 1743–51. https://doi.org/10.1890/0012-9658(2002)083[1743:HMOPSA]2.0.CO;2.

Sauer, J. R., K. L. Pardieck, D. J. Ziolkowski, A. C. Smith, M.-A. R. Hudson, V. Rodriguez, H. Berlanga, D. K. Niven, and W. A. Link. 2017. "The First 50 Years of the North American Breeding Bird Survey." *The Condor* 119(3): 576–593. https://doi.org/10.1650/condor-17-83.1.

Schlossberg, S., D. I. King, S. Destefano, and M. Hartley. 2018. "Effects of Early-Successional Shrubland Management on Breeding Wood Thrush Populations." *The Journal of Wildlife Management* 82(8): 1572–81. https://doi.org/10.1002/jwmg.21559.

Schuler, T. M., W. M. Ford, and R. J. Collins. 2002. "Successional Dynamics and Restoration Implications of a Montane Coniferous Forest in the Central Appalachians, USA." *Natural Areas Journal* 22(2): 88–98.

Sherman, L., C. D. Barton, J. C. Guzy, R. N. Davenport, J. J. Cox, J. L. Larkin, T. Fearer, J. C. Newman, and S. J. Price. 2024. "Wetland Creation and Reforestation of Legacy Surface Mines in the Central Appalachian Region (USA): A Potential Climate-Adaptation Approach for Pond-Breeding Amphibians?" *Water (Basel)* 16(9): 1202. https://doi.org/10.3390/w16091202.

Snyder, B., C. Barton, M. Lacki, S. J. Price, and Z. Hackworth. 2024. "Bat Activity on High Elevation Reforested Coal Mines in the Monongahela National Forest, West Virginia." *Ecological Restoration* 42(2): 108–122.

Stephenson, S. L., and J. F. Clovis. 1983. "Spruce Forests of the Allegheny Mountains in Central West Virginia." *Castanea* 48(1): 1–12.

Stull, R. B. 2015. *Practical Meteorology: An Algebra-Based Survey of Atmospheric Science*. Vancouver: University of British Columbia.

Sturtz, S., U. Ligges, and A. Gelman. 2005. "R2WinBUGS: A Package for Running WinBUGS from R." *Journal of Statistical Software* 12(3): 1–16. https://doi.org/10.18637/jss.v012.i03.

The Cornell Lab. 2014. "Merlin Bird ID." Mobile App. https://merlin.allaboutbirds.org/.

Trani, M. K. 2002. "Southern Forest Resource Assessment Highlights: Terrestrial Ecosystems and Wildlife Conservation." *Journal of Forestry* 100(7): 35–40. https://doi.org/10.1093/jof/100.7.35.

USDA Forest Service. n.d. "Monongahela National Forest – about the Forest." Monongahela National Forest. https://www.fs.usda.gov/wps/portal/fsinternet3/cs/main/mnf/about-forest.

Vásquez-Grandón, A., P. J. Donoso, and V. Gerding. 2018. "Forest Degradation: When Is a Forest Degraded?" *Forests* 9(11): 726. https://doi.org/10.3390/f9110726.

Vitz, A. C., and A. D. Rodewald. 2006. "Can Regenerating Clearcuts Benefit Mature-Forest Songbirds? An Examination of Post-Breeding Ecology." *Biological Conservation* 127(4): 477–486. https://doi.org/10.1016/j.biocon.2005.09.011.

Wickham, J., P. B. Wood, M. C. Nicholson, W. Jenkins, D. Druckenbrod, G. W. Suter, M. P. Strager, C. Mazzarella, W. Galloway, and J. Amos. 2013. "The Overlooked Terrestrial Impacts of Mountaintop Mining." *BioScience* 63(5): 335–348. https://doi.org/10.1525/bio.2013.63.5.7.

Williamson, T. N., and C. D. Barton. 2020. "Hydrologic Modeling to Examine the Influence of the Forestry Reclamation Approach and Climate Change on Mineland Hydrology." *The Science of the Total Environment* 743: 140605. https://doi.org/10.1016/j.scitotenv.2020.140605.

Wilson, M. C., X.-Y. Chen, R. T. Corlett, R. K. Didham, P. Ding, R. D. Holt, M. Holyoak, et al. 2016. "Habitat Fragmentation and Biodiversity Conservation: Key Findings and Future Challenges." *Landscape Ecology* 31(2): 219–227. https://doi.org/10.1007/s10980-015-0312-3.

Wood, P. B., and F. K. Ammer. 2015. "Grasshopper Sparrow Reproductive Success and Habitat Use on Reclaimed Surface Mines Varies by Age of Reclamation." *Wildlife Society Bulletin* 39(3): 512–520.

World Meteorological Organization, Commission for Maritime Meteorology. 1970. *The Beaufort Scale of Wind Force (Technical and Operational Aspects)*. Geneva: WMO.

Zipkin, E. F., A. DeWan, and J. Andrew Royle. 2009. "Impacts of Forest Fragmentation on Species Richness: A Hierarchical Approach to Community Modelling." *Journal of Applied Ecology* 46(4): 815–822. https://doi.org/10.1111/j.1365-2664.2009.01664.x.

Zipper, C. E., J. A. Burger, J. G. Skousen, P. N. Angel, C. D. Barton, V. Davis, and J. A. Franklin. 2011. "Restoring Forests and Associated Ecosystem Services on Appalachian Coal Surface Mines." *Environmental Management* 47(5): 751–765. https://doi.org/10.1007/s00267-011-9670-z.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Davenport, Rebecca N., Christopher Barton, John Cox, Jacquelyn C. Guzy, Lauren Sherman, Jeffery L. Larkin, Todd Fearer, and Steven J. Price. 2025. "Initial Responses of Songbird Communities to Forest Reclamation on Legacy Surface Mines." *Ecosphere* 16(10): e70423. https://doi.org/10.1002/ecs2.70423