CENTRAL APPALACHIAN MINE REFORESTATION ASSESSMENT (CAMRA) TOOL

About this report

While underground and surface coal mining have long provided prosperity for much of Appalachia, the scars they leave behind on the landscape impede further economic development and natural restoration, especially in the current age of declining coal production. For years, “reclamation” meant the conversion of mined lands to still unproductive grassland or stunted forest, but new, informed approaches are changing that trajectory. Assessing the success of modern reforestation efforts increasingly requires more nuanced and far-reaching techniques in order to attain a quantifiable panorama of Appalachian forests. To contribute to the growing body of novel reforestation systems, the project team used Google Earth Engine to develop the Central Appalachian Mine Reforestation Assessment (CAMRA) Tool, which uses a two-phased, multi-index algorithm to assess the progress of reforestation on former mined lands.

This report explores a set of five questions that simultaneously evaluates reforested sites in Kentucky, Virginia, and West Virginia while testing the CAMRA Tool for accuracy and utility.

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Partners

Appalachian Voices is an environmental nonprofit organization that works at the nexus of the ongoing shift from fossil fuels to clean, 21st-century energy sources—it fight mountaintop removal coal mining, fracked-gas pipelines, and other harms to the people and places of Appalachia, and it advances energy efficiency, solar and wind power, and other economic solutions that create community wealth and sustain Appalachia’s mountains, forests, and waters.

4E Analytics is an environmental consulting firm specializing water quality, coding, and geographic information systems.

Green Forests Works’ mission is to re-establish healthy and productive forests on formerly mined lands in Appalachia. Reforesting these unproductive sites will create a renewable and sustainable multi-use resource that will provide economic opportunities while improving ecosystem services.

SkyTruth uses the view from space to inspire people to protect the environment. We utilize technology to identify and monitor threats to the planet’s natural resources such as offshore drilling and oil spills, fracking, mountaintop removal mining, and overfishing of the oceans. We believe better transparency leads to better management and better outcomes. By sharing our findings with the public for free, we move policy makers, governments and corporations towards more responsible behavior in the environment. We arm citizen activists with the tools they need to be more effective advocates. We provide researchers and scientists with critical data that can inform groundbreaking work and aid in the effort to begin asking a new set of questions.

Downstream Strategies is an environmental and economic development consulting firm with offices in Morgantown, Lewisburg, and Davis, West Virginia. We are considered the go-to source for objective, data-based analyses, plans, and actions that strengthen economies, sustain healthy environments, and build resilient communities. We offer services that combine sound interdisciplinary skills with a core belief in the importance of protecting the environment and linking economic development with natural resource stewardship.

Background

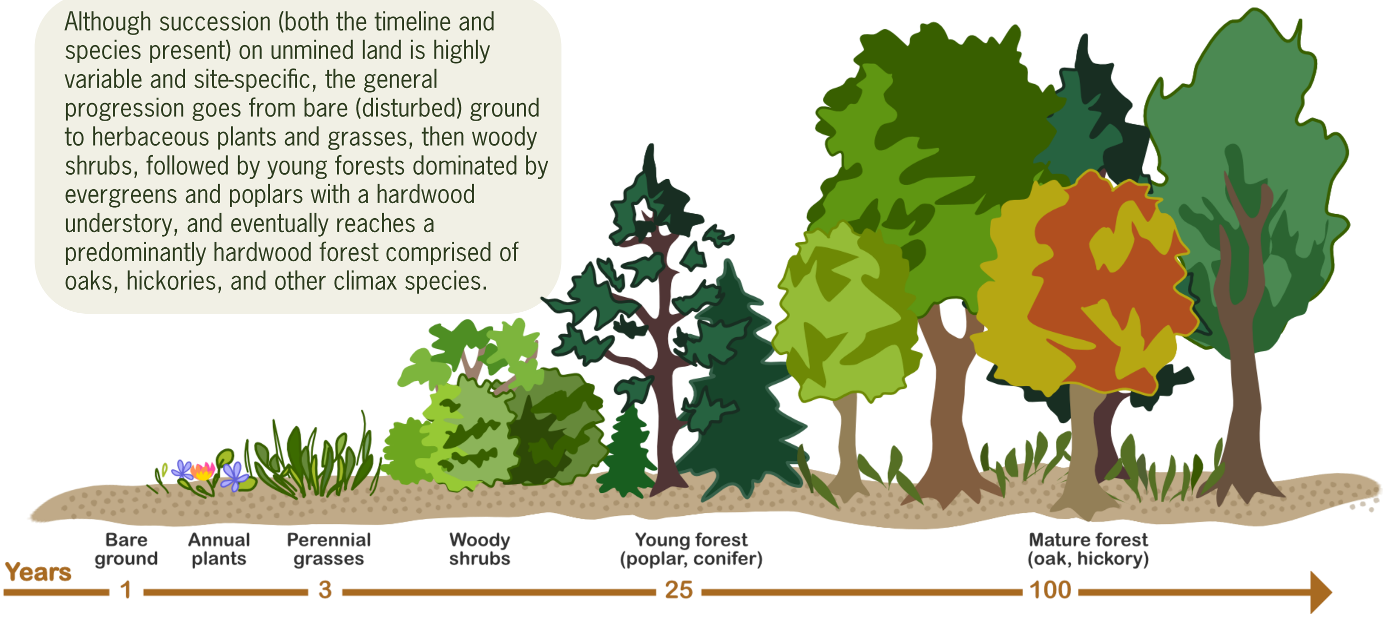
Appalachia commands stunning vistas throughout its range, and its unique geology and abundance of natural resources have long made it a destination for industries and travelers alike. Its expansive seams of coal gave rise to perhaps the most prominent of these industries: coal mining. Since the 1970s, underground mining has increasingly been replaced with surface mining, including "mountaintop removal" (MTR), which quickly became a dominant force altering the landscape. At MTR sites, land at the summit of a mountain is removed using explosives until a coal seam is revealed. Then, the displaced land, or overburden, is pushed into surrounding valleys.

The land lost to surface mining creates jarring scars upon the horizon, but because the productivity and diversity of Appalachian forests rival those of any forests across the globe, much more than mere scenery vanishes. Surface mining radically changes the topography, vegetation, and soil of affected land: the resultant shrubs, grasses, and nonnative plants that grow after mining make that area hostile to the reestablishment of the previously dominant hardwood forests.

Per the Surface Mining Control and Reclamation Act (SMCRA) of 1977, a mined area must be restored to its "approximate original contour" and be reclaimed and revegetated consistent with the surrounding area.

However, reclamation of mine lands came to mean reclamation with herbaceous, non-native vegetation for grazing livestock, even though most mine sites would never be used for managed grazing. Indeed, the establishment of non-native shrubs and grasses on these sites has left many previously mined areas in a state of arrested succession: thick grasses and shrubs and compacted soils hinder the reestablishment of ecologically productive hardwood forests. To address these less productive "grazing" lands across Appalachia, reclamation experts conceived the Forestry Reclamation Approach (FRA) was conceived as a set of best management practices that would help achieve healthy and productive forests similar to those found before mining began.

Although succession (both the timeline and species present) on unmined land is highly variable and site-specific, the general progression goes from bare (disturbed) ground to herbaceous plants and grasses, then woody shrubs, followed by young forests dominated by evergreens and poplars with a hardwood understory, and eventually reaches a predominantly hardwood forest comprised of oaks, hickories, and other climax species.



A superior approach to reclamation

The Appalachian Regional Reforestation Initiative (ARRI), formed by the U.S. Department of the Interior's Office of Surface Mining Reclamation and Enforcement and composed of experts in public and private sectors, developed the Forestry Reclamation Approach (FRA) in 2005. The FRA is a collection of reclamation and reforestation techniques informed by decades of intensive research, expertise, and involvement of scientists and practitioners. It includes five steps that promote the natural succession and establishment of sustainable, high-quality forest habitat on mined lands.

1) Create a suitable rooting medium that is no less than 4 feet deep and comprised of topsoil, weathered sandstone, and/or the best available material.
2) Loosely grade the topsoil or topsoil substitute established in Step 1 to create a non-compacted growth medium.
3) Use ground cover vegetation that is compatible with growing trees.
4) Plant two types of trees: early successional species for wildlife and soil stability, and commercially valuable crop trees.
5) Use proper tree planting techniques. (ARRI, 2005)

Now, 15 years since the establishment of the FRA, reclamation experts, community groups, policymakers, and other interested parties stand at a crossroads. Has reforestation of Appalachian surface mines worked? Does the FRA produce superior results? Is reforestation happening at a scale that is measurable on former mine sites? Are there discernible geographic patterns of reforestation on formerly mined lands? How do reforested areas compare to pre-mining areas? The Central Appalachian Mine Reforestation Tool Assessment (CAMRA) aims to answer these questions and more, to determine to what degree, if any, remedial action needs to be taken to improve practitioners' approaches to forestry reclamation in Central Appalachia.

While the FRA and other reforestation techniques have helped transition previously mined lands to more productive uses by establishing plant communities with native deciduous trees, it should be noted that these mined-land ecosystems still differ from native forests in multiple respects: they lack the same level of diversity as native forests, especially in the understory; they rarely do not include nonnative species; and their soil and hydrologic properties also stray from those of native forest ecosystems on unmined land. So, while these plant communities may not achieve the same level of productivity as the native counterparts that they resemble, they still represent a progression away from the futile reclamation of the past.

Using remote sensing with Google Earth Engine to assess reforestation

Using the powerful and free-to-use platform Google Earth Engine, the project team developed an algorithm to assess reforestation efforts on mine lands in Central Appalachia by building on a successful previous algorithm that used Google Earth Engine to map mining-related land disturbance. Comparing satellite imagery from 1985 through 2020, this project provides a long-term look at the reclamation progress on mine lands—how long it takes for a forest to establish (known as "years-to-recovery"). The CAMRA algorithm is unique in that it takes a twofold approach, first assessing disturbance extent and then assessing reforestation.

The key to the CAMRA algorithm is remote sensing: the detection and collection of reflected or emitted radiation from Earth's surface. Remote sensors capture spectral bands, which are groups of different wavelengths along the electromagnetic spectrum, such as visible, ultraviolet, and near-infrared (NIR) bands. For example, two key bands used to assess foliage are NIR, because vegetation strongly reflects it, and red (R), because vegetation strongly absorbs it. The CAMRA algorithm, which yields the Aggregated Recovery Metric (ARM), is actually a combination of three different indices used to measure vegetation health: Normalized Difference Vegetation Index, Normalized Difference Moisture Index, and Normalized Burn Ratio.

The Normalized Difference Vegetation Index (NDVI) provides a standard measurement of greenness of healthy vegetation by calculating the ratio between the R and NIR values. The NDVI generates values between -1 and +1. The lowest values typically depict non-vegetated land, urbanized land, or water areas, and values closest to 1 depict dense green vegetation. In this project, NDVI helps differentiate between the stages of forest succession and between healthy hardwood forest stands and stressed vegetation.

The Normalized Difference Moisture Index (NDMI) yields the vegetation's water stress level and canopy cover by calculating the ratio of NIR and shortwave infrared (SWIR) values. The NDMI also generates values between -1 and +1, with the lowest values depicting no vegetation and the highest values depicting widespread canopy cover and minimal or no water stress.

The Normalized Burn Ratio (NBR) emphasizes land areas that have been burned from a fire. In this context, a disturbed mine land has a similar spectral fingerprint to a burned area, so NBR is used to inform the extent of disturbed land.

CAMRA uses the Aggregated Recovery Metric (ARM) to combine the NDVI, NDMI, and NBR.

The fusion of these three indices signifies a generalized site health assigned to a specific area. Then, the mean is compared to the mean value of healthy and unmined Appalachian reference forests for the same U.S. Environmental Protection Agency Level IV Ecoregion that the study site is in.

Percent recovery is defined as: (Site ARM / Healthy Forest ARM)

ARM = ((((NDVI + NBR) / 2) + NDMI) / 2)

The output of the ARM is also between –1 and +1, but is converted to a percentage. The percentage represents a site's progression to reclamation benchmark (such as 70%, 80%, 90%, and so forth). The 95% benchmark denotes near-final forest recovery.

Also considered in the analysis is years-to-recovery. This metric is the time period between the last year a site was mined and the first year its percent recovery was greater than or equal to the recovery level of interest as defined by the ARM output (e.g., 80%, 90%, etc.). While site recovery fluctuates, the first year it reaches each recovery benchmark is a meaningful definition of recovery. The highest tier of reclamation designated was the 95% recovery threshold, or *near-final forest recovery*, which can be assumed as mostly reclaimed or mostly forested.

A new tool for reforestation assessment

The history of mine land reclamation, the evolving understanding of best practices, and the increasing sophistication, accessibility, and prevalence of tools like Google Earth Engine served as the stimulus for this project. While on-the-ground examinations of mine sites offer accurate assessments of species composition and visual changes, satellite analysis with Google Earth Engine can offer a large-scale, nuanced, and objective picture of forest reclamation on mine sites, particularly in their change over time. In conjunction with inspections afield, Google Earth Engine has the potential to transform how reclamation specialists approach forest recovery, from strategizing and visualizing to completing reclamation. Mine sites in Kentucky, Virginia, and West Virginia were the focal point for this project.

Because of the spotty record of previous reclamation efforts, many “reclaimed” mine sites in Appalachia are not classified as forest in the National Land Cover Dataset, but as grassland. This deficiency is largely due to arrested succession from soil compaction, leaving would-be forests in the early stages of succession. The algorithm used in Google Earth Engine, ARM, incorporates the most common and telling indices for assessing vegetative health and provides a multifaceted set of criteria for determining reforestation progress. Google Earth Engine can help researchers and practitioners define which areas are in arrested succession and those in which reforestation occurring successfully; this will allow for more efficient planning and resource allocation, which is increasingly crucial as the bond pool available for funding reclamation continues to dwindle. To test how well Google Earth Engine and ARM are equipped to address reclamation issues, the following pages present information relating to each of these research questions:

- Is reforestation successfully happening on mine lands?
- Where is reforestation happening on mine lands?
- How long does reforestation take to establish on previously mined land?
- Is it possible to determine if surface mines are compliant with reforestation requirements of mine permits as measured solely by satellite imagery?
- Is it possible to tell if mines employing the Forestry Reclamation Approach are doing better than those that employ more traditional techniques?

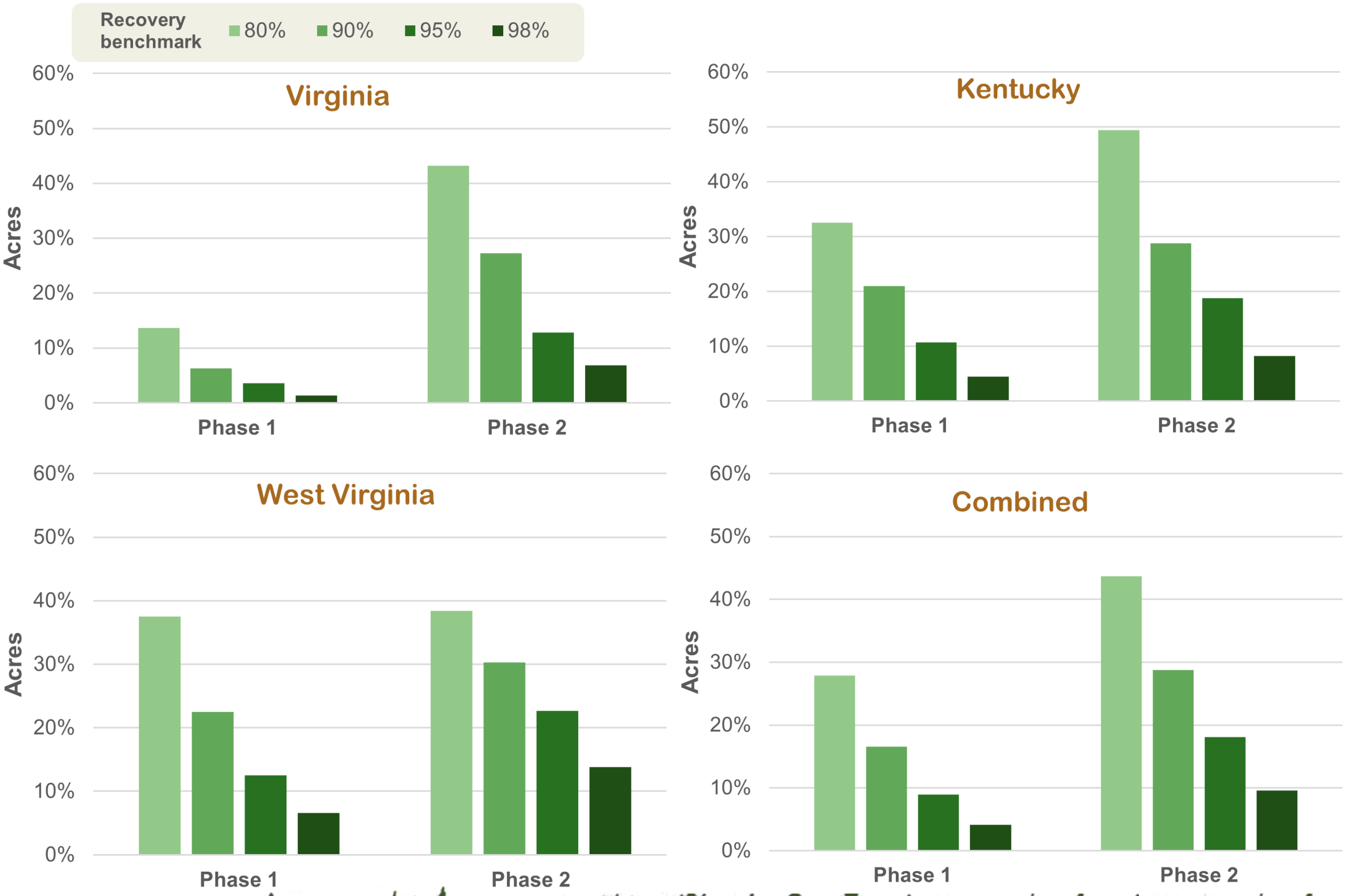
This report is just a small piece of the greater project initiative. The independent data collected and analyzed herein—including GIS shapefiles, each individual component of the ARM index, and a variety of supplemental data—are publicly accessible. While each of the above questions is answered in brief, an included methodology section provides more detail.

Is reforestation successfully happening on mined lands?

Areas are mined incrementally, and as a new section begins a round of mining, the previous section should begin the reclamation process, which is tied to a series of bond releases. The initial stages of succession are the quick revegetation of disturbed lands by herbaceous plants, grasses, and shrubs, but genuine forest takes time to establish. Likewise, the reclamation process occurs over years and is separated into different stages, known as bond releases. The specifics that determine which phase of bond release a mine site qualifies for differs by state, but generally, the following applies:

- Phase I: Backfilling, regrading, drainage control (including stream reconstruction), reseeding, structure removal, equipment removal, discharge treatment, eliminating highwalls, and mobilizing reclamation equipment
- Phase II: Vegetation must successfully reestablish itself within two growing seasons and is subject to a vegetative survey; replanting of woody plants and follow-up reseeding may occur; continued environmental monitoring
- Phase III (completely released): Vegetation must successfully sustain for five years; baseline water quality is not being degraded; wetlands mitigated; forest trees established; reclamation considered complete
  - ⇒Post-mining land use (PMLU): Each mine site will have a designated post-mining land use standard, which may require additional reclamation work. Often in recent years, the PMLU is unmanaged forest, but not always.

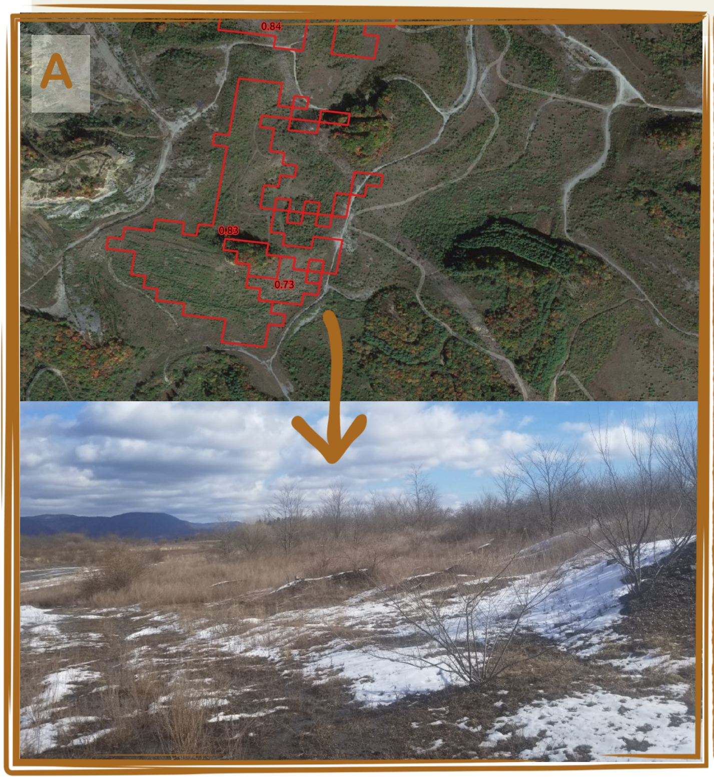
According to the available phase data for the three states, the reclamation sites are indeed following a positive trajectory between Phase 1 and Phase 2. While the increase in acreage for each recovery benchmark may not be dramatic, higher benchmarks (95% and 98%) denote developing forest, which is achieved slowly. In no instance did a recovery threshold lose acreage between the phases. Mine sites are also not required to immediately apply for Phase 2, so many Phase 1 sites can have existing full vegetation.

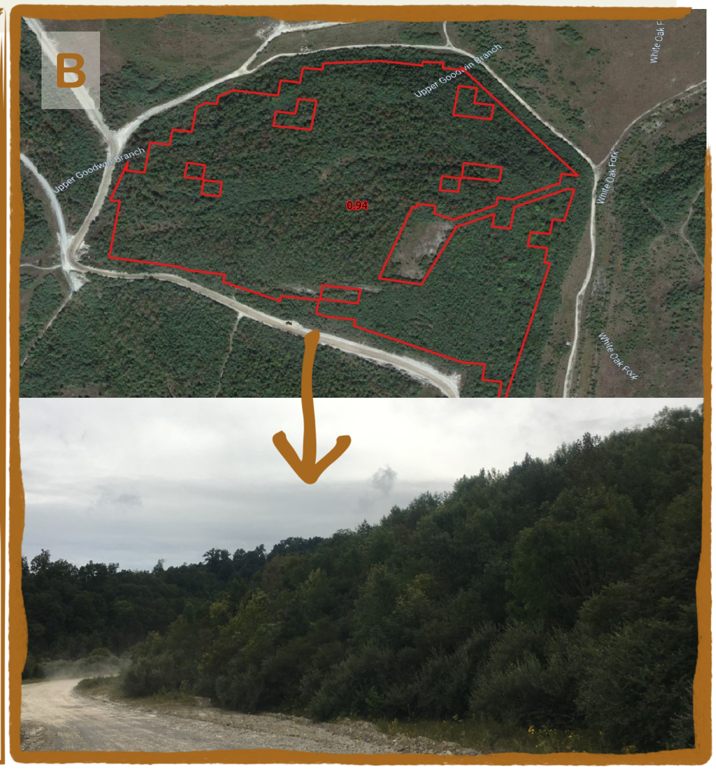


Where is reforestation happening on mined land?

Because individual reclamation goals vary from mine to mine, a general assertion of which areas are reforesting more successfully than others is moot. Instead, it is more informative to compare a mine site against itself over time or against comparable recovery areas with similar ecological circumstances, timelines, policies, and reclamation objectives.

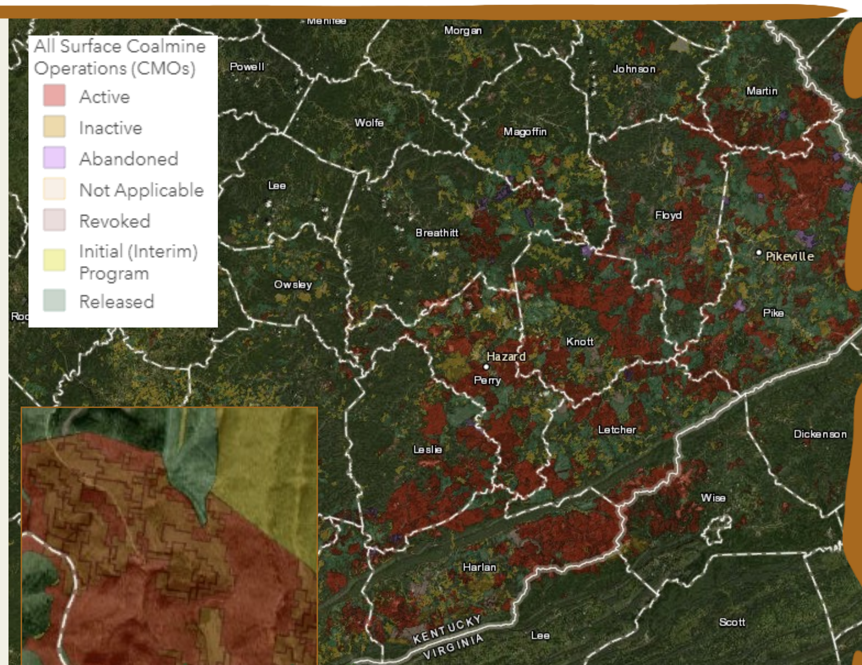
Below are two examples of reforestation results. Example A, which used traditional reclamation techniques, is an example of poor reforestation. The aerial image shows a marked lack of forest and the ground-truth photo confirms the area is largely grass with few woody shrubs. Conversely, Example B, which used FRA, is an example of successful reforestation. The forest is clearly visible from the aerial photo and the photo displays dense and dark trees.





A feature component of this project is a public, interactive web map with associated data and shapefiles available for download. Two versions of the ARM algorithm are provided, one for user-defined, specific areas of interest and one for the entirety of Central Appalachia. Likewise, two shapefiles are available, one for all of Central Appalachia and one that is clipped to current mining permit boundaries.

Web map: https://arcg.is/1LO9nK

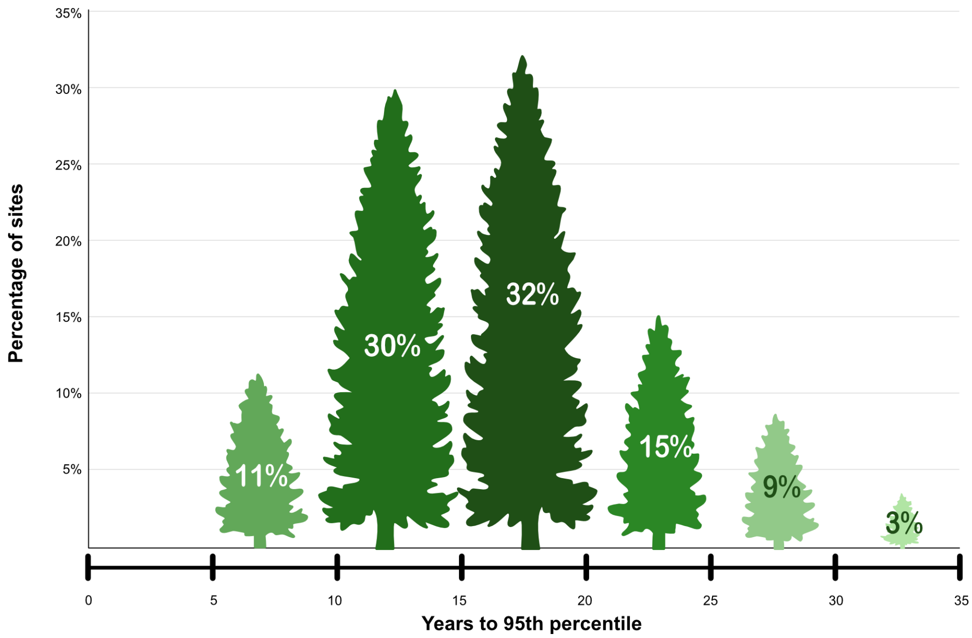


How long does reforestation take to establish on previously mined land?

To determine how long a site took to reach the 95th percentile recovery threshold (or, mostly reclaimed), the year the site was last mined was subtracted from the year the site's ARM result was 95% or over. For example, a site that was mined for the last time in 1985 and achieved the 95% mark in 2004 took 19 years. Note that although data for FRA sites extends to 35 years, FRA has only been in implementation for the last 15 years, so the full dataset does not encompass only FRA techniques. Additionally, the graphs below represent a subset of the data that achieved the 95% mark. See page 13 for more information on data limitations.

Traditional techniques

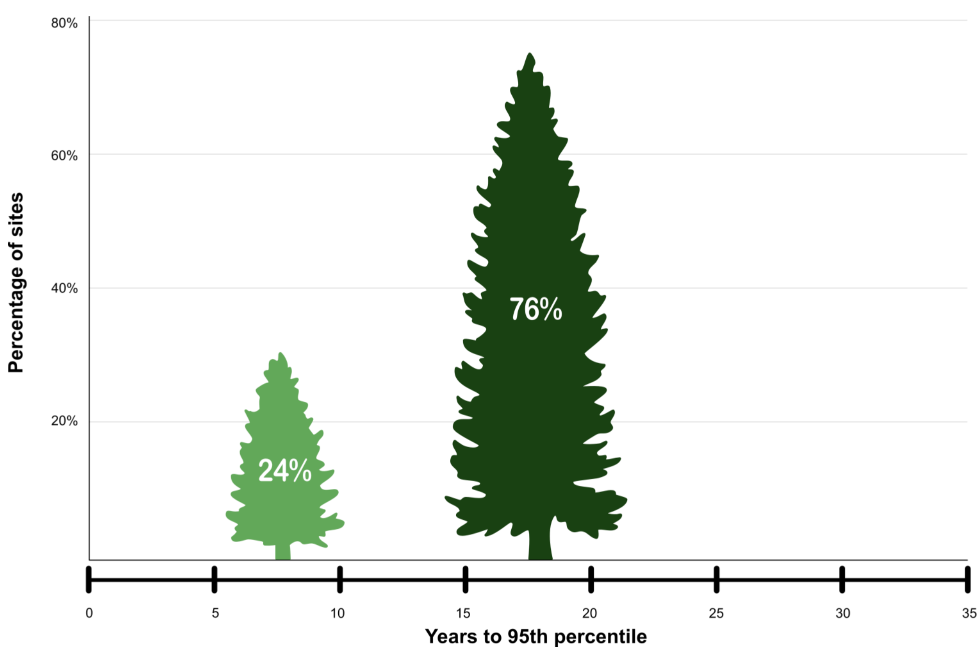
According to the 14,943 non-FRA sites analyzed, most (62%) achieved the 95% recovery threshold between 10 and 19 years, with 30% reaching it between 10 to 14 years and 32% between 15 to 19 years. The shortest amount of time to the recovery threshold was 5 to 9 years, which 11% of the sites reached. The remaining 27% of sites took 20 to 24 years (15%), 25 to 29 years (9%), and, the longest, 30 to 34 years (3%).



FRA techniques

At 195 sites, the available data for FRA sites was significantly less than that available for those using traditional reclamation techniques. The data shown includes only the subset of FRA sites that were first mined after 1984, underwent a second mining event in the past 15 years, and successfully attained the 95% recovery threshold in that time frame (17 sites). Many FRA sites that did not reach the benchmark have simply not had enough time to recover.

Like in traditional reclamation sites, more than three-quarters (76%) of sites reached the recovery threshold between reached 10 and 20 years. However, over one-quarter (24%) reached the threshold in under 10 years.

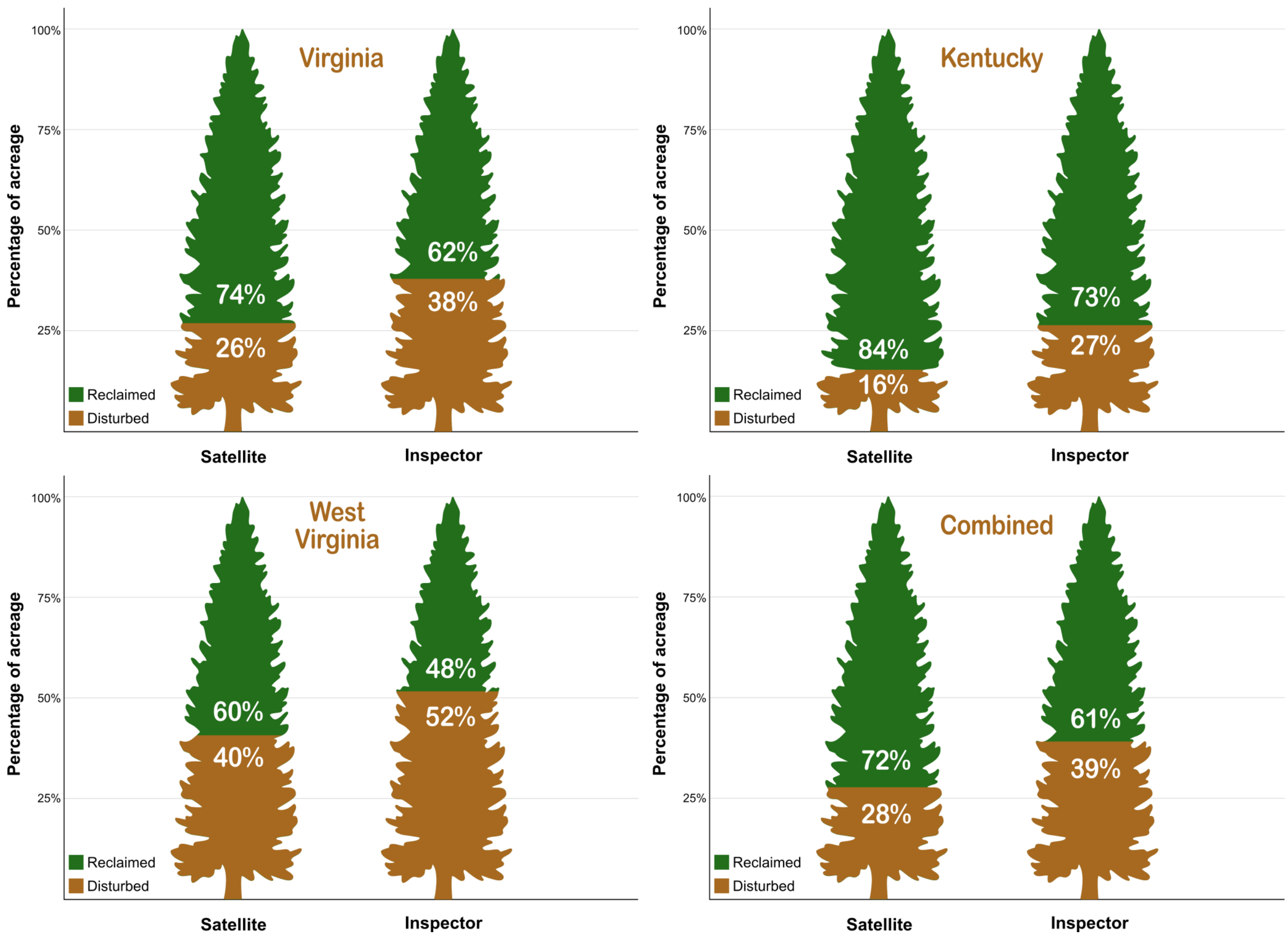


Is it possible to determine if surface mines are compliant with reforestation requirements of mine permits as measured solely by satellite imagery?

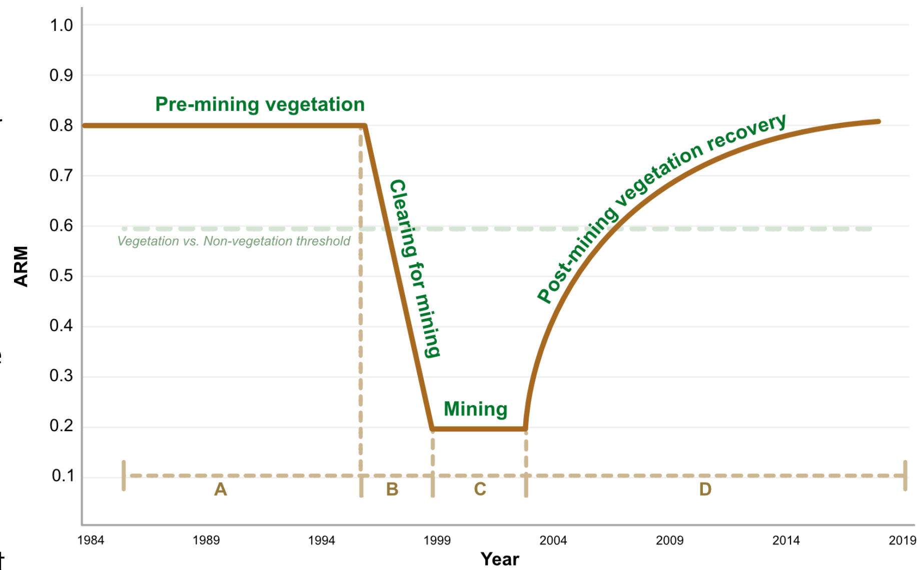
The ratio of disturbed-to-reclaimed land is generally determined by an inspector who makes field-based visual estimates of the reclamation status of a site. These figures are then factored in to defining the site's bond release phase and identifying what additional reclamation measures are needed.

This study sought to compare the standard disturbed-to-reclaimed numbers reported by inspectors and those calculated through a remote analysis of satellite imagery. The threshold used to define recovery was 70%, which represents the transition from grasslands to tree growth (see more in the Methodology section). The data examined included 2018 Landsat satellite imagery and 2020 inspector data for the same 277,825 acres in Kentucky, 53,574 acres in Virginia, and 408,589 acres of land in West Virginia. The results indicated that, while discrepancies were relatively moderate, inspectors consistently classified an average of 11.7% higher disturbed area than the satellite imagery calculations did.

This difference can be contributed to an overrepresentation of reclaimed land in the satellite imagery due to the inclusion of autumn olive and other vegetation that would yield higher ARM values without indicating healthy reclamation. Additionally, inspectors may also err on a conservative reporting of reclaimed land area due to the natural limitations of observations afield and the same uncertainty of indicator vegetation that affects satellite imagery analysis.

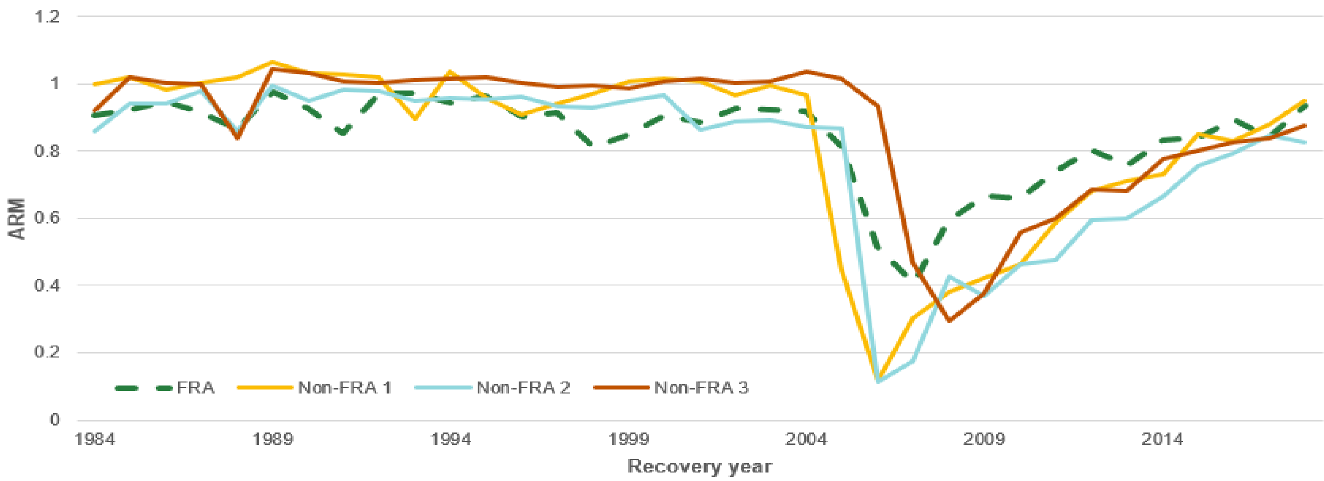


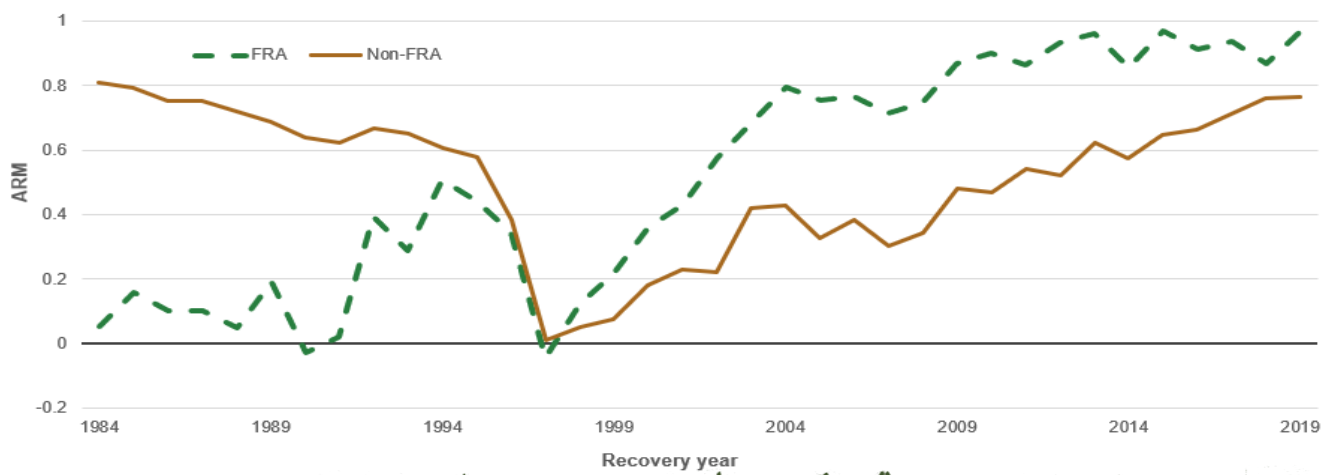
Is it possible to tell if mines employing the Forestry Reclamation Approach are doing better than those that employ more traditional techniques?

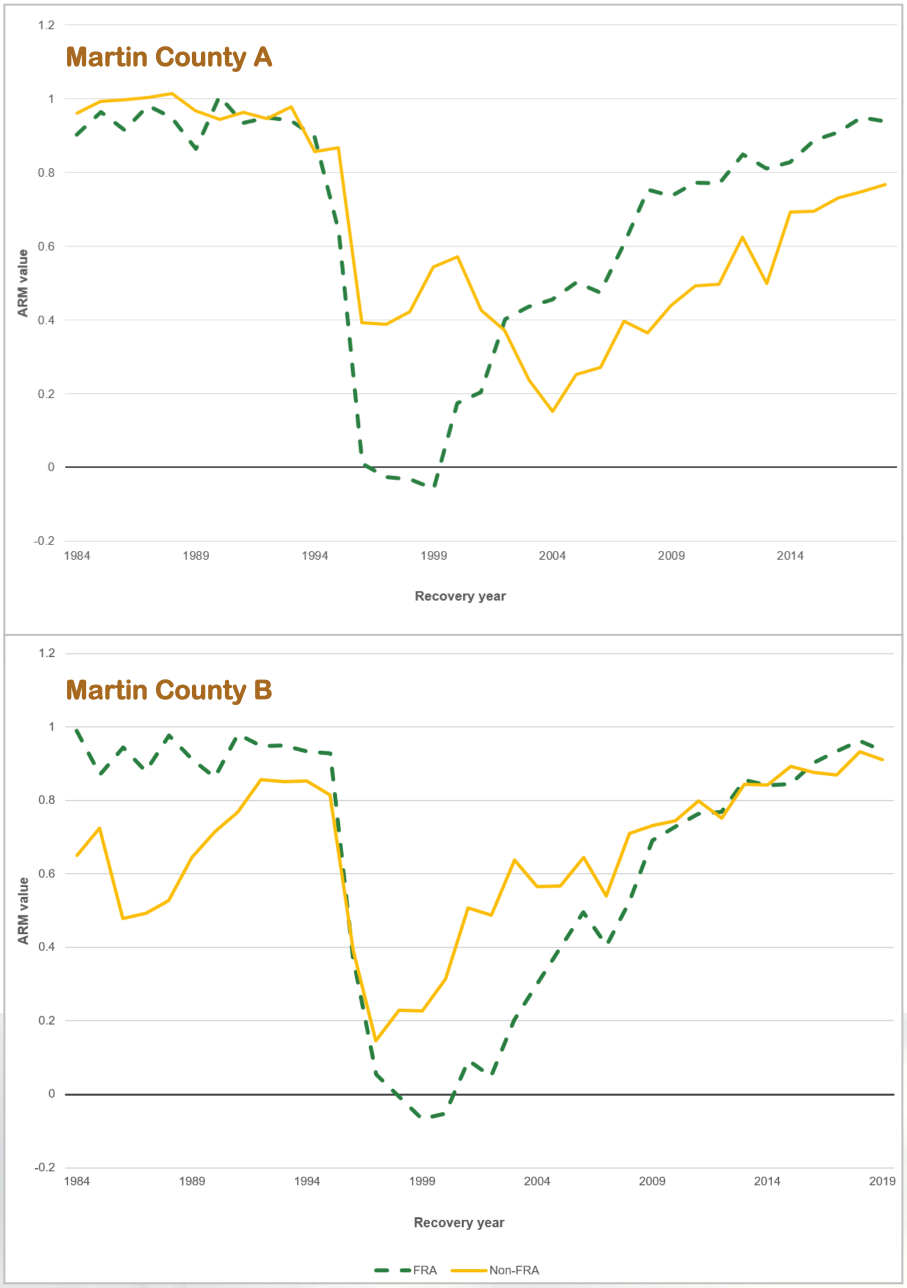


Based on a comparison of a small number of FRA to non-FRA sites, FRA sites do seem to revegetate more quickly immediately post-mining, whereas non-FRA sites tend to recover more gradually. Granted, early revegetation is primary succession, which includes herbaceous plants and grass and woody shrubs. Unless native trees are planted successfully, forest-like vegetation does not typically develop for several decades once the reclamation process begins; even the 70% ARM mark denotes grassland and not forest canopy.

The graph to the right illustrates the basic trajectory of ARM values pre-, during, and post -mining. The four main stages are A) High and generally consistent in pre-mining vegetation, B) Steep drop due to clear-cutting vegetation in preparation for mining, C) Static and low as mining takes place, and D) Gradual increase as vegetation recovers once mining is complete.

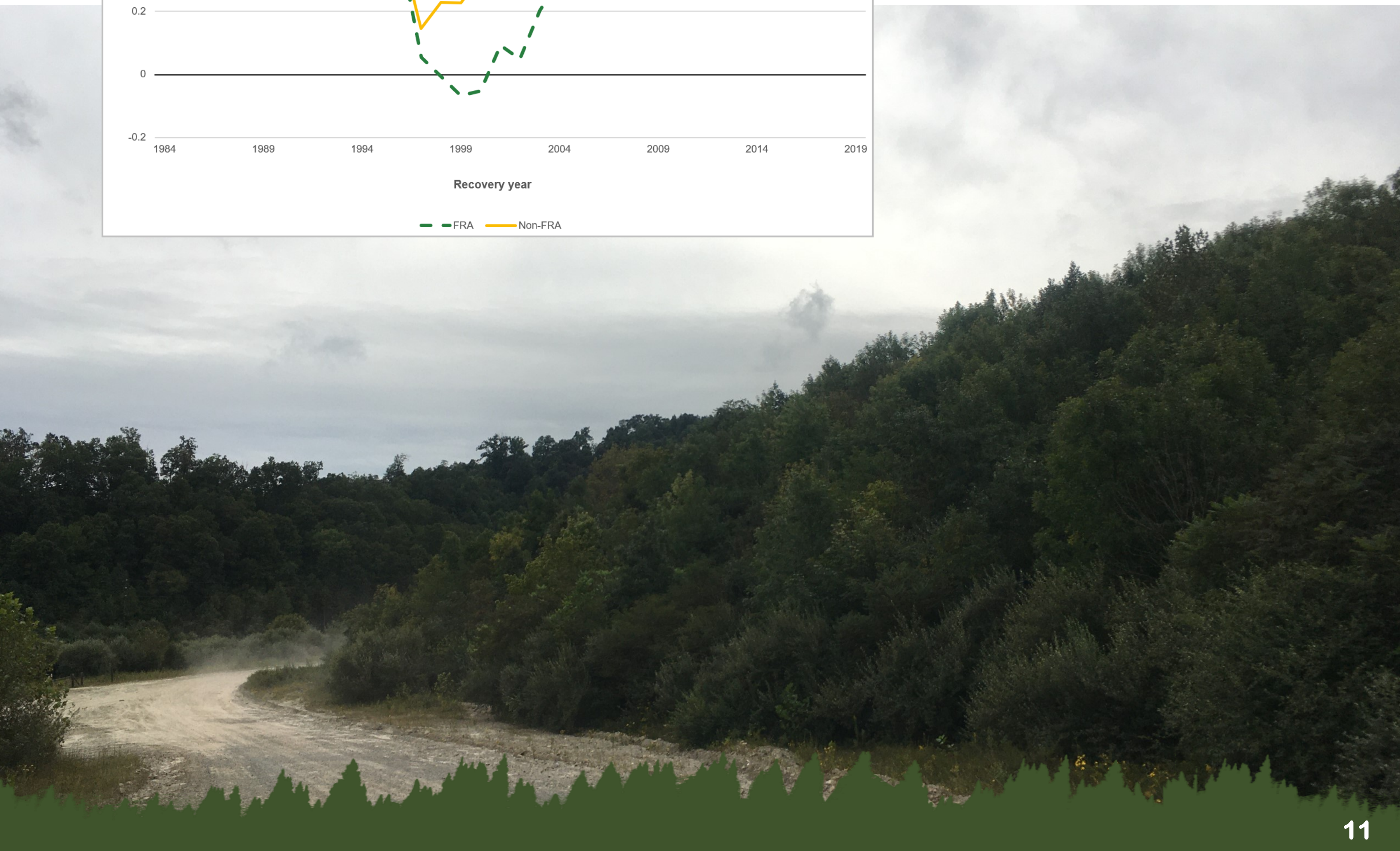






The two graphs on the left depict different areas of a reclaimed mine site in Martin County, Kentucky. The image is also of the site; note that the same image was previously used as an example of good reclamation results.

Areas at both of the Martin County sites employed the FRA. The FRA trajectory at Martin County A exhibited the typical pattern of FRA reclamation, which is a steeper and immediate increase in ARM values and a sustained improvement thereafter. Martin County B, however, shows that the FRA site actually lagged behind the progress of the traditional site, but later caught up with and slightly surpassed it.



Conclusion

The algorithms and resulting GIS dataset contain many columns of data that allow users to characterize mine site recovery. The ARM model is included in the data along with other dataset components that will help aid in site characterization. The model does successfully allow for a quantitative measure of site recovery since 1984. This application of the algorithm in Google Earth Engine could be used as an additional tool for mine site assessment to complement field work.

Based on the results of the ARM model and other publicly available GIS data from state agencies, it appears that, currently, very few mines have achieved a more advanced state (higher than 95% ARM/recovery threshold) of reforestation or revegetation when controlling for variables such as post mined land use. However, the CAMRA tool will provide the ability to continually monitor the conditions of each site over time. The tool's results are also well within the ballpark figures of mine inspectors' calculations of disturbed and reclaimed acres as reported on mine permits.

The satellite-measured data indicated that the FRA sites do reclaim faster than their non-FRA counterparts, which is consistent with other studies that also bear that result.

Assumptions and data limitations

The algorithm has three versions:

1. The first analyzes the entire coal-bearing region and produces feature geometries of areas of like recovery;
2. The second allows the user to define the geography and produces the data for that defined geography; and
3. The third produces feature geometries of areas of like recovery, but allows the user more control over their area of focus.

False positives. The first version of the algorithm that produces a dataset across the entire region includes false positives. For example, areas with logging and gas well roads, due to their similar appearance to mined sites, get characterized as mining and their recovery gets flagged even though no mining has taken place at these locations. Several polygons occur outside of the coalfields and in the Ridge and Valley Province.

One solution to this problem is to take the mined land dataset, run a GIS intersection command with known existing mine permit boundaries, and then recalculate the data on the newly created recovery geographies. However, this approach also has some limitations as it ignores mines that have been completely bond-released. Depending on user needs, either judicious use of the other two algorithms or the current mined recovery GIS data could resolve this issue.

Nonlinear recovery patterns. The nonlinear pattern of NDVI values on spatial analyses of recovering mine sites is well documented in scientific literature. The ARM model, which is largely based on NDVI, likewise exhibits a similar pattern of recovery. Because of the model's nonlinear nature, there may be a disconnect between how the public perceives the values and what the values actually represent. For instance, a 60% ARM value does not mean 60% reforested, but would rather indicate an emerging grassland; 85% ARM would be characteristic of a young forest or poorly reclaimed forest; and 95% ARM would depict the beginning establishment of mature forests in their recovery. The model has been calibrated against sites that were ground-truthed afield in order to have a sense of the actual recovery status; the full range of mine sites are not available, so the model would benefit from additional feedback based on other sites in the study area.

Autumn olives and other vegetation. Including the NDMI moisture index was intended to help differentiate between mines in which autumn olive, a common invasive species on disturbed mine sites, was established and mines in which forests with healthy species composition had recovered. Unfortunately, in the few sites where test trials were run, the model did not significantly discern between healthy recovered forests and mature autumn olive groves.

Due to the various limitations of the model and data, the CAMRA's multistate analysis of the data should only be considered an approximation of mining and recovery in the region and would best be used in conjunction with other sources of information when drawing comparisons on scales greater than an individual mine site.

Next steps and other resources

The hope of this project is to allow coalfield residents, researchers, and mine inspectors to be able to use this dataset to help characterize mine site recovery and provide useful knowledge that will inform policies, goals, and actions. The tools are publicly available, including the variants of the CAMRA algorithm, which are also able to be modified. By releasing the dataset and algorithms out into the world, the project partners hope to normalize the use of Google Earth Engine as a tool to measure mine site recovery.

Appalachian Voices and SkyTruth remain committed to hosting this dataset on the webserver, available here: https://skytruth.org/mtr-data-files/

Is reforestation happening on mined lands?

For each state, GIS datasets were acquired. The CAMRA algorithm shapefile was run through an intersection command with active mining permit boundaries as defined by the shapefile attributes. Sites were then further selected to ensure the Post Mine Land Use (PMLU) was "forest'' and the reclamation stage was either Phase 1 or Phase 2. The area was calculated in acres for Phase 1 and Phase 2 sites.

Phase 3 reclamation sites (completely released) were considered, the assigned PMLU was difficult to determine at these sites, making their inclusion unsuitable.

How long does it take for reforestation to happen on mined lands?

The GIS shapefile for the CAMRA algorithm was run through an intersection command with active mining permit boundaries with a known PMLU of "forest." From the resulting intersection dataset, sites last mined prior to year 1984 were removed. Sites in which the last mined year was 1984 were removed from the resultant intersection data. Sites where reclamation had not yet hit the 95th percentile recovery benchmark were also discarded. A new field was created to house the difference between the year the site hit the 95th percentile benchmark from the last mined year. The results of that column were placed into a histogram to show the frequency of sites reaching recovery at different time periods.

OSMRE provided the data for FRA sites. Many of the sites in the dataset had been previously mined, meaning they had two mining events. Sites where mining commenced prior to 1984 were removed to be consistent with the other dataset. The previous mining also made both years-to-recovery datasets unusable in many cases, because the algorithm populates the fields with years-to-recovery data appearing from before the second mining event. The data used was a subset of data that was mined after 1984, had a mining event in the past 15 years, and successfully recovered in that timeframe. There are other FRA sites from the dataset that have simply not had enough time to recover.

Is it possible to determine if surface mines are compliant with reforestation requirements of mine permits as measured solely by satellite imagery?

Mine inspectors are required by SMCRA to regularly go on inspections. They often collect data as they are afield at the mine site and transfer this information into inspection reports. The inspector data obtained for Kentucky, Virginia, and West Virginia included the number of acres deemed "disturbed" and acres deemed "reclaimed." Comparisons were made between the disturbed acreage reported by the inspectors and disturbed acreage as measured by the SkyTruth disturbance algorithm data that CAMRA is based on.

For the Reclamation section: an intersection command was run between the CAMRA-produced GIS file and the active mine permit boundaries. The resultant data was rerun through the second CAMRA algorithm that assigns spectral values based on specific geographies. Polygons smaller than 1 pixel were removed from the dataset.

During the intersection command, the permit number and current acreage of the permit were transferred to the CAMRA data. Pivot tables were then used to sum the averages of reclaimed areas per permit and totals as well as derive the total percentage of reclaimed area per state. For this calculation, a 70% reclamation benchmark is assumed to be a meaningful benchmark of recovery, as it indicates when grasslands begin to incorporate tree growth.

Is it possible to tell if mines employing the Forestry Reclamation Approach are doing better than those that employ more traditional techniques?

Several sites where the FRA was employed were provided to us by Green Forest Works, OSMRE, and Dr. Carl Zipper of Virginia Tech. Recovery was graphed. For comparison to a non-FRA site, sites were selected in which a significant ARM drop of 60% or more was observed in the same year as the reference site. Sites were further selected of similar size and known PMLU of "forest" using GIS data available from the state. Two graphs are shown in the report.

Data is available here: https://skytruth.org/mtr-data-files/

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