Possible Ecological Indicators of Ecosystem Function Around Mining Areas Using Soil, Water and Biological Characteristics: A Case Study

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Presented at ASRS, Butte, MT, June 2025

Ecological Indicators (EI)

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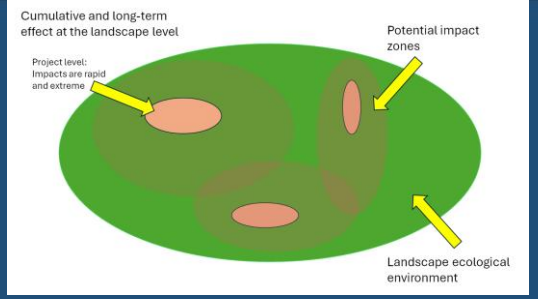
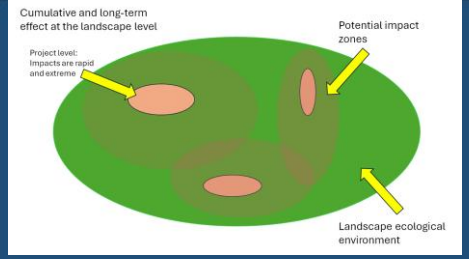
Aerial view of a surface coal mine in Wyoming. Photo by BLM Wyoming.



- Measurable parameters or values that are indicative of the health and condition of an ecosystem. They can be living organisms (species) or environmental variables (temperature, water quality, or soil health).
- Examples include soil quality index (SQI), Water Quality Index (WQI), Air Quality Index (AQI), Aquatic life and habitat, Forest Cover, crop productivity
- EI are used to assess areas of concern in an ecosystem toward its management, provide information to the public and stakeholders.
- EI may be used to assess health at the landscape or project levels.



Project and Landscape Level Ecosystem Assessments

- Project-level assessments are absolutely essential to restore and/or to enhance project-level ecosystem functions and to evaluate interactions with other industrial projects within the landscape.
- Landscape-level assessments in conjunction with project-level assessments are required to plan and manage alternate ecosystem management options to enhance ecosystem function and ecosystem services.
- Authors think that project-level indicators must be considered in developing landscape level indicators and ecosystems management options.
- Landscape-level assessments alone may not provide adequate information for developing appropriate and effective “Ecosystems Management Options”

Our Goals for Restoration of Minerals Development Projects

- Restoration should ensure that:
- Environmental impacts are contained within project boundaries and do not extend into the adjoining landscape level areas/ ecosystems.
- Since natural resources environments are disturbed during exploitation, restoration could/should consider alternate ecosystem services (ES) to enhance regional socio-economic conditions.
- The above should be done in collaboration with regional stakeholders.
- Similar case can also be made for unhealthy and damaged ecosystems.
- This requires the development of Ecological Indicators for monitoring, assessment, and management.

Problem Statement

- Currently, several EI assess environmental quality at the landscape level and may not describe ecosystem function at the project level.
- EI at the landscape level may change spatially and temporally reducing their usefulness.
- We hypothesize that at the project level soil physical and chemical properties, site physical characteristics, and planted species are the primary variables affecting ecosystem function.
- Therefore, we attempt to identify EIs using accepted and readily quantifiable and relevant project level indices in disturbed soils.
- Such EI may also be composited to develop landscape-level indicators such as WQI, WPI, and IBI to track changes in ecosystem function.

- A case study of a reclaimed surface mine is used to research the hypothesis.

Research Hypothesis

Assess if solids, water, and biotic properties of soils can be used at the project level as EI.

Pre-disturbance characterization

Archived data from government agencies, published research data

Ecologically restored areas

21 sample plots on case study area

Measure physical, chemical and biological properties

Comparative analysis

Results and analysis

Case Study Characteristics

- Located in the Appalachian Coal Region with 100-year mining history.
- 65 acres located around TN-KY Border north of Knoxville.
- Borders Clear Fork to the North and Powell Valley to the south.
- Contour mining was practiced.
- Surface mined around 2007-2015 and reclaimed.
- Around 1 m of coal seams were mined.

Concepts of Contour Mining

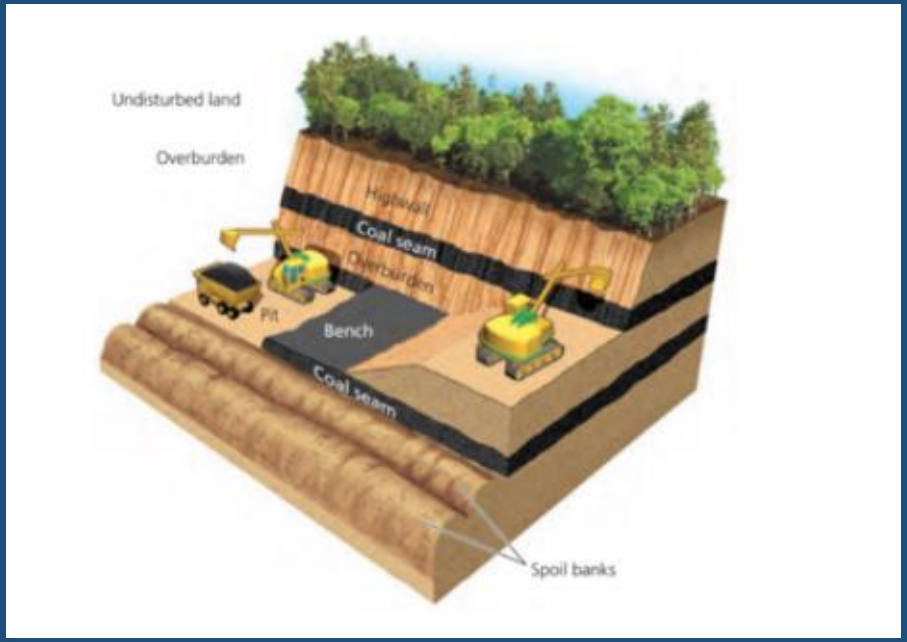
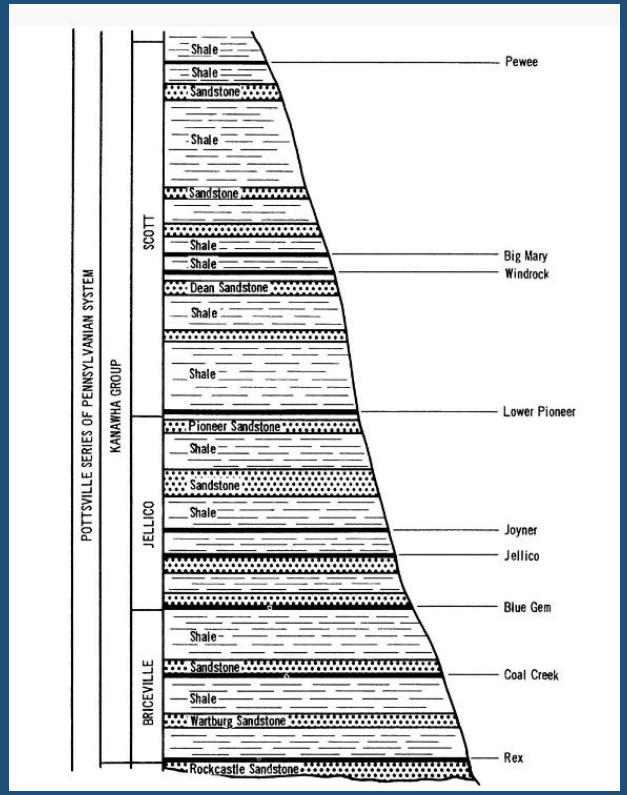
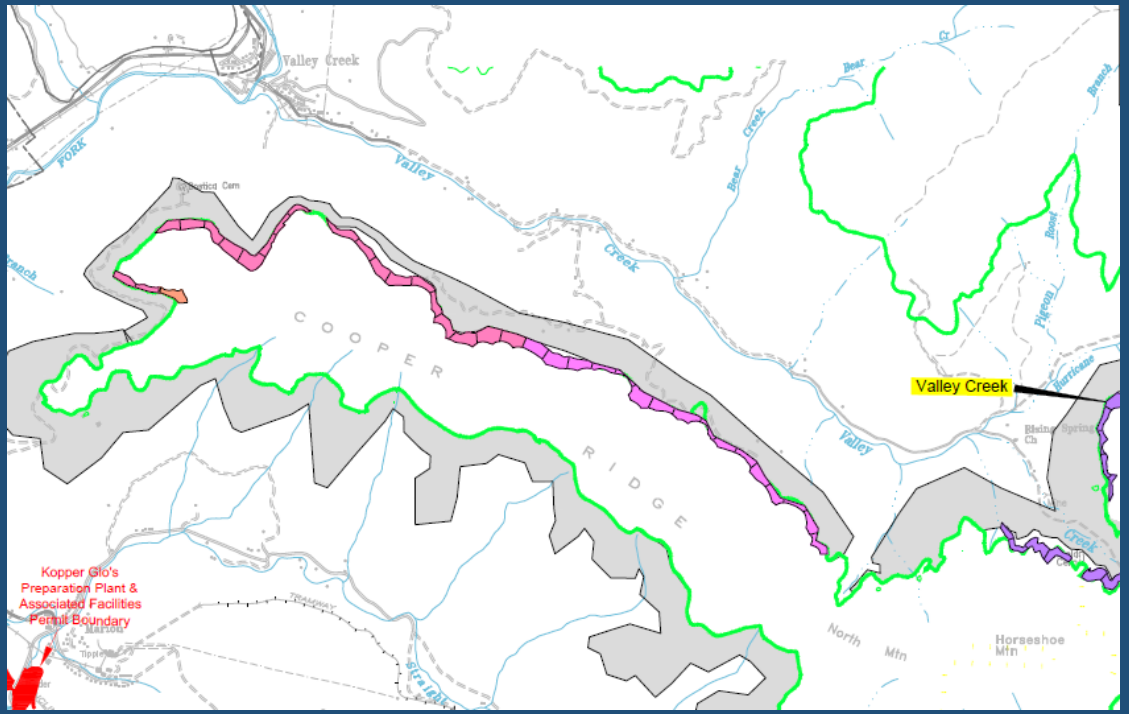


Image credit: MNGE 230- Introduction to Mining- Penn State

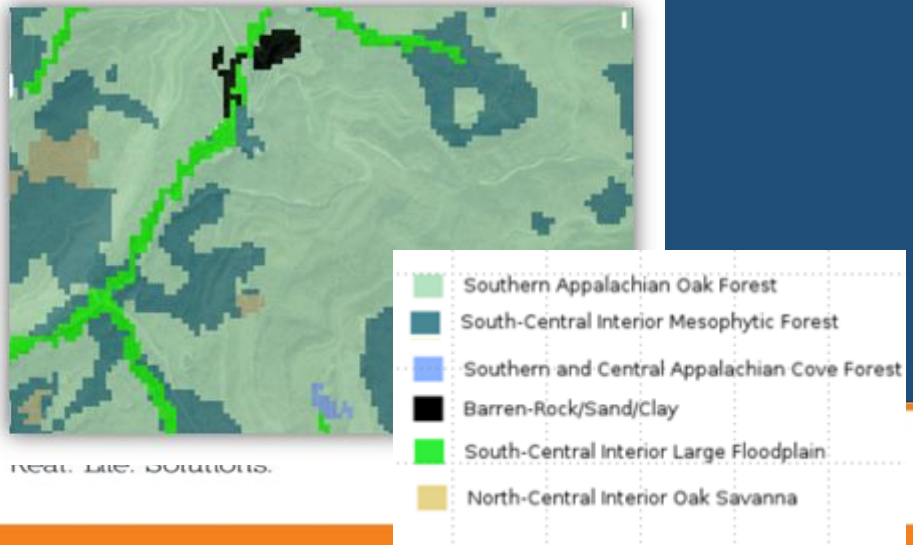
Lithologic Log and View of Mining Operations



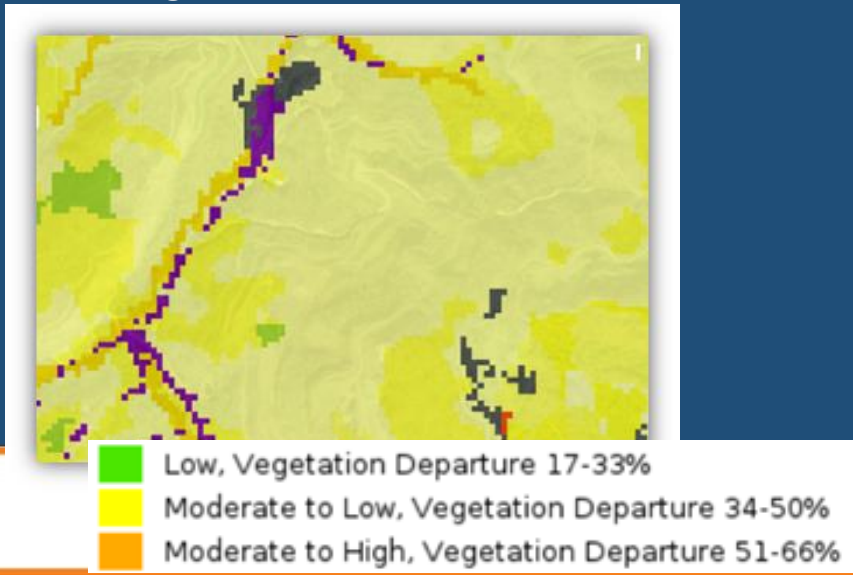


Pre-Mining Topographic and Vegetation Environments

- Terrain is typically steep and rugged, no major urban centers
- Matured plateaus and dendritic erosional valleys
- Surface elevations between 350-700 m above MSL
- Expected vegetation

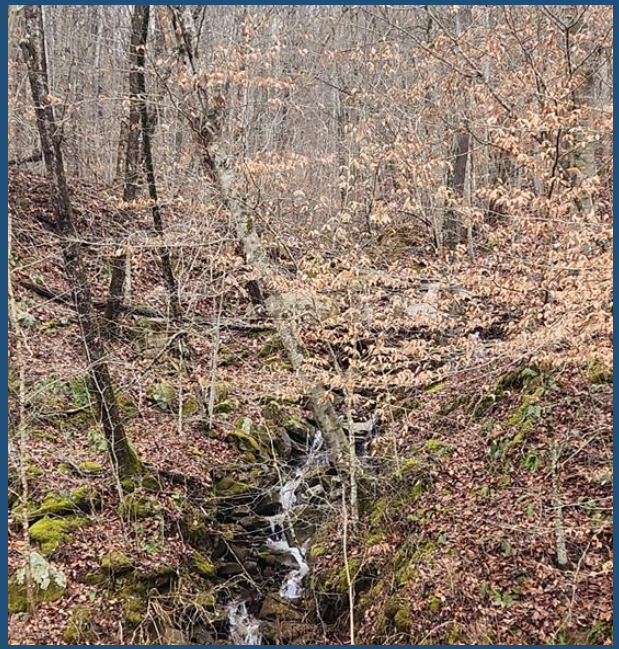


Vegetation condition in 2001



Climate Characteristics

- Four seasons with mild, moist winters and warm summers.
- Average annual rainfall is 1.4 m -most of it occurs during winter and spring months.
- Winters are mild with temperatures varying between -1 to 10 deg C
- Summer temperatures typically range from 15-27 C.
- Precipitation during winter is primarily rain



Regulatory Environments

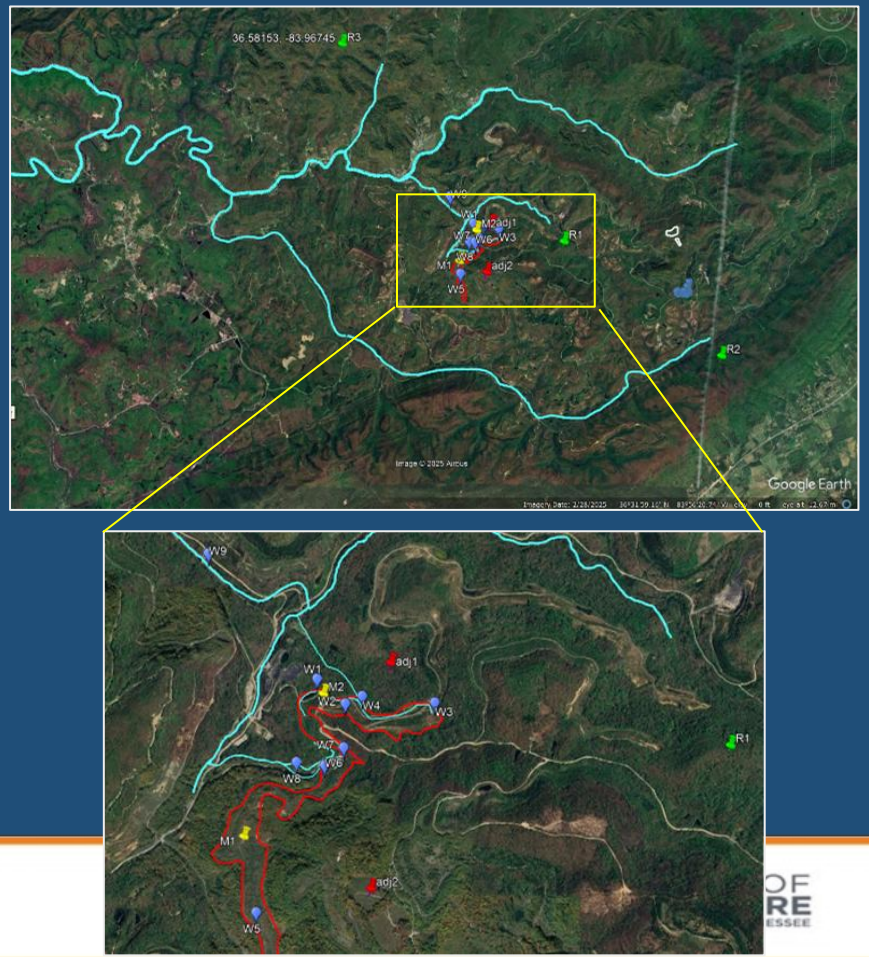
- 65 acres located around TN-KY Border north of Knoxville.
- Regulated by Federal Laws and enforced by OSMRE
- Amended Clean Air Act of 1970, Clean water Act of 1977, The SMCRA of 1977, and The RCRA of 1976 govern the site
- Concurrent reclamation activities consistent with industry standards and federal laws.
- Some portions are located close to local communities.
- Mining is not permitted within 100m of residential dwelling, Church, school, or similar structures without approval.
- Environmental liabilities due to previous mining are well documented.

Mining and Reclamation Operations

- Contour mining practiced with 1-2 cuts around the mountain.
- Pit width about 150 ft wide with haul roads about 30-ft wide.
- No topsoil removal, storage, or replacement operations
- Overburden blasted, hauled, and dumped along the mountain slope with limited selective placement, with greater sandstone-rich materials in the upper meter. Overburden was graded with no additional compaction prior to planting tree seedlings
- Overburden slopes are approximately natural slopes of about 37 deg.
- No additional soils placed on graded overburden prior to planting.
- Irrigation was through natural rains only.
- Coal was not blasted prior to removal.

Sampling and methodology: landscape level

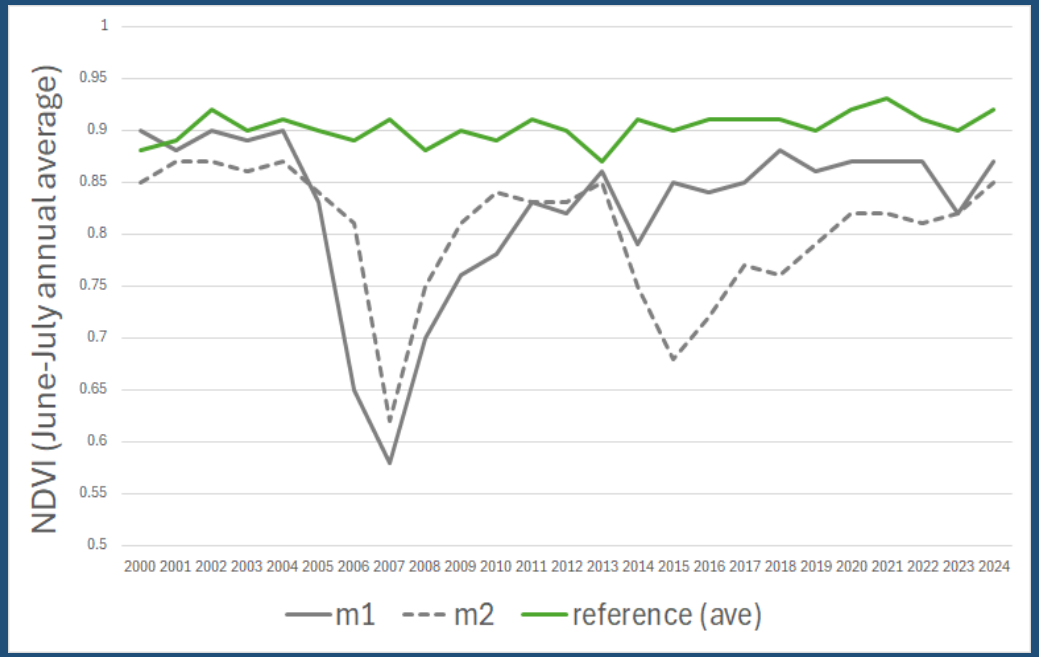
- NDVI - 250m 16 day average from MODIS for points at the widest section at the northern end of the site, and southern end, 2 points in adjacent unmined areas, and 3 points in forested reference areas, June & July 2000 - 2024.
- Evapotranspiration- ECOSTRESS Evapotranspiration PT-JPL Daily L3 Global 70 m for same points as above for all available dates (2019-2024), using samples collected between 8 am and 6 pm.
- GLM test for difference between mined and unmined reference areas.

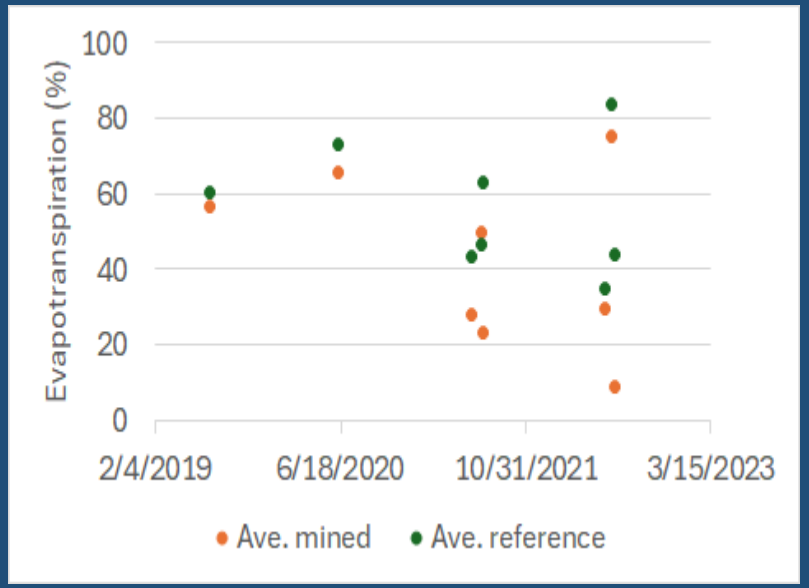


Sampling and methodology: project level

- 21 plots placed in zones of “good”, “moderate” and “poor” tree growth using stratified random sampling.
- Composite soil sample (0-10 cm depth) within each plot for soil chemistry and counts of ectomycorrhizal root tips.
- Soil core from 0-5 cm and 5-15 cm depth at plot center for soil density and texture.
- Tree species, stem count, and DBH (if ≥2.54 cm) on 0.04 ha plot.
- Biomass calculated for trees ≥ 2.54 cm /DBH (Chojnacky et al. 2014).
- GLM test for difference between zones.
- Partial correlation controlling for year to test site

Landscape indicators Results: Vegetative cover and Evapotranspiration



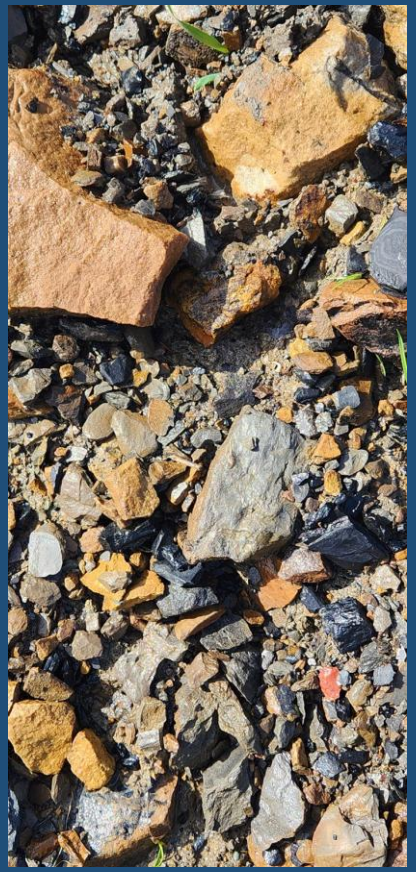


No significant differences, but potential for future use as more data becomes available.

2000-2005 No significant differences 2022-2024 Ref > mined
Spatial resolution insufficient for monitoring adjacent area

Results and Discussion: Soil Characteristics

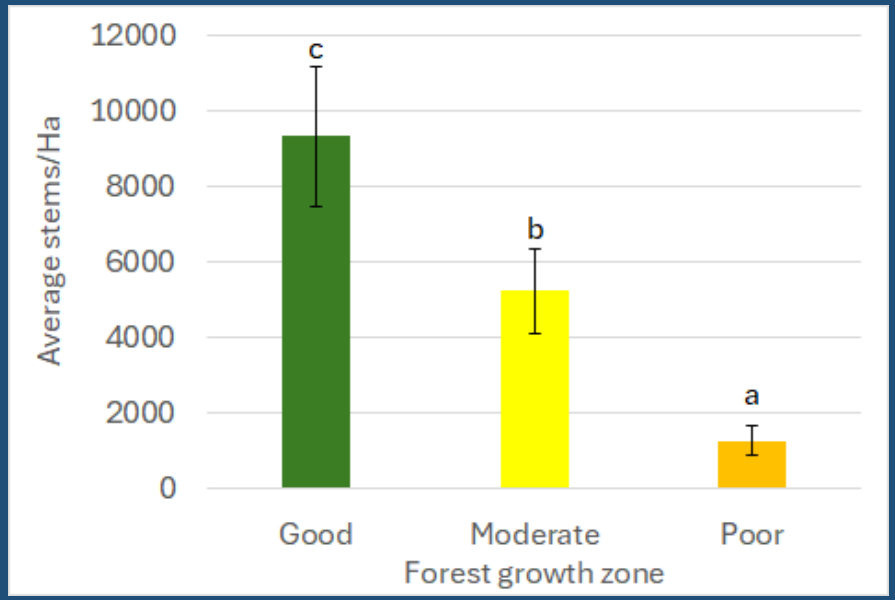
	Minesoil	Adjacent (NRCS)
pH	4.4 - 7.0	5.1 - 5.3
CEC	7.1 - 20.2	6.8
Bulk density	1.0 - 2.0 g/cm3	1.3 - 1.4 g/cm3
Depth to bedrock	1.8 - 15 m	0.5 - 1 m
% Clay	13 - 42	19
% Sand	15 - 48	36
% Silt	30 - 55	45



Relationships between tree growth and site characteristics

Column1	Column2	biomas	slope%	cec	Ca	Cu ppm	soil den
BA	Correlation	0.917	0.595	0.351	0.433	-0.422	-0.493
	Significance	<.001	0.006	0.129	0.056	0.064	0.027
biomass	Correlation	1	0.516	0.472	0.482	-0.517	-0.616
	Significance (2-tailed)		0.02	0.036	0.031	0.019	0.004
slope%	Correlation			0.266	0.181	-0.352	-0.73
	Significance (2-tailed)			0.258	0.446	0.128	<.001
CEC	Correlation				0.873	-0.534	-0.558
	Significance (2-tailed)				<.001	0.015	0.011
Ca ppm	Correlation					-0.606	-0.499
	Significance (2-tailed)					0.005	0.025
Cu ppm	Correlation					1	0.595
	Significance (2-tailed)					.	0.006

Results and Discussion: Tree growth



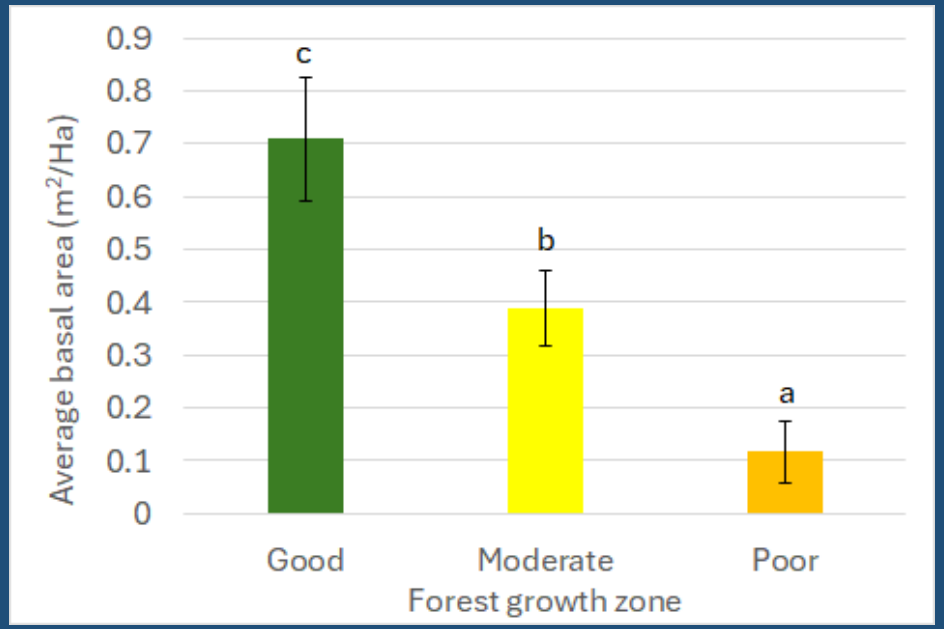
Growth zones differed significantly in slope% ($p \leq 0.01$), but not in elevation or aspect.

Good

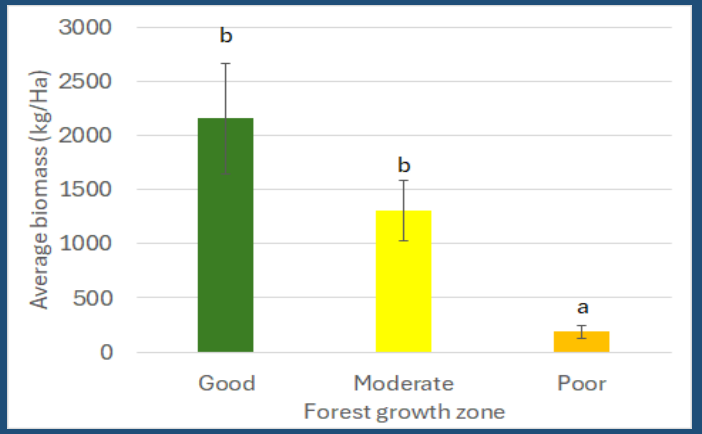
Moderate

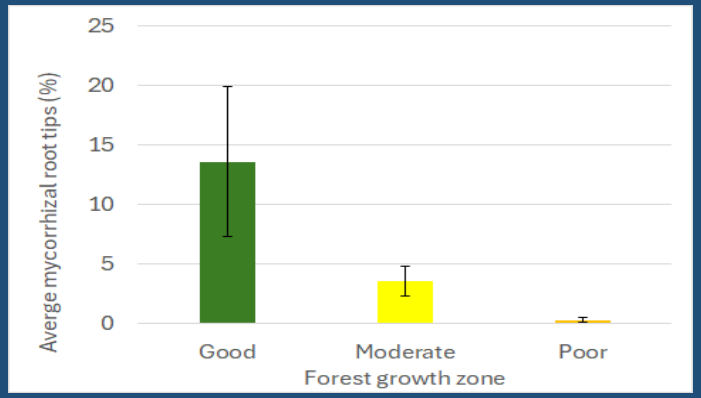
Poor

Results and Discussion: Tree growth



Timber harvest site of similar age has BA 2.5 m^2/Ha





Not significant due to large number of zero values

Significant Statistical Correlations, Authors' Observations and Hypotheses

- Vegetation was not correlated with soil pH, CEC, MC, soil texture, or clay size fraction.
- Graded slope, bulk density, and Cu content were positively correlated with vegetation. Relatively shallow slopes had higher soil bulk density and poor vegetation.
- The flat areas, or "benches", were generally all haul roads or staging areas.
- Soil chemistry data represents the water within the soil. Water pH levels were good.
- pH data at mid-slope is not related to slope, soil texture, or year of mining or reclamation
- Mycorrhizal data is positively correlated with vegetation and may be a potential EI.
- Biomass was correlated with CEC and age after planting.
- Both basal area and biomass were good EIs of forest vegetation.
- NDVI data may serve as EI at a landscape level, but not at the project level.
- Sedimentation was observed in the streams around the base of reclaimed slopes.

Concluding Remarks

- Case study represents a small mine in a mountainous ecosystem with limited available premining and post mining investigation data.
- Mining and reclamation operations were state regulated, and did not follow strict scientific operational guidelines.guidelines.
- Even with the above constraints, study results point positively to the authors' hypotheses that project-level characterization data can serve as good EIs.

- Study has led to another hypothesis **" Characterization of geochemistry of overburden and immediate floor strata associated with coal seam/s"** could be good EIs to represent ecosystems function.
- Authors plan to investigate the hypothesis further.

Limitations of the Study and Future Plans

- A few potential EIs at project level were tested on a single case-study site.
- Tested landscape level indicators NDVI lacked data and had poor resolution, but should be investigated further for ecological restoration and management.
- Additional analyses with available data are planned.
- Authors believe that development of EIs at the project level is important and should be given higher priorities than in the past.
- Geochemistry of parent rocks and soils associated with the coal seams was not considered as part of characterization.

Background on Authors' Geochemistry Hypothesis

- Production activities 1) increase surface area and volume of associated rocks and minerals, and their mixing, 2) disrupt and/or modify water resources and contact duration with mixed materials, 3) discharge plumes of solids and water into ponds, streams and rivers, 4) change surface topography, 5) leach out minerals from mixed materials, 6) increase erosion rates, etc.
- Ecological restoration works with the modified solids-moisture environments that are different than prior to mining. They affect vegetation, water chemistry, and pollutant loading over time that influence habitat, humans, and fisheries.
- Authors think that geochemical characterization should be the primary foundation of project-level EIs with second-tier variables involving surface topography, texture, bulk density, to project biomass, time to recovery of soils, NDVI, etc
- We think performing geochemical studies on roof and floor lithologies, geochemical leaching potential in conjunction with minerals and mineral wastes should be characterized to develop Ecological Restoration management.

ACKNOWLEDGEMENTS

Thanks to:

Cord Rawls, August Knowles, and Jacob Kelley for field assistance

Mr. Seth Cude for providing his insights into this research

University of Tennessee Office of Undergraduate Research and Fellowships for funding

This work is supported by McIntyre-Stennis grant no. TEN00MS-111 accession no1014114 from the USDA National Institute of Food and Agriculture

Relevant Literature

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Questions and comments!