B A N I S T E R I A

A JOURNAL DEVOTED TO THE NATURAL HISTORY OF VIRGINIA

ISSN 1066-0712

Published by the Virginia Natural History Society

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Banisteria 61: 90–101

RESEARCH ARTICLE

OBSERVATIONS OF YELLOW-SPOTTED WOODLAND SALAMANDERS (*PLETHODON PAULEYI* FELIX, WOOTEN, PIERSON, & CAMP, 2019) ON ABANDONED SURFACE COAL MINES IN THE CUMBERLAND MOUNTAINS OF VIRGINIA, USA

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Editor: J. C. Means | Received 30 May 2026 | Accepted 4 August 2026 | Published 23 September 2026

https://virginianaturalhistorysociety.com/2026/01/14/number-61-2026/

Citation: Meade, W. C., M. Elliott, H. M. Hill, and W. H. Smith. 2026. Observations of yellow-spotted woodland salamanders (*Plethodon pauleyi* Felix, Wooten, Pierson, & Camp, 2019) on abandoned surface coal mines in the Cumberland Mountains of Virginia, USA. Banisteria 61: 90–101.

ABSTRACT

The yellow-spotted woodland salamander (*Plethodon pauleyi* Felix, Wooten, Pierson, & Camp, 2019) is a recently-described rock outcrop specialist endemic to portions of the Cumberland Mountains and adjacent areas in eastern Kentucky, northeastern Tennessee, southwestern Virginia, and southern West Virginia. *Plethodon pauleyi* was recently petitioned for federal listing under the United States Endangered Species Act on the basis of its high degree of habitat specialization, restricted range, apparent rarity, and incompatibility with legacies of surface mining across the Appalachian coalfields. However, few to no data exist confirming if this species is indeed incompatible with lands experiencing past coal extraction. We performed a survey of potential *P. pauleyi* habitat across Wise and Dickenson Counties in Virginia, USA, finding 13 new localities of the species. Six of these localities were found in rock outcrop habitat impacted or created by past surface coal extraction, including artificial highwalls and remnant natural outcrops altered by mining. Follow-up comparisons confirmed that habitat variables commonly associated with rock outcrop plethodontids did not significantly vary between mined outcrops and nearby reference outcrops not associated with surface mines. Our results confirm that *P. pauleyi* is capable of occupying at least some former surface mines, particularly in situations where mature forest cover has become reestablished following mining. These results further provide data that can inform the design of future survey efforts and ongoing state and federal conservation status assessments.

Keywords: Amphibian, conservation, disturbance, ecology, reclamation.

INTRODUCTION

Rock outcrop specialist plethodontid salamanders include several species in the genera *Aneides* and *Plethodon* endemic to the Appalachian Mountains of eastern North America (Gordon, 1952; Wynn et al., 1988). These taxa are specialized to cracks and crevices in vertical rock substrate, including cliffs, bluffs, and isolated rock outcrops embedded within forest ecosystems (Smith et al., 2015). Such cracks and crevices provide cool and moist refugia (Smith, 2024), as well as nest sites and hibernacula (Rossell et al., 2019), for resident plethodontids, with salamanders often selecting refugia nonrandomly based on specific attributes of available crevices (Smith et al., 2017; Novak & Barrett, 2023).

The yellow-spotted woodland salamander (*Plethodon pauleyi* Felix, Wooten, Pierson, & Camp, 2019) is an outcrop-specialized member of the Wehrle's Salamander (*P. wehrlei* Fowler & Dunn, 1917) complex first described in 2019 (Felix et al., 2019). *P. pauleyi* is restricted to a small area of the Cumberland Mountains in southwestern Virginia, eastern Kentucky, southern West Virginia, and northeastern Tennessee and is commonly found within or adjacent to exposed rock outcrops (Hutcheson et al., 2021; Miller-Murthy, 2022). Little information exists to date on the species' habitat requirements, although existing data suggest that *P. pauleyi* prefers deep crevices within moist sandstone and shale rock outcrops as refugia (Felix et al., 2019). The species is also considered unusually rare, with only 21 localities identified in recent assessments of the species (Center for Biological Diversity, 2022).

Plethodon pauleyi's presumed rarity and high degree of habitat specialization have led to the species being petitioned for federal Endangered Species Act protection (Center for Biological Diversity, 2022). This listing petition cited overlap between *P. pauleyi*'s geographic range and the extent of historic and ongoing surface coal extraction across the Cumberland Mountains as justification for the need for federal listing. The Cumberland Mountains Ecoregion is colocated with some of the highest rates of surface coal mining in eastern North America (Pericak et al., 2018), with a majority of the land area within this region held in private ownership by corporate extractive industry interests (ALOTF, 2014). The aforementioned listing petition and an accompanying 90-day finding review from the U.S. Fish and Wildlife Service (USFWS, 2022) presumed that *P. pauleyi*'s habitat requirements make the species incompatible with landscape change from ongoing or past surface coal extraction, with the species absent from portions of its range impacted by past coal mining. However, few data exist to inform this conclusion, particularly at the landscape scale.

As part of surveys conducted in 2025 and 2026 for an ongoing State Wildlife Grant-funded project investigating the ecology of *P. pauleyi*, we located multiple instances of *P. pauleyi* occupying exposed rock substrate associated with past surface coal extraction, specifically contour or "strip" mining. These observations included natural outcrops modified by past coal extraction and artificial "highwalls" created by the exposure of subsurface strata during the process of surface coal extraction. Here we present the results of these surveys, as well as analyses comparing attributes of mining-associated outcrops harboring *P. pauleyi* with nearby, undisturbed and natural rock outcrops.

MATERIALS AND METHODS

Organismal surveys

We performed surveys for *P. pauleyi* in 2025 and 2026 at 34 sites across the Pound River watershed in Wise and Dickenson Counties in southwestern Virginia, USA (Fig. 1). These surveys were performed as part of ongoing work to clarify the geographic distributions and habitat associations of members of the *P. wehrlei* complex in Virginia. The Pound River watershed was targeted for this work due to its proximity to historic localities of *P. pauley*i in Virginia (Felix et al., 2019), as well as the abundance of potentially suitable rock outcrop habitat in the predominantly sandstone and shale Wise and Norton Formations (Miller, 1969).

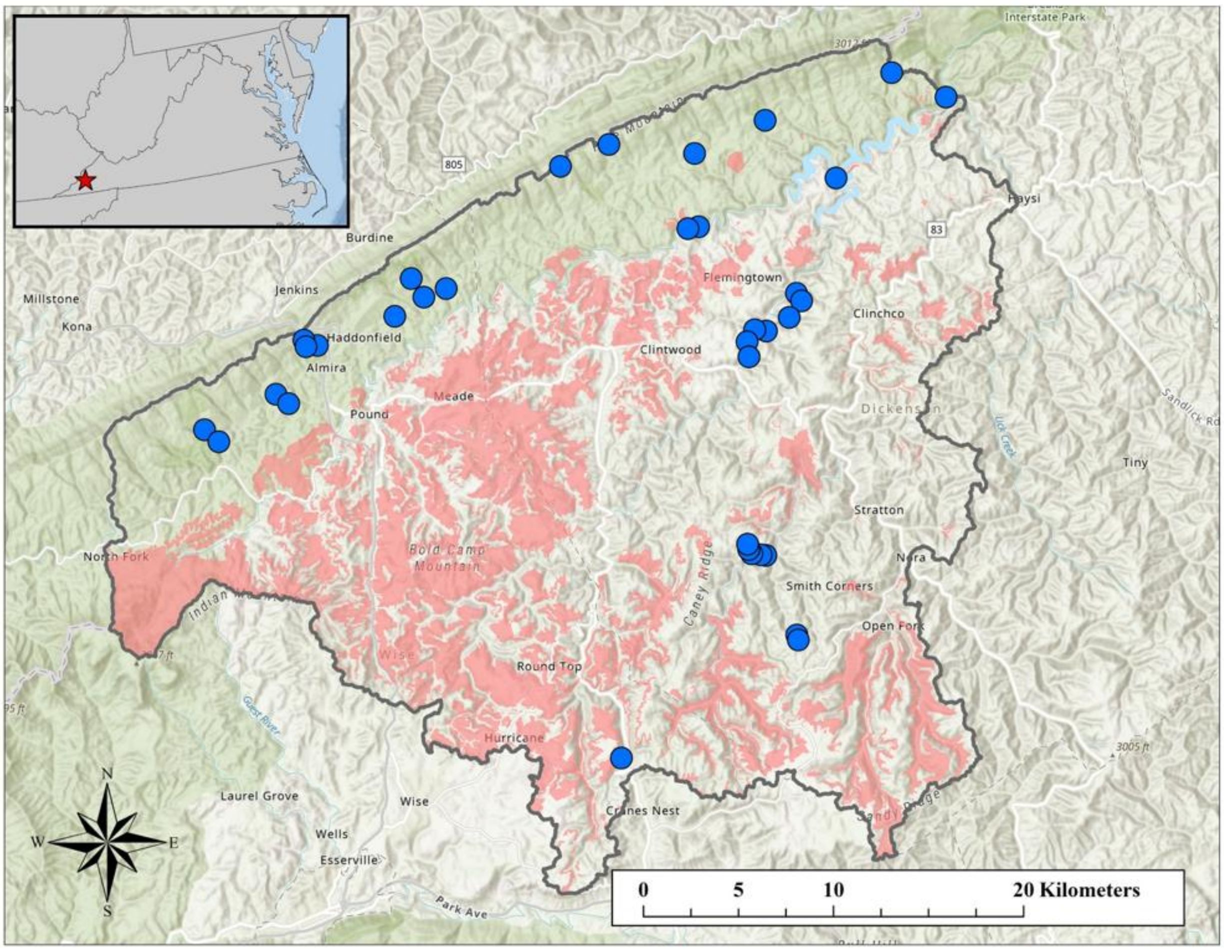

Figure 1. Study area across the Pound River watershed (outlined area) in Wise and Dickenson Counties in Virginia, USA, with sampling sites denoted by blue circles. Red-shaded areas denote lands impacted by past coal extraction, as identified by Pericak et al. (2018). Red star in inset map denotes location of study area within Virginia.

We selected survey sites from this study area based on the presence of exposed surface outcrops as identified by light detection and ranging (LiDAR) datasets (e.g., Smith & Mullins, 2021), mature hardwood forest cover, and public conservation lands or private lands accessible with permission of the landowner. We surveyed tracts undisturbed by past surface coal extraction and tracts with older (pre-1977) surface mines where hardwood forest cover has regenerated following the completion of mining activity. We did not survey any active surface mines within the study area due to safety and ownership considerations.

Surveys at each site consisted of area-constrained visual encounter surveys, with all accessible rock outcrops and forest habitat within 10 m of the outcrop searched for *P. pauleyi*. We did not survey excessively steep or unstable portions of outcrops at each site due to safety considerations. We specifically inspected all available crevices and outcrop surfaces for *P. pauleyi* using an LED flashlight. We similarly searched the forest floor and beneath all available cover objects within 10 m of the outcrop at each site. Survey visits were timed as randomly as possible within site accessibility considerations, including both nocturnal and diurnal visits. We surveyed each site a minimum of two times if *P. pauleyi* was not detected on the initial survey visit, with successive survey visits spaced at least one week apart.

Habitat comparisons and statistical analyses

In addition to performing surveys for *P. pauleyi*, we examined habitat attributes between outcrops not associated with surface mining and those impacted by past surface coal extraction in cases where *P. pauleyi* was detected. We surveyed 12 habitat variables at each site, with variables selected to reflect the condition of crevice refugia and the forest context surrounding each crevice (e.g., Smith et al., 2017; Hinkle et al., 2018). For crevice refugia, we measured the maximum crevice height, maximum crevice width, maximum crevice depth, and minimum distance from the crevice to the ground surface. We measured crevice depth as the maximum distance a 5 mm diameter probe could be inserted into the crevice, with remaining crevice attributes measured using a fiberglass measuring tape.

We also measured the temperature and relative humidity (RH) of each accessible crevice. We used a TPI-597C1 (Beaverton, Oregon, USA) digital hygrometer/psychrometer with a 30 cm-long probe (accurate to ± 2% RH and ± 0.1°C) to measure both variables, with interior crevice measurements recorded at the maximum depth the probe could be inserted into the crevice. We then recorded the ambient temperature and RH 1 m from the crevice and at the same height above ground level as the crevice using the same probe. We subtracted ambient measurements from interior measurements for both variables, using these standardized differences in temperature and RH for subsequent statistical comparisons.

Lastly, we also characterized the forest structure surrounding each outcrop, selecting variables associated with rock outcrop specialist plethodontids (e.g., Smith et al., 2017; Hinkle et al., 2018). We measured percent canopy cover, slope, litter depth, the number of trees surrounding the rock face, size (diameter at breast height, or DBH) of trees surrounding the rock face, and aspect of the rock face. We measured canopy cover and slope at the rock face using a spherical densiometer (Marianna, Florida, USA) and Suunto (Vantaa, Finland) clinometer, respectively. We measured remaining variables using a 10m x 10m plot centered on the rock face and extending outward into the surrounding forest. We chose this plot size to reflect similar habitat assessments within the broader study region and to limit potential influences on microclimate and vegetation structure from neighboring rock outcrops in cases where multiple outcrops occurred in close proximity to one another. We measured tree DBH using a Forestry Suppliers (Jackson, Mississippi, USA) diameter tape.

We compared habitat similarity between outcrops associated and not associated with past coal extraction using a multivariate analysis of similarity (ANOSIM; Clarke, 1993) in R v.4.2.1 using the vegan package (Oksanen et al., 2026). Data were normalized prior to the construction of a dissimilarity matrix (Euclidean distance). We permuted our dissimilarity matrix 9999 times to assess significance, using a significance level of $\alpha = 0.05$.

Results

We detected *P. pauleyi* at 13 (38.2%) of all sites surveyed in 2025-2026. All *P. pauleyi* were found within rock crevices or traversing outcrop surfaces near the crevice opening (Fig. 2), with no individuals encountered on the adjacent forest floor. Geographic coordinates and other detailed locality information have been withheld at the request of the Virginia Department of Wildlife Resources (J. Kleopfer, personal communication). Locality information is on-file with the Virginia Department of Wildlife Resources.

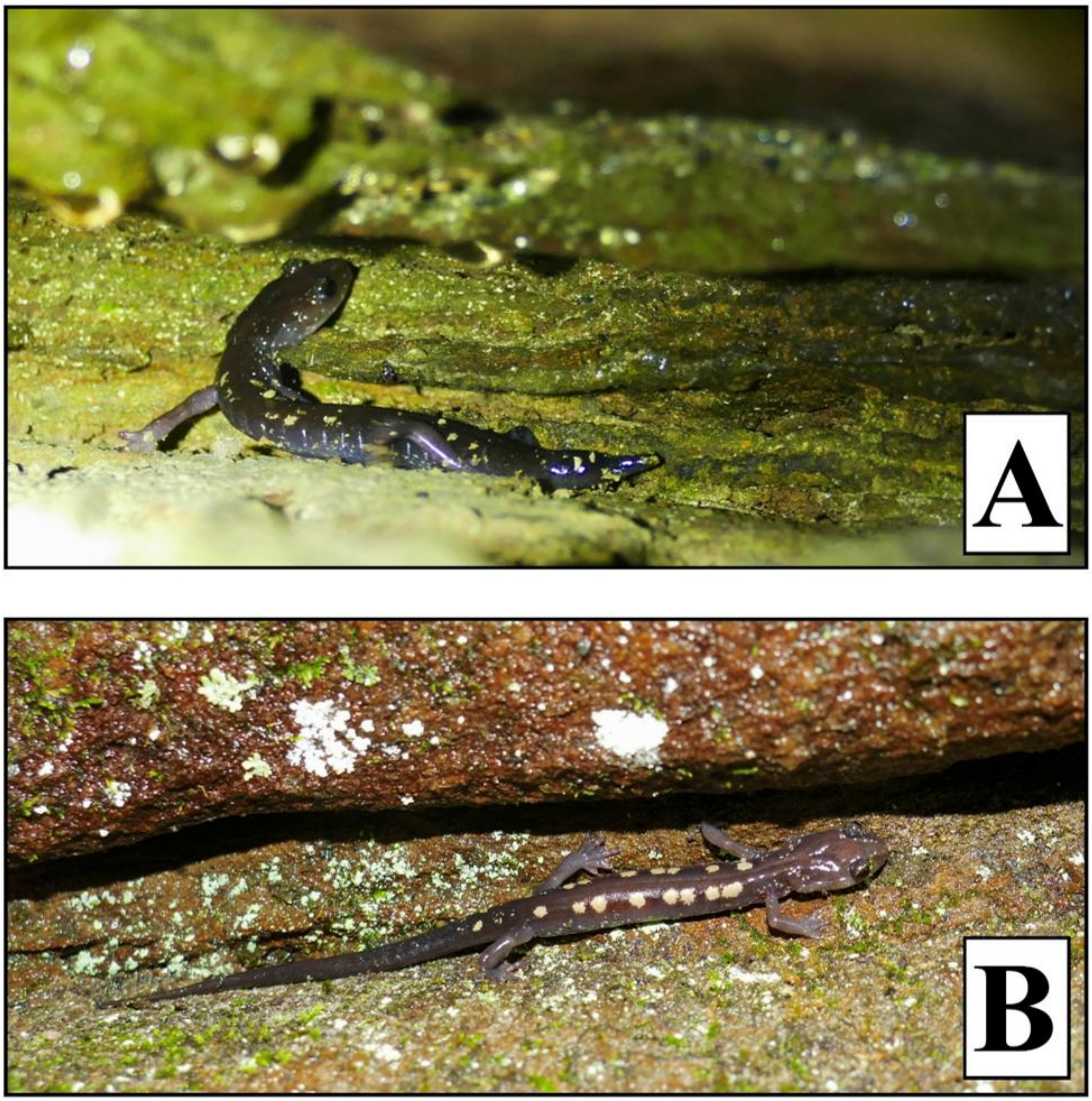

Figure 2. Examples of yellow-spotted woodland salamanders (*Plethodon pauleyi* Felix, Wooten, Pierson, & Camp, 2019) as encountered *in situ* during surveys in Wise and Dickenson Counties, Virginia, USA in 2025 and 2026: (A) an adult occupying a horizontal crevice, and (B) an adult found traversing an open rock surface below a crevice opening.

We documented multiple *P. pauleyi* occupying outcrops modified by past surface coal extraction (Table 1). This included five outcrops associated with former (pre-1970) mining operations near John W. Flannagan Reservoir and an additional locality associated with a pre-1970 surface mine near Big Ridge. Outcrops near John W. Flannagan Reservoir included natural sandstone outcrops located at the immediate margin of areas blasted and cleared for the construction of contour mines and associated haul roads, as well as artificial outcrops associated with vertical highwalls initially exposed during coal extraction (Fig. 3A). *P. pauleyi* was found in crevices within remaining portions of natural outcrops at these sites and in crevices within artificial highwalls. Outcrops at the Big Ridge locality were exclusively sandstone-shale outcrops exposed during the initial coal extraction process and left as a vertical highwall following the completion of mining activity (Fig. 3B). This site contained both adults and younger juveniles, indicating recent reproduction. Mature hardwood forest cover (mixed mesophytic forest) has regenerated at all six sites following initial mining activity, with full (>95%) canopy cover present. All sites also largely lacked non-native or invasive vegetation, with the exception of scattered instances of planted White Pine (*Pinus strobus* Linnaeus) along mine bench margins.

Table 1. Observations of yellow-spotted woodland salamanders (*Plethodon pauleyi* Felix, Wooten, Pierson, & Camp, 2019) from former surface mines in Wise and Dickenson Counties, Virginia, USA in 2025 and 2026.

Locality	Date(s)	Elevation (m asl)	Individuals encountered	Site description
Site 1	1 May 2025 9 May 2025 11 March 2026	487	1 adult 1 adult 2 adults	Remnant natural outcrop on margin of abandoned mine haul road
Site 2	13 May 2025	490	2 adults	Remnant natural outcrop on margin of abandoned mine haul road
Site 3	9 May 2025	493	1 adult	Remnant natural outcrop on contour mine margin
Site 4	18 June 2025 2 July 2025	488	1 juvenile 1 adult, 1 juvenile	Surface mine highwall
Site 5	9 March 2026	472	1 adult	Surface mine highwall
Site 6	9 March 2026	474	2 adults	Surface mine highwall above gated underground mine portal

We did not detect a significant difference between outcrops not associated with former coal mining and outcrops associated with past coal extraction containing *P. pauleyi* (Global R = 0.1069, P = 0.1152). Habitat attributes were largely similar between outcrop types, including attributes related to crevice structure, crevice microclimate relative to ambient conditions, and forest structure within 100 m^2 surrounding the outcrop (Table 2).

Figure 3. Visual examples of yellow-spotted woodland salamander (*Plethodon pauleyi* Felix, Wooten, Pierson, & Camp, 2019) habitat on former surface mines in Dickenson County, Virginia, USA: (A) mined highwall habitat co-located with a gated portal for an abandoned deep mine, and (B) a remnant natural outcrop located at the margin of an abandoned highwall and contour mine bench (flattened area along bottom and right of image).

DISCUSSION

Past assessments have assumed that *P. pauleyi* is absent from areas impacted by past coal extraction, given the intensity of landscape alterations associated with surface mining activity (Center for Biological Diversity, 2022; USFWS, 2022). In contrast to these assumptions, we located numerous instances of *P. pauleyi* occupying both natural rock outcrops that had been altered by past surface coal extraction and artificial outcrops created during the process of contour mining. To our knowledge, these observations are the first confirming that *P. pauleyi* is capable of occupying landscapes recovering from past coal extraction.

Table 2. Summary of habitat attributes (mean ± 1SD) recorded for twelve rock outcrop and forest variables at yellow-spotted woodland salamander (*Plethodon pauleyi* Felix, Wooten, Pierson, & Camp, 2019) localities impacted (n = 6) and unimpacted (n = 7) by surface coal extraction in the Pound River watershed in Virginia, USA in 2025-2026. Temperature and relative humidity data both reflect interior crevice conditions relative to ambient conditions (interior minus ambient).

Habitat variable	Mined sites	Unmined reference sites
Crevice Height (cm)	6.2 ± 3.4	6.8 ± 4.9
Crevice Width (cm)	32.2 ± 5.6	29.7 ± 11.8
Crevice Depth (cm)	28.3 ± 5.1	28.0 ± 8.6
Crevice Distance (cm) Above Ground Level	108.5 ± 14.2	97.7 ± 22.0
Crevice Temperature (ºC)	-2.2 ± 1.4	-1.4 ± 1.2
Crevice Relative Humidity (%)	6.0 ± 5.0	6.4 ± 4.9
Canopy Cover (%)	98.7 ± 1.9	97.9 ± 1.9
Litter Depth (cm)	2.8 ± 1.2	1.8 ± 1.1
Aspect (degrees azimuth)	211.6 ± 66.5	211.3 ± 101.9
Slope (%)	-52.4 ± 8.9	-49.1 ± 15.7
Number of Trees	7.7 ± 2.5	5.3 ± 2.5
Tree Diameter (cm) at Breast Height	16.2 ± 5.1	27.6 ± 16.7

Plethodontid salamanders are particularly predisposed to potential negative impacts from surface coal extraction, due to their sensitivity to environmental change and strict temperature and moisture requirements (Feder, 1983; Welsh & Droege, 2002). However, past work has found that some plethodontids can colonize post-mined landscapes in cases where habitat requirements persist or regenerate following the completion of mining activity. Hinkle et al. (2018) found widespread occurrences of Green Salamanders (*Aneides aeneus* Cope & Packard, 1881) within and at the margins of former surface mines in the Virginia coalfields where natural rock outcrops were retained following mining. While Hinkle et al. (2018) did not detect instances of salamanders occupying artificial highwalls, those authors did find salamanders occupying mining-impacted outcrops in cases where native hardwood forest structure had regenerated in the decades following mining (e.g., Holl, 2002).

Our results mirror this previous work, finding not only instances of *P. pauleyi* in mining-associated outcrops but even evidence of recent reproduction in one artificial highwall on a 50+ year-old abandoned surface mine. It is impossible to discern if these individuals represent populations of *P. pauleyi* that existed throughout the duration of mining activity or if they recolonized these sites in the decades following disturbance. Similar to the results reported by Hinkle et al. (2018), however, we did not detect significant dissimilarity in habitat conditions between the aforementioned sites and nearby sites with no history of surface mining. These results suggest that *P. pauleyi* is capable of occupying landscapes impacted by past coal extraction in situations where native forest cover has regenerated following mining and the structural attributes of rock outcrops mimic those occupied elsewhere by the species. We also note that our results are similar to those recorded during surveys of *P. pauleyi* in nearby states, where *P. pauleyi* has been anecdotally recorded occupying disturbed rock walls resulting from road construction not associated with surface mining (Hutcheson, 2021; Center for Biological Diversity, 2022).

We are cautious about applying our results beyond the specific ecological contexts examined in our study and stress that our results should not be interpreted as indicative of *P. pauleyi*'s tolerance of all forms of surface mining. Surface coal extraction in central Appalachia has taken numerous forms since the early to mid-twentieth century, ranging from the linear contour mines investigated in this study to much larger mountaintop removal mining approaches (Skousen & Zipper, 2021), the latter of which have become widespread across the region in recent decades (Pericak et al., 2018). These mining strategies have variable spatial footprints and employ differing degrees of landscape alterations (Wickham et al., 2007; Maigret et al., 2019), and all require decades of time to pass before mature native forest structure can become reestablished (Avera et al., 2015; Thomas et al., 2023). While we found evidence that *P. pauleyi* can occupy older (pre-1977) contour mines when mature hardwood forests have recovered following mining, different levels of habitat suitability may exist on mines experiencing extractive and reclamation approaches that differ from those surveyed here. We also note that amphibian population health and resilience to future stressors are both driven by a complex set of factors beyond basic site occupancy that were not addressed through our dataset, such as abundance, age and sex ratios, and population genetic attributes (Heyer et al., 2014). Future work examining covariates of site occupancy and other demographic measures in *P. pauleyi,* as well as how such covariates are impacted by differing mining and reclamation approaches, will be needed to fully understand the scope of impacts from legacy coal extraction on this species.

Our results suggest that existing assumptions that *P. pauleyi* is incompatible with landscapes impacted by past coal extraction are partially unsupported. In this study, surveys of localities experiencing significant past disturbance from surface coal extraction led to the discovery of six new populations of this species, nearly doubling the number of known localities in Virginia and filling substantial gaps in *P. pauleyi*'s range within the state. Surveys that overlook sites with past mining legacies run the risk of underestimating *P. pauleyi*'s distribution and abundance, and such sites should be incorporated into future survey and monitoring efforts. Post-mined landscapes across central Appalachia are increasingly being targeted for new land uses, such as industrial facilities and utility-scale solar farms, under the assumption that such landscapes are “brownfields” lacking species of conservation concern (Zipper et al., 2021; Mariotti & Engstrom, 2025). The *P. pauleyi* site showing signs of recent reproduction reported in this study was featured in a recent analysis highlighting former mines that should be prioritized for development into utility-scale solar facilities (The Nature Conservancy, 2024) – an activity that would require substantial forest clearing and likely reduce or eliminate available *P. pauleyi* habitat. As our understanding of the basic ecology of this species improves, detailed assessments of its response to both initial habitat disturbance and mineland reclamation strategies will be needed to understand how best to approach the design of effective species management and mineland reuse strategies rangewide.

Acknowledgements

We are grateful to J.D. Kleopfer, Kevin Hamed, Kevin Hutcheson, Stephen Richter, Martina Hines, Courtney Hayes, and Asha Miller-Murthy for helpful insight into historic *Plethodon pauleyi* localities and survey methods. Ninah Bamba, Savanna Busick, Jacob DeNeef, Katie Dunn, and Megan Roark provided helpful assistance during field surveys. Sampling activities for this project were performed under Virginia Department of Wildlife Resources Scientific Collection Permit No. 2907603 and with support from the State Wildlife Grants program.

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