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Rahul Gondalia Date

Remote Sensing Vegetation Reclamation on Surface Mines in Appalachia: A Case Study on Hobet Mine in West Virginia

By

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
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in Global Environmental Health
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Abstract

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By Rahul B. Gondalia

Background: Surface mining in Appalachia has been a large contributor to land-use change in the region. Under the Surface Mining Control and Reclamation Act of 1977 (SMCRA), mine operators assume responsibility to reclaim affected lands post-mining. Evaluating vegetation reclamation is especially important in this region because of its rich biodiversity and the ecosystem services provided.
Aims: The aims of this study were to: 1) monitor temporal changes of vegetation productivity from 1984 to 2010 in specific areas of interest on Hobet Mine and 2) evaluate whether vegetation productivity in mining-permitted lands have properly recovered the vegetation to equal or greater productivity to natural vegetation cover.
Methods: Satellite imagery of Hobet Mine from 1984 to 2010 was collected from the Thematic Mapper sensor on Landsat 5. ENVI was used to calculate the Normalized Difference Vegetation Index (NDVI) for each usable dataset in a Reference Area of Interest (AOI) and three mining-permitted AOIs. ANOVA and Tukey's Studentized Range Test was used to determine if mean NDVI values between and within three benchmark periods (in June of 1986, 1996, and 2007) and AOIs were significantly different. Finally, Minimum Distance Supervised Classification of the benchmark NDVI images was used to classify dense vegetation, sparse vegetation, and barren, mined lands over the study region and four AOIs.
Results: From 1984 to 2010, the maximum mean NDVI values in the Reference AOI were mostly over 0.60. After mining, NDVI values in the three mining-permitted AOIs increased from 0 and appeared to stabilized below 0.60. By 2007, there was a significant difference between the mean NDVI in the Reference AOI and those in the mining-permitted AOIs. Classification results showed that vegetation recovery occurred on approximately 50% of the land in the mining-permitted AOIs.
Conclusion: While vegetation productivity on mined lands increased and approached that of natural vegetation cover, the trajectory of increase tended to stabilize significantly below. Moreover, classification results suggest that only around half of mined areas were restored to equal or greater vegetation productivity. These results have significant implications on the loss of ecosystem services due to surface mining in Appalachia.

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Introduction

Background

The United States hosts the largest recoverable coal reserves in the world, 72% of which is mined in Wyoming, West Virginia, Kentucky, Pennsylvania, and Montana. Approximately 50% of the electricity consumed in the US is generated using coal, and the rate of coal production has increased from 5.4 billion to over 9 billion kilograms of coal per year. With current consumption levels, the recoverable coal reserves in the United States are expected to last for at least 200 years (USEIA 2011). The US Energy Information Administration and the Department of Energy project electricity generation from coal to increase by 25% from 2009 to 2035, but decrease from 45% to 43% in total power generation due to the increase in energy demand from natural gas and alternative sources (USEIA 2011).

Globally, roughly 40% of coal is retrieved from surface mining, while 60% is recovered from underground mines. Surface mines are more widespread in the developed world. In the US, surface mines account for about 67% of coal production. Surface mining can recover a higher portion of coal (90% or greater) relative to underground mining, and is the economically preferential method if the coal seam is near the surface (WCI 2009). This method of mining is generally applied on large areas that have a flat to moderately rolling terrain. The process is highly mechanized and can require explosives, large power shovels, draglines, earth movers, and extensive engineering (Stracher et al. 2010; Miller 2010).

The three forms of surface mining are contour, auger, and area mining, but the coal extraction process is generally similar between these forms. As outlined by the National Research Council (2007), the surface mining procedure is as follows:

1) Vegetation and topsoil removal and storage for later use
2) Drill and blast the strata overlaying the coal seam
3) Load and transport the fragmented strata, now called spoil
4) Drill and blast the coal seam
5) Load and transport the coal
6) Backfill mined area with spoil, then grade land
7) Spread topsoil over graded land
8) Establish vegetation to ensure control of soil erosion and water quality
9) Release the area for other purposes

Topography and geology dictate the method of surface mining because of issues in the accessibility of coal seams, loading and transporting coal, and storing spoil (NRC 2007; GAO 2009).

Coal Mining in Appalachia

Coal mining in the Appalachian region in the US produced 334.4 million tons of coal in 2010, approximately 31% of national coal production. The region has 442 underground and 656 surface mines (DOE 2011). Coal mining is one of the major drivers of land change in this region, largely contributing to the conversion of forest to grass-/shrub-lands from the 1970's to present (Sayler 2011). Surface mining in the mountainous areas in Appalachia primarily use one or a combination of contour, augur, and area mining, also called mountaintop removal mining.

The Appalachian region is highly biodiverse because of its geographic location, physiology, and elevation (Elliott et al. 1999). Appalachian forests consist of nearly 40 economically important tree species as well as numerous herbaceous understory species, making this area one of the most biodiverse non-tropical ecosystems (Ricketts et al. 1999). Large scale land disturbance, such as surface mining, can have adverse impacts on the diversity and vegetation productivity of the affected land (Palmer et al. 2010; Erener 2011). Appalachian forests provide ecosystem services, such as carbon sequestration, watershed and water quality protection, wildlife habitat, and aesthetic value, and have been known to significantly decrease after surface mining disturbances (Townsend et al. 2009; Amichev et al. 2008). Therefore, reclamation processes are an essential component of surface mining to uphold the economic and ecosystem services provided by the land.

Regulation

Surface coal mining can adversely affect wildlife by degrading aquatic and terrestrial habitats, which are especially important for threatened and endangered species protection. It can also decrease air and water quality, which has many implications on the public health of neighboring communities. The Surface Mining Control and Reclamation Act (SMCRA) was established in 1977 by the Office of Surface Mining Reclamation and Enforcement (OSM) within the US Department of the Interior with the objective to abate potential negative consequences of surface mining. The Act regulates active mines and the reclamation of abandoned mines to prevent environmental degradation from surface mining by including "performance standards, permit requirements, reclamation bond requirements, inspection and enforcement authority, and restrictions on mining on certain lands" (TEEIC 2012). In brief, the act requires mine operators to provide post-mining land-use plans, restore affected areas to original or more commercially productive conditions, protect surface and ground water quality and quantity, and ensure the protection of fish, wildlife, and their habitats (SMCRA 1977).

With regards to vegetation, the Act requires permit-holders to establish a "diverse, effective, and permanent vegetative cover…capable of self-generation and plant succession at least equal in extent of cover to the natural vegetation." Additionally, mine operators must assume responsibility of revegetation for five full years after the last year of seeding, fertilizing, or irrigation in regions where annual average precipitation is more than sixty-six centimeters, or ten full years in regions where average annual precipitation is sixty-six centimeters or less (SMCRA 1977).

Reclamation in Practice

Prior studies indicate that reclamation of previously mined land has not properly restored the land to pre-mining conditions (Simmons et al. 2008; Amichev et al. 2008). For instance, ground water samples from reclaimed sites have significantly higher levels of chemicals constituents involved in mining practices, specifically zinc, sodium, selenium, and sulfates, which have adverse impacts on fish and macroinvertebrate species (EPA 2011; Pond et al. 2008). Streams, if not been buried by mining spoil, have increased base flow rates which can influence the ecology of downstream habitats. Snakes and grassland birds have been found to be more plentiful on reclaimed mining lands, while amphibian and salamander species populations have significantly decreased (EPA 2011; Pond et al. 2008). Finally, reclaimed sites have soils that are higher in bulk density, lower in organic content, with low water-infiltration rates, and low nutritional content (Negley and Eshleman 2006).

Vegetation differences between unaltered and reclaimed areas are apparent. Non-native grasses and herbaceous species, rather than native deciduous species of the natural forest, are often planted on mined lands. These species are less resource intensive and grow quickly in the new soil conditions. This leads to quick soil stabilization and minimal sedimentation and surface water contamination caused by erosion (Palmer et al. 2010; Angel et al. 2005). The establishment of predominantly herbaceous species impedes efficient succession of native forest species in reclaimed areas (Simmons et al. 2008). The resulting species on this land often sequester less carbon relative to those in undisturbed areas in the region. Amichev et al. (2008) project carbon sequestration on reclaimed lands to be approximately 77% of that of unaltered forests after 60 years, posing a significant threat to terrestrial carbon storage due to surface mining activities.

The Surface Mining Control and Reclamation Act requires a monitoring plan for mining and post-mining activities. Manual field monitoring at each site over a mining and reclamation period may be time consuming and expensive. Remote sensing techniques can alleviate this burden by providing a cost-effective method for monitoring certain aspects of reclamation, particularly vegetation productivity and land-use change. Also, due to the public availability of satellite imagery in the United States, and the frequency of coverage over a given site, remote sensing can be an effective tool in monitoring change.

Study Objectives

West Virginia permitted over 12,500 acres of land to undergo mountaintop removal mining in the last four decades, therefore studying mining and reclamation procedures in this region is particularly important (Burns et al. 2007). Using remote sensing techniques, this study aimed to monitor and evaluate vegetation changes of mined lands on Hobet Mine in southwestern West Virginia, specifically to:

1) Monitor temporal changes of vegetation productivity from 1984 to 2010 in specific areas of interest, and
2) Evaluate whether vegetation productivity on mining-permitted lands have properly recovered the vegetation to equal or greater productivity to the natural vegetation cover

Methods

Study Site

Hobet Mine is located in southwestern West Virginia in Lincoln and Boone Counties (Figure 1). Much of this area, particularly Boone County, is heavily mined for coal excavation (WVDEP 2012). The mine is in the central Appalachian region of the United States, which has a mixed mesophytic forest cover, consisting of oak and northern hardwood tree species (Sayler 2011).

Hobet Mine is owned by Hobet Mining, LLC, a surface and underground coal mining company based in Madison, West Virginia. The company was founded in 1977 and is currently a subsidiary of Patriot Coal Corporation (Bloomberg Businessweek 2012). Since 1977, Hobet Mining, LLC has owned 42 mining permits, accounting for approximately 15,000 acres of land in West Virginia. Of this, about 7,200 acres have been mechanically disturbed, 2,000 of which have been reclaimed. These numbers may be inconsistent with true values because much of the available public data are not complete or up-to-date (Table 1) (WVDEP 2012). Satellite imagery from 1984 to 2010 over Hobet Mine can be viewed in Figure A-1 in the Appendix.

Logan and Boone Counties have an annual precipitation greater than 66 centimeters, thus Hobet Mining, LLC must monitor revegetation on altered lands for 5 years after the last year of seeding, fertilizing, or irrigating, as stated in the SMCRA of 1977 (WVEPD 2012). Reclamation plans on Hobet mine include rangeland, wildlife habitat, and pasture, however there has been an increase of forestland reclamation permits. Past planting reports and reclamation plans state that large areas of reclaimed land consist of herbaceous grasses, interspaced with non-herbaceous species, including autumn-olive, black alder, bicolor lespedeza, Virginia pine, and white pine (Shank 2009). Table 2 contains information about these species.

Table 1: Mining Permit Information on Hobet Mine

	Permit ID	Total Acres	Acres Disturbed	Acres Reclaimed	Issue Date	Region of Interest
	H012000	32	9	0	5/26/97	
	H029100	50	50	0	6/29/92	
	I073200	24	24	0	1/18/81	
	I073200	24	24	0	1/18/81	
	O000681	256	256	0	9/3/81	
	O501097	340.4	340.4	0	6/30/97	
	P049500	70.5	70.5	0	5/29/80	
	R040500	26	22.5	0	1/25/83	
	S003285	1454	1339	996	4/12/85	Permit Region 2
	S003882	620	16.22	0	2/12/82	
	S010677	640	420	0	7/18/77	
	S012878	1392.8	89	0	6/8/78	Permit Region 1
	S500203	479.72	479.72	0	4/1/04	
	S500207	498	0	0	12/19/08	
	S500306	221	0	0	11/17/06	
	S500307	78.8	0	0	10/23/07	
	S500396	2779.73	0	0	9/4/96	
	S500404	345.7	284.7	0	1/21/05	
	S500806	408.5	0	0	6/19/07	
	S501101	479	132.72	0	7/10/02	
	S501692	1923.7	1591.03	0	11/24/92	
	S502095	1101.34	954.36	0	11/30/95	
	S502202	112	0	0	12/17/03	
	S502497	85	0	0	3/16/98	
	S502689	540	364	364	11/9/89	Permit Region 3
	S502991	501	286	286	10/10/91	
	S508088	550	368.6	368.6	2/16/89	
	U500599	5.1	0	0	7/21/99	
	U500798	17.48	17.48	1.15	7/30/98	
	U500894	27.16	27.16	0	9/7/95	
	U501495	25.34	11.05	11.05	11/13/95	
	U503698	52.6	0	0	9/1/00	
Total	**32**	**15160.87**	**7177.44**	**2026.8**		**3**

Table 2: Prominent non-herbaceous species used for revegetation on Hobet Mine

Species	Type	Native	Invasive	Native Habitat	Source
Autumn-olive (*Elaeagnus umbellata)*	Tree	No	Yes	East Asia	EFETAC*
European black alder (*Alnus glutinosa*)	Tree	No	No	Europe	EFETAC*
Bicolor lespedeza (*Lespedeza bicolor*),	Shrub	No	Yes	Japan	EFETAC*
Virginia pine (*Pinus virginiana*)	Tree	Yes	No	North America	USDA
White pine (*Pinus strobus*)	Tree	Yes	No	North America	USDA

*Eastern Forest Environmental Threat Assessment Center

Mining permits and associated geospatial information was obtained from the West Virginia Department of Environmental Protection in the form of GIS data layers (WVDEP 2012). Of the permitted areas, three particular regions of interest were chosen to evaluate vegetation change over time: Mining-permitted regions S502095 (Permit Region 1), S003285 (Permit Region 2), and S502689 (Permit Region 3) (Figure 2).

Figure 1

Hobet Mine, West Virginia

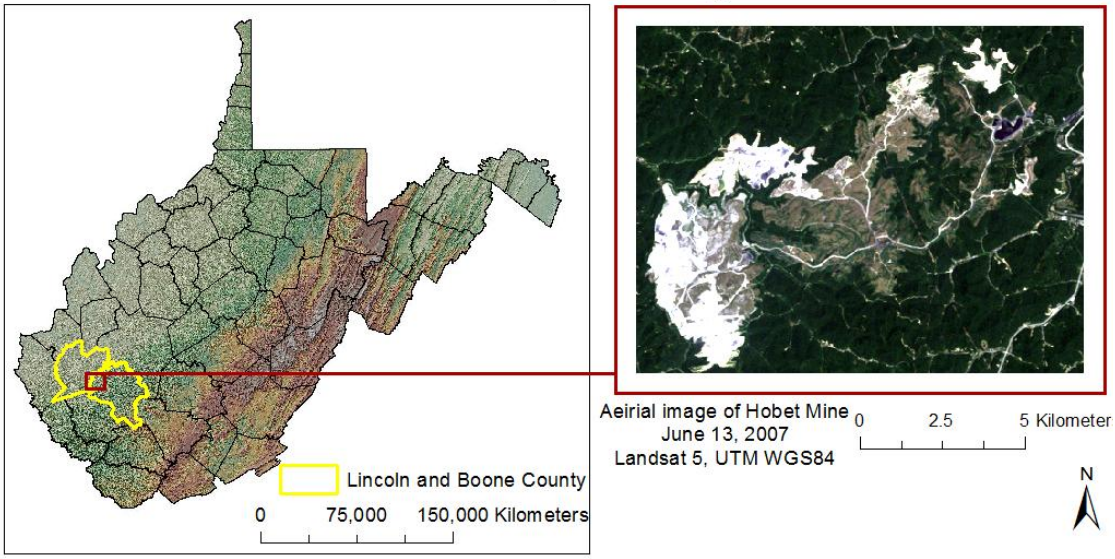
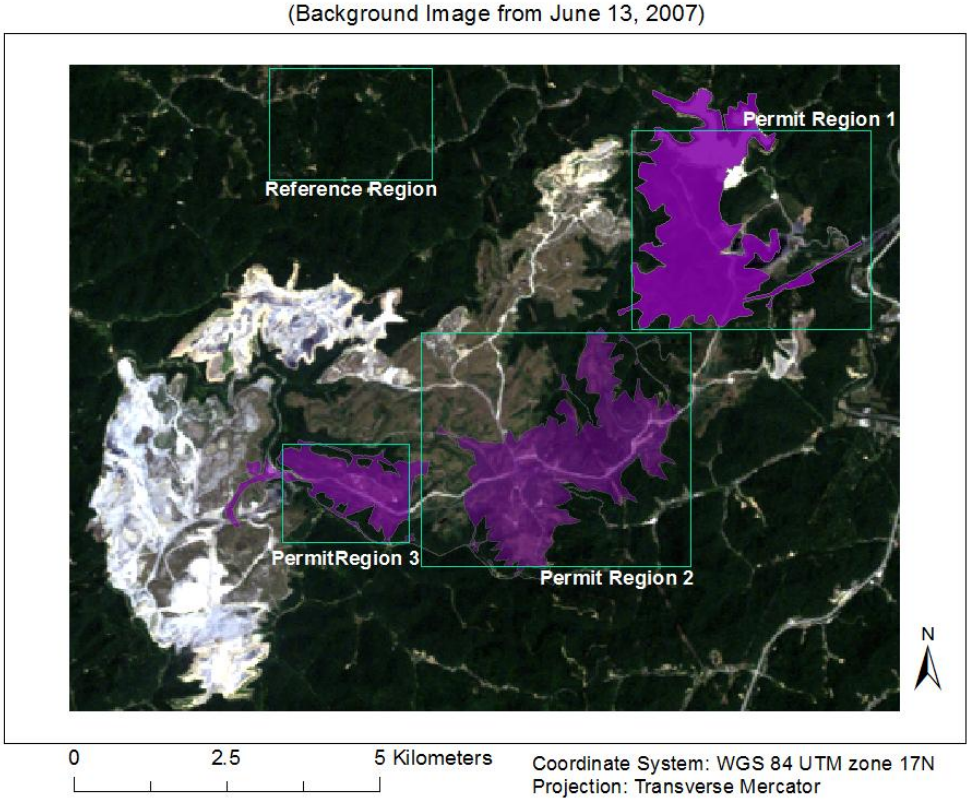


Figure 2

Regions of Interest

(Background Image from June 13, 2007)



Remotely Sensed Data Acquisition

The National Aeronautics and Space Administration (NASA) instituted the Landsat program in the 1970's, which yielded 39 years of continuous satellite imagery of the Earth using 7 satellites. The Landsat 5 satellite, the 5th of the Landsat series, launched into orbit on March 1st 1984. The platform contained two sensors: the Multispectral Scanner System (MSS) and the Thematic Mapper (TM). After over eleven years of service, the MSS sensor was decommissioned in August of 1995. The TM sensor was operational for over 26 years after launch. Since November of 2011, the electronic equipment associated with the sensor has been degrading, and image acquisition has temporarily been terminated. The Thematic Mapper is a multispectral scanning sensor that is advantageous over the MSS sensor due to its "higher image-resolution, sharper spectral separation, improved geometric fidelity, and greater radiometric accuracy and resolution" (NASA 2012).

Landsat 5 orbits the Earth approximately 14.5 times a day at an altitude of 705 kilometers and an inclination of 98.2°. The orbit is polar and sun-synchronous, and there is repeated coverage over a given location every 16 days. The TM data consist of seven spectral bands; Bands 1-5 and 7 have a spatial resolution of 30 meters, while Band 6, the thermal band, has a resolution of 120 meters (NASA 2012). The spectral range and technical specifications for the TM sensor can be found in Tables 3 and 4.

Data from the Thematic Mapper sensor on the Landsat 5 platform were used in this study because of its continuous, undisturbed series of available satellite imagery from 1984 to 2010, which coincides to years of mining on Hobet

Mine, and its advantages over the MSS sensor. Consistently using Landsat 5 over the 26-year period allowed for land change analyses over the study site without having to control for spectral variability associated with using multiple platforms.

Data were obtained using the United States Geological Survey (USGS) Global Visualization Viewer (glovis.usgs.gov) from the Thematic Mapper (TM) sensor on Landsat 5 from 1984 to 2010, on Path 18 and Row 34. The collected data were projected on a Universal Transverse Mercator (UTM) geographic coordinate system, using the World Geodetic System (WGS) from 1984. All data for each available date were acquired for analysis, however those with cloud cover over the study region were excluded, resulting in a sum of 137 usable data products. A Landsat 5 TM product for a given date consisted of seven bands of data. Products were downloaded using Global Visualization Viewer between September 2011 and February 2012. For the complete list of all usable data, refer to Table A-1.

Table 3: Thematic Mapper Bands (NASA 2012)

Band	Wavelength µm	Resolution
1 (Visible Blue)	0.45-0.52	30 m
2 (Visible Green)	0.52-0.60	30 m
3 (Visible Red)	0.63-0.69	30 m
4 (Near Infrared)	0.76-0.90	30 m
5 (Short-wave Infrared)	1.55-1.75	30 m
6 (Thermal Infrared)	10.4-12.5	120 m
7 (Short-wave Infrared)	2.08-2.35	30 m

Table 4: Thematic Mapper Technical Specifications (NASA 2012)

Sensor type	Opto-mechanical
Spatial Resolution	30 m (120 m - thermal)
Spectral Range	0.45 - 12.5 µm
Number of Bands	7
Temporal Resolution	16 days
Image Size	185 km X 172 km
Swath	185 km
Programmable	Yes

Data Quality

USGS Landsat 5 data products were corrected with either Level 1 Product Generation System (LPGS) or National Land Archive Production System (NLAPS). Although LPGS and NLAPS previously had different methods of aligning spectral bands to each pixel, since December of 2008 both methods use identical processes. However, resampling methods are not consistent. Each has different ephemeris files and algorithms to process quaternion, gyro, and gyro drift, which results in slight differences between the two products (USGS 2011). These differences in geometric correction would not significantly affect data processing and analyses in this study.

Radiometric calibration of the data products were processed by USGS using an updated Calibration Parameter Files (CPF) developed in May of 2007. This level of calibration enhances the data products of TM on the Landsat 5 platform and is more radiometrically comparable to the Landsat 7 Enhanced Themetic Mapper Plus (EMT+) sensor (Chander et al. 2007).

Data Processing using ENVI

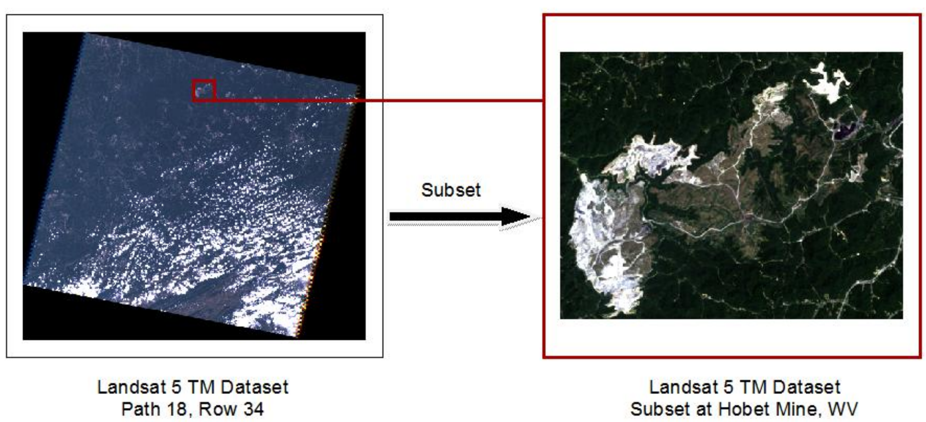
All data products were processed using ENVI 4.8, a geospatial imagery analysis software (Exelis 2012). Data extraction tools for this study include Normalized Difference Vegetation Index (NDVI) transformation and Minimum Distance Supervised Classification.

Pre-processing

Layer Stacking is a method used to combine multiple layers of data into a single dataset. Layers can include Digital Elevation Models (DEMs), Light Detection and Ranging (LiDAR) data, and spectral band data, among others (ITTVIS 2008). The Landsat 5 TM products include seven images corresponding to each of the seven spectral bands. Prior to analysis, Bands 1-5 and 7 were Layer Stacked to create a comprehensive dataset for each date. Band 6, the thermal infrared band, was not included in the Layer Stack because it is not typically used in vegetation analysis. Next, the Layer Stacked data were subset to include only the study region to decrease file size and increase processing efficiency in later analysis (Figure 3).

Figure 3

Subsetting Landsat 5 Data Products:
Example from June 13, 2007 Dataset



Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) has been used as an indicator for plant growth, vegetation cover, and biomass production using multispectral remote sensing data (USGS 2010). As sunlight hits various objects, certain spectral wavelengths are absorbed while others are reflected, in varying degrees. Chlorophyll greatly absorbs visible light from 0.4 to 0.7 micrometers, while the mesophyll leaf structure of vegetation strongly reflects near-infrared light from 0.7 to 1.1 micrometers. Healthy vegetation, abundant in chlorophyll, have particularly low reflectance (thus high absorption) of visible red light (Band 3 from the TM sensor), while having a high reflectance (thus low absorption) of near-infrared light (Band 4 from the TM sensor). The NDVI calculation is as follows:

$$NDVI = \frac{Near\ IR\ Band - Red\ Band}{Near\ IR\ Band + Red\ Band},$$

yielding a value between -1.0 to 1.0. Higher NDVI values correspond to a greater abundance of chlorophyll, an indicator for vegetation productivity (Weier and Herring 2012; USGS 2010)

NDVI was calculated for each usable Landsat 5 TM data product from 1984 to 2010. By visual inspection of NDVI images, an area with unaltered, natural vegetation cover was chosen as the Reference Area of Interest (AOI) (Figure 4). The NDVI values of the Reference AOI were calculated for all data products. Monthly averages were then calculated to observe the annual seasonality of NDVI. It was determined that average NDVI values peaked in the month of June. Using this information, three June dates were chosen between 1984 and 2010 as benchmark periods to monitor change: 1) June 19 1986, 2)

June 14 1996, and 3) June 13 2007. Using datasets from approximately the same date can reduce error caused by differing atmospheric conditions, solar azimuth, and phenological characteristics in vegetation.

The mining-permitted regions of interest, Permit Region 1, Permit Region 2, and Permit Region 3, were visually inspected to observe specific mined areas, those with NDVI values below 0.2. Within these regions, one specific Area of Interest (AOI) per permitted region was chosen for NDVI change analysis (Figures 5, 6, and 7) (Table 5). Lastly, NDVI was calculated for all usable data products in each of the three Permit AOIs.

Descriptive statistics were obtained in the Reference AOI and three Permit AOIs to observe NDVI change on the three aforementioned benchmark periods. Using the General Linear Model (GLM) procedure in SAS 9.3 (Cary, NC), 1) ANOVA was used to determine whether there were differences of mean NDVI and 2) Tukey's Studentized Range (HSD) Test was used to determine which mean NDVI values differed, between and within the benchmark periods and AOIs.

Figure 4

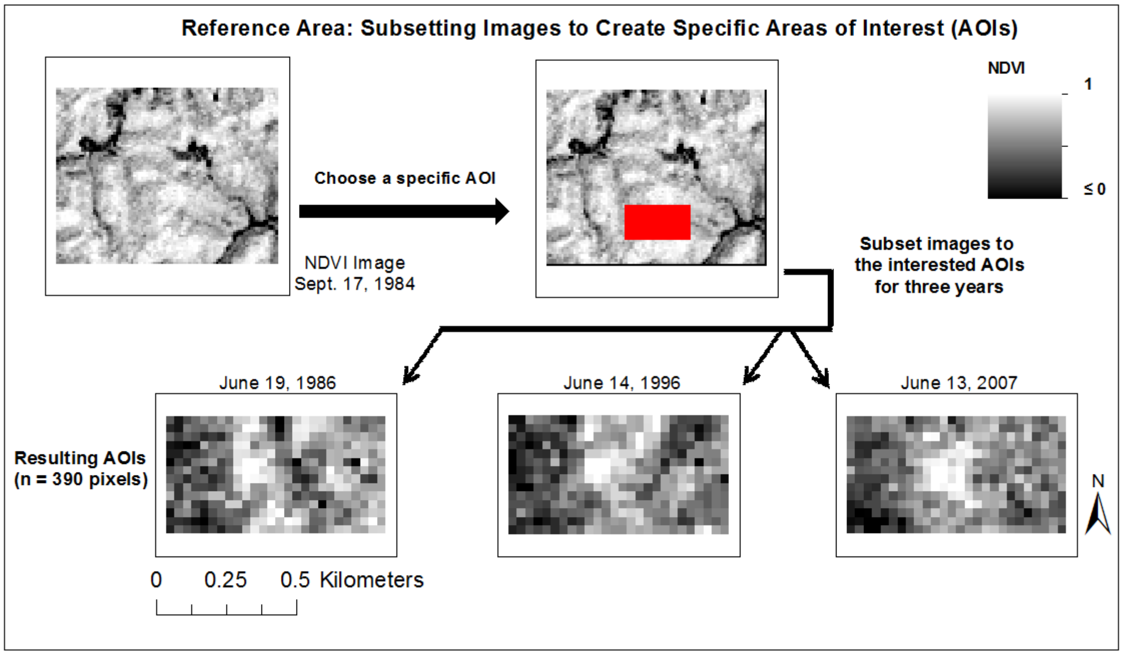


Figure 5

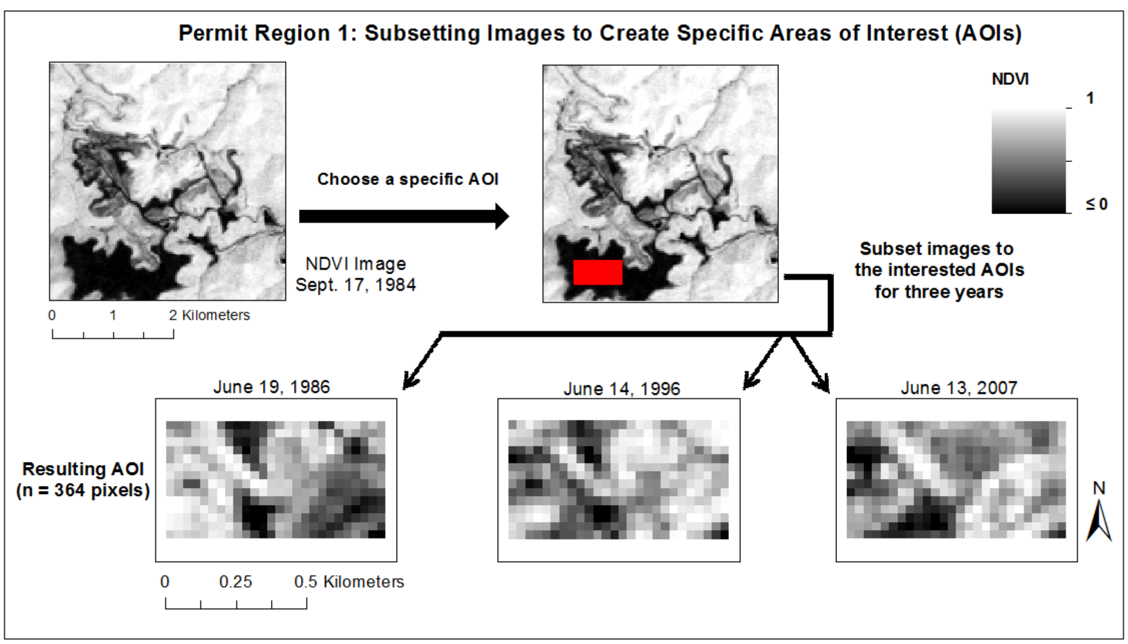


Figure 6

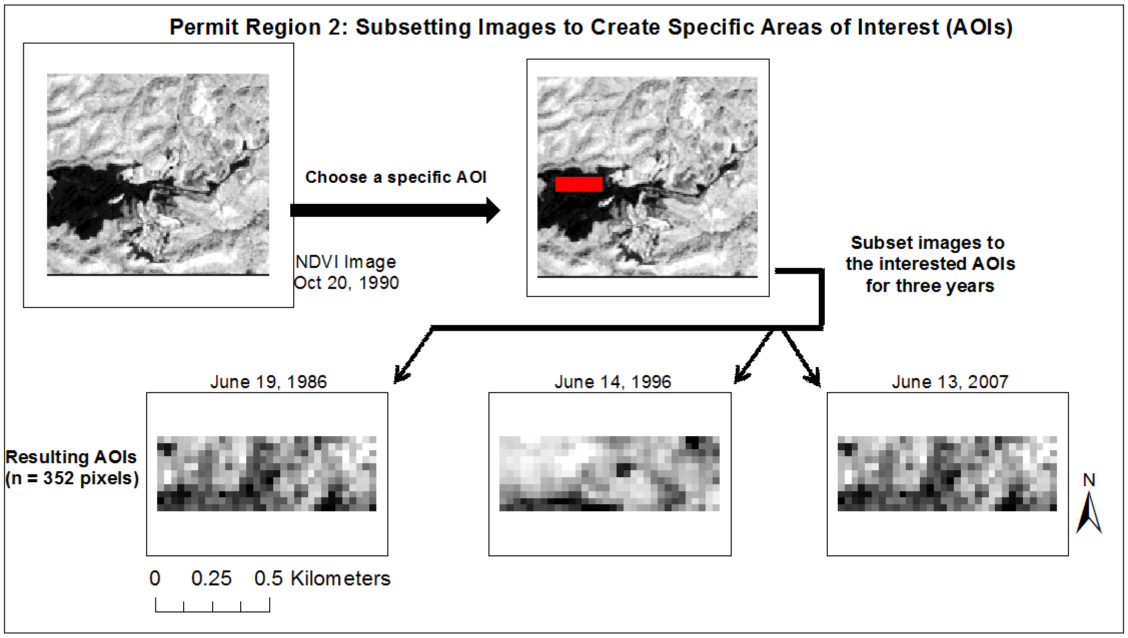


Figure 7

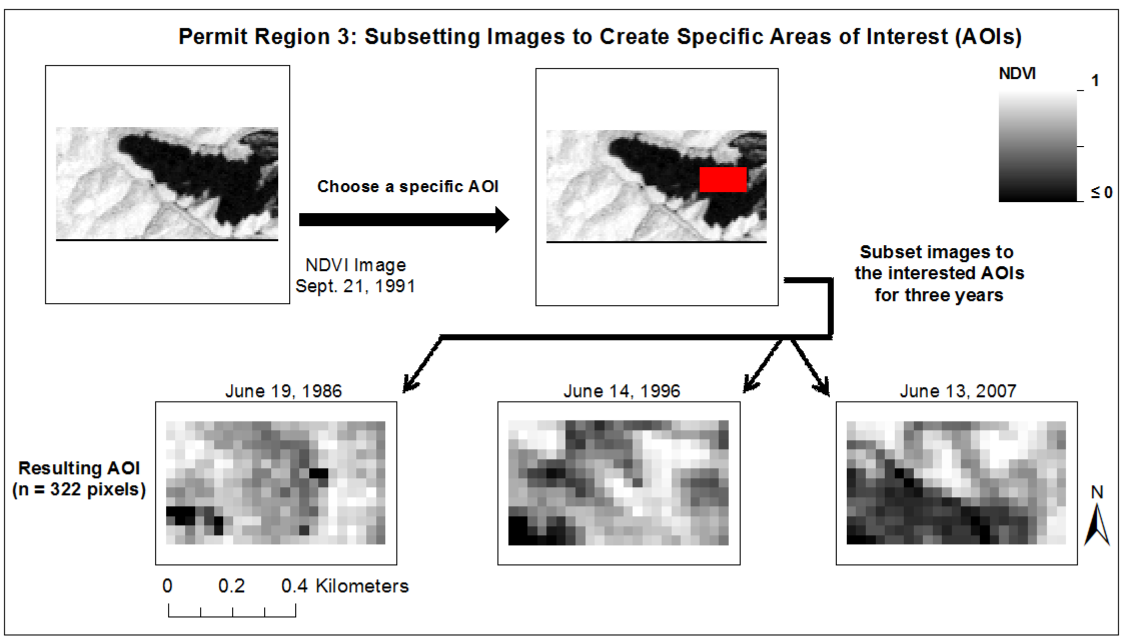


Table 4: Summary of Areas of Interest (AOI)

Permit ID	Area of Interest	Year Mined	Pixels in AOI (n)	Spatial Resolution
NA	Reference	NA	390	30m
S502095	Permit AOI 1	1984	364	30m
S003285	Permit AOI 2	1990	352	30m
S502689	Permit AOI 3	1991	322	30m

Land Cover Classification

Land classification is a process used to visualize differences in land cover over a region by grouping pixels with similar spectral characteristics. For example, sunlight absorption and reflectance on a body of water differs from that of a deciduous forest. Therefore, the pixels of water have different spectral characteristics than those of a deciduous forest, thus is classified into a separate group. Temporal changes of land cover can be quantitatively assessed by comparing classification maps from different dates, given that the classification techniques are consistent between the time periods. In this study, NDVI images calculated with Bands 3 and 4 from Landsat 5 TM data were used to classify land cover over Hobet Mine for each of the three benchmark periods.

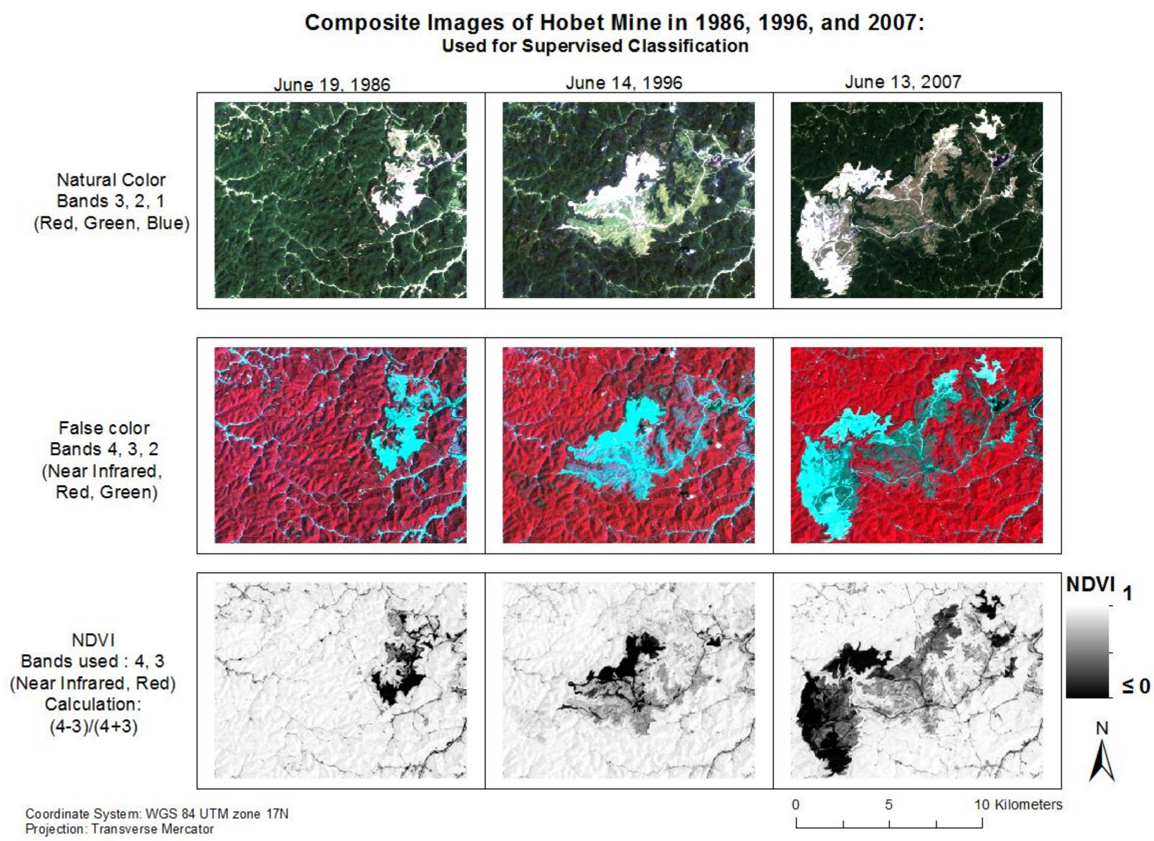
There are two primary methods of classification: unsupervised and supervised classification. Unsupervised classification clusters pixels in a dataset based on statistics, without any user input. This method is preferred when land cover in a region is unknown or difficult to delineate. Supervised classification clusters pixels in a dataset into classes corresponding to user-defined training sets. A user-defined training set is polygon of a known land cover type. From this polygon a spectral signature is calculated. Multiple training sets are created until the number of land cover types the user wants to classify is met. Finally, land cover in an image is classified using the spectral signatures obtained from the original training sets (Exelis 2012; Soofi 2005).

Supervised classification was used in this study because land cover in the study region was easy to decipher using visual interpretation (Exelis 2012). Also, the Minimum Distance technique was chosen because only one input image, the NDVI image, was used. Other supervised classification techniques, such as Maximum Likelihood, Mahalanobis Distance, and Parallelepiped classification require at least two input images.

Training sets were created by visually distinguishing vegetation differences using the following composite images: Bands 3, 2, 1 (true color), Bands 4, 3, 1 (false color), and NDVI (Figure 8). The composite of Bands 4, 3, and 1, shows densely vegetated areas as bright red, while barren, mined land is cyan. These false color composite images allow the user to more easily distinguish between different vegetation land cover types. The NDVI images shows densely vegetated areas as white, while barren land is dark. Three composite images per benchmark period were used to select polygons for three training sets: dense vegetation, sparse vegetation, and barren land.

Minimum distance classification used the mean vectors of the spectral signatures obtained from the three training sets, and calculated the Euclidean distance from each unknown pixel to the mean vector for each of the three classes. No standard deviation or distance thresholds were selected, resulting in the classification of all pixels (Exelis 2012). Following classification, ancillary data (from WVEPD) were used to mask areas where Hobet Mining, LLC mining permits are held to view only changes in land cover at these permitted regions. Finally, classification characteristics of the four AOIs were analyzed to evaluate the progress of vegetation reclamation.

Figure 8



Results and Discussion

Aim 1: Monitor temporal changes of vegetation productivity from 1984 to 2010 on specific areas of interest

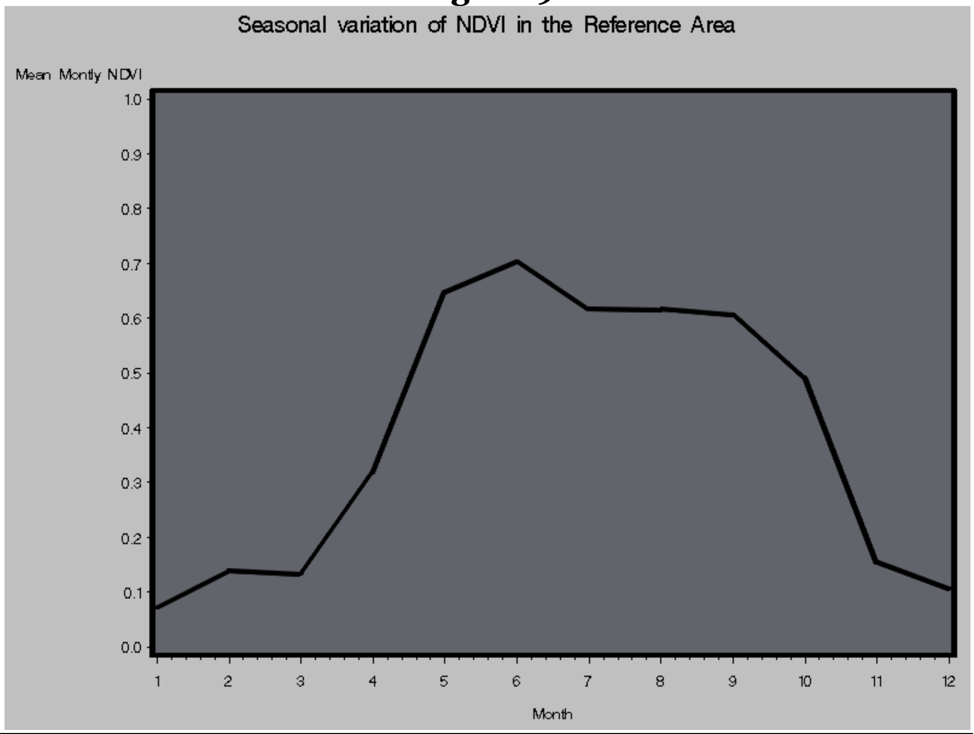
Reference AOI

NDVI was calculated in the Reference Area of Interest (AOI). To observe the seasonal trends of NDVI, monthly averages were calculated, as seen in Table 6, and can be graphically viewed in Figure 9. Mean NDVI values in the Reference AOI ranged from 0.07 in January (n = 12 months) to up to 0.70 in June (n = 10 months), consistent to what is expected given the climate at that latitude. For further analysis, Landsat 5 TM products from three benchmark periods, one per decade between 1984 and 2010, in June were chosen to extract high NDVI values for comparison: June 19 1986, June 14 1996, and June 13 2007.

Table 6: Mean Monthly NDVI of Reference AOI

Month ID	Month	Mean NDVI	n Months
1	January	0.07	12
2	February	0.14	2
3	March	0.14	7
4	April	0.33	11
5	May	0.65	6
6	June	0.70	10
7	July	0.62	15
8	August	0.62	20
9	September	0.61	13
10	October	0.49	20
11	November	0.15	13
12	December	0.11	7

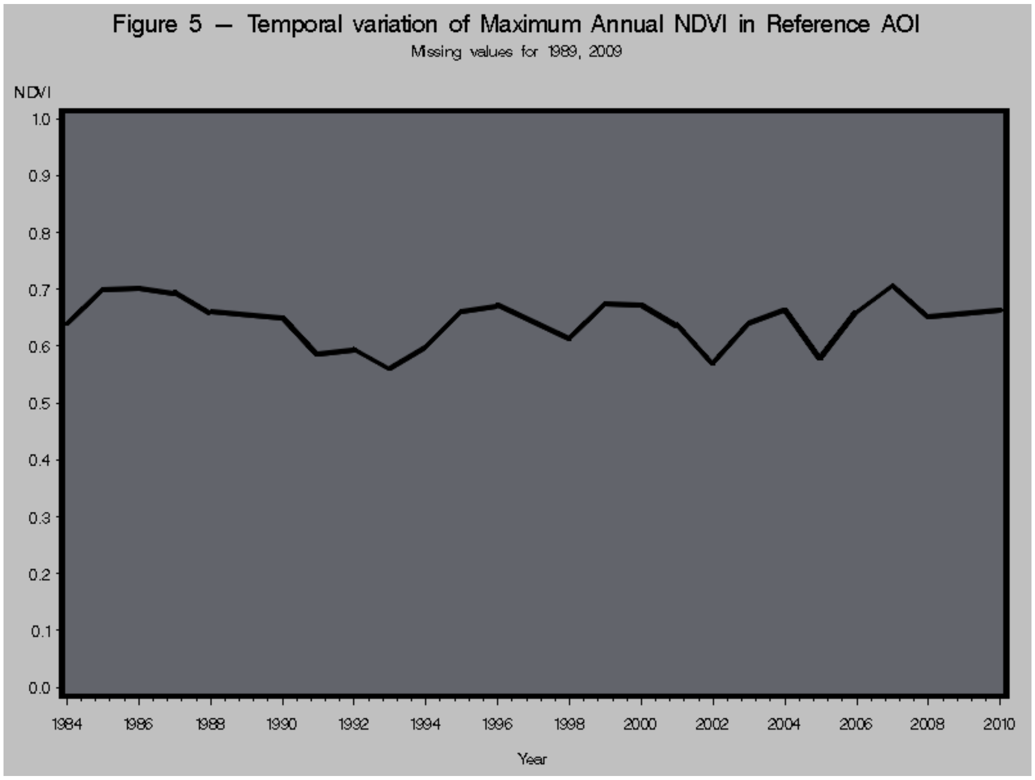
Figure 9



High mean NDVI values, those above 0.60, were found in the months May, June, July, August, and September, ranging from 0.61 in September (n = 13 months) to 0.70 in June (n = 10 months). These months were categorized as months in the growing season.

For each year, the maximum NDVI value from a growing season date was plotted to view temporal vegetation productivity change in the Reference AOI (Figure 10). In the years 1989 and 2009, Landsat 5 TM datasets without cloud cover over the study region were not available, thus these years were excluded. For the remaining dates, the maximum NDVI during the growing season ranged from 0.58 on August 9 of 1993 to 0.75 on June 13 of 2007. The exact dates and corresponding summary statistics of the maximum mean NDVI of the Reference AOI during the growing season from 1984 to 2010 can be found in Table A-2.

Figure 10



Descriptive statistics were obtained to examine NDVI change by-pixel for each benchmark period in the Reference AOI. Table 7 provides a summary of statistics for the Reference AOI, while Figure 11 and Table 8 provide a graphical visualization and a quantitative representation of the interquartile range of NDVI, respectively.

Table 7:
Summary NDVI Statistics of Ref AOI in 1986, 1996, and 2007

Date	Minimum	Maximum	Mean	Std. Dev.
June 19, 1986	0.69	0.78	0.74	0.016
June 14, 1996	0.66	0.75	0.70	0.016
June 13, 2007	0.69	0.80	0.75	0.016

Figure 11: Boxplots of NDVI in the Reference AOI

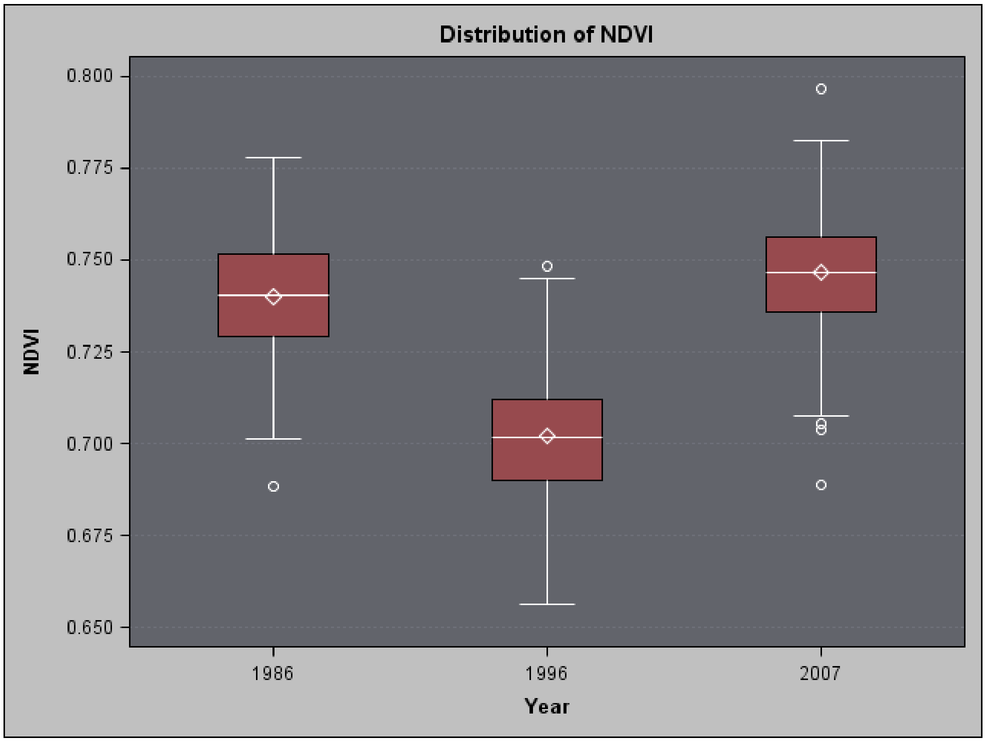


Table 8: Percentile Values and Interquartile Range (IQR) of NDVI in the Reference AOI

June 19, 1986		June 14, 1996		June 13, 2007	
Percentile	***NDVI***	***Percentile***	***NDVI***	***Percentile***	***NDVI***
100	0.78	100	0.75	100	0.80
75	0.75	75	0.71	75	0.76
50	0.74	50	0.70	50	0.75
25	0.73	25	0.69	25	0.74
0	0.69	0	0.66	0	0.69
IQR	0.22	IQR	0.22	IQR	0.02

The ANOVA procedure showed that the mean NDVI values across the benchmark periods in the Reference AOI were not the same (df = 2, F = 829.30, p < 0.001) (Table A-6).

Using the General Linear Model (GLM) procedure, Tukey's Studentized Range (HDS) Test was used to compare the NDVI means between the three benchmark periods in the Reference AOI. The test showed a significant difference of means between years 1986 and 1996, 1996 and 2007, and 1986 and 2007: 0.0378 ($p < 0.05$; CI: [0.0352, 0.0407]), 0.0444 ($p < 0.05$; CI: [0.0417, 0.0472]), and 0.0065 ($p < 0.05$; CI: [0.0037, 0.0093]), respectively (Table 9). However, these NDVI differences of means were minimal and all below 0.05. With respect to NDVI values, a change of 0.05 can be influenced by temperature and precipitation characteristics weeks or months previous to the dates of interest (Linli and Jun 2010). Furthermore, no land-cover change was visible when inspecting the images for each benchmark period. In addition, the temporal variation of maximum annual NDVI between 1984 and 2010 was no greater than 0.05, with NDVI values consistently over 0.60, indicating no unusual change of vegetation productivity during the study period.

Table 9: Tukey's Studentized Range Test for Mean NDVI Ref AOI

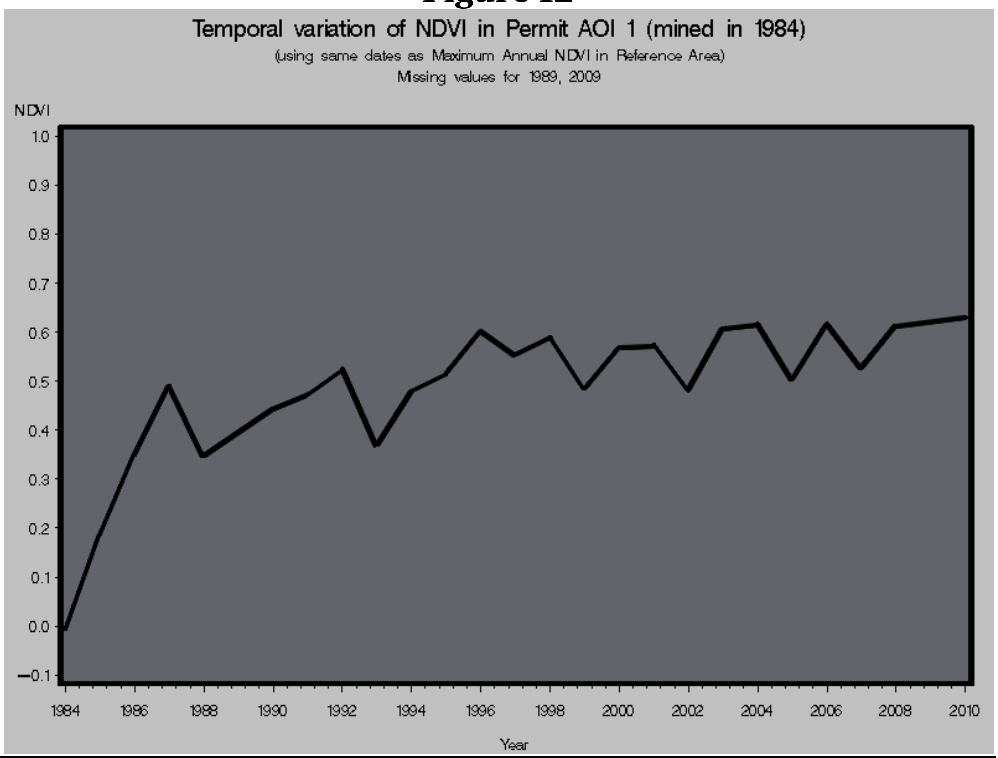
Benchmark Period Comparisons	Difference Between Means	Simultaneous 95% Confidence Limits		Significant at 0.05 level: ***
1986 vs. 1996	0.0378	0.0352	0.0407	***
1996 vs. 2007	-0.0444	-0.0472	-0.0417	***
1986 vs. 2007	-0.0065	-0.0093	-0.0037	***

Permit Area of Interest 1

The dates with maximum average NDVI for each growing season from 1984 to 2010 in the Reference AOI were used to observe temporal NDVI change in Permit AOI 1. Permit AOI 1 was mostly mined in 1984, which yielded an NDVI value of -0.0057. This value corresponded to barren areas of rock or sand, with little or no vegetation (Weier and Herring 2012). Reclamation activities drastically increased vegetation productivity to nearly 0.50 by 1987. From 1987 to

2010, the NDVI in the area slowly increased, maximizing at 0.63 in 2010 (Figure 12 and Table 10). The exact dates and corresponding summary statistics of the maximum average NDVI of Permit AOI 1 during the growing season from 1984 to 2010 can be found in Table A-3.

Figure 12



Descriptive statistics were obtained to examine NDVI change by-pixel for each benchmark period in Permit AOI 1. Table 10 provides a summary of statistics for Permit AOI 1, while Figure 13 and Table 11 provide a graphical visualization and a quantitative representation of the interquartile range of NDVI, respectively.

Table 10:
Summary NDVI Statistics of Permit AOI 1 in 1986, 1996, and 2007

Date	Minimum	Maximum	Mean	St. Dev
June 19, 1986	0.00	0.58	0.35	0.14
June 14, 1996	0.30	0.72	0.60	0.08
June 13, 2007	0.26	0.71	0.53	0.10

Figure 13: Boxplots of NDVI in Permit AOI 1

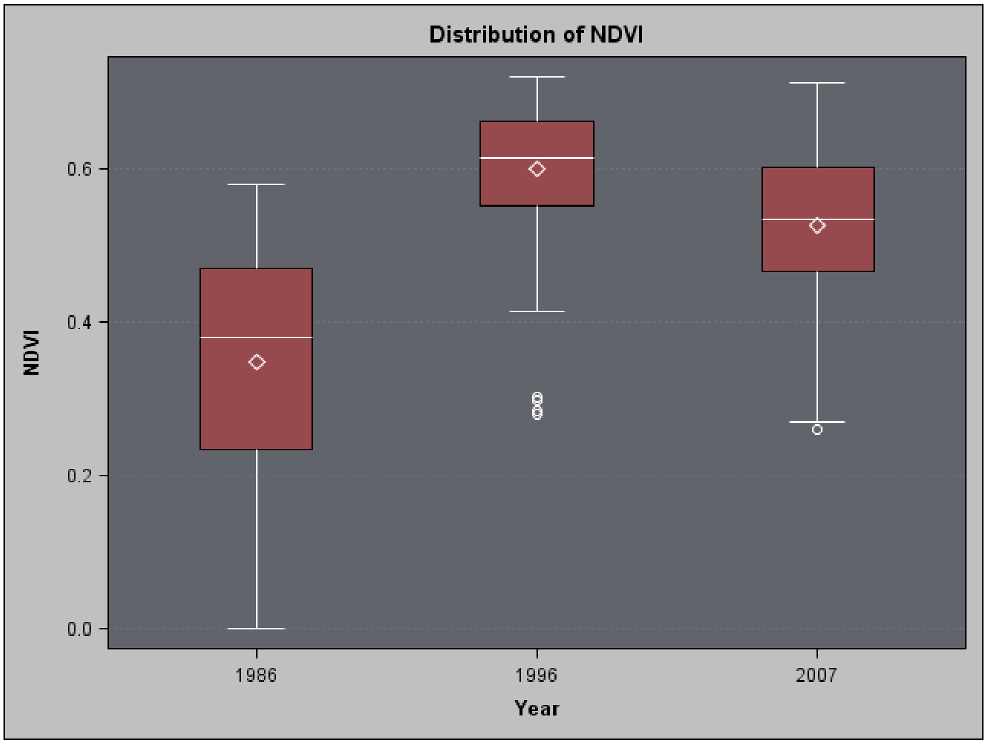


Table 11: Percentile Values and Interquartile Range (IQR) of NDVI in Permit AOI 1

June 19, 1986		June 14, 1996		June 13, 2007	
Percentile	***NDVI***	***Percentile***	***NDVI***	***Percentile***	***NDVI***
100	0.58	100	0.72	100	0.71
75	0.47	75	0.66	75	0.60
50	0.38	50	0.62	50	0.53
25	0.23	25	0.55	25	0.47
0	0.00	0	0.30	0	0.26
IQR	0.24	IQR	0.11	IQR	0.14

The ANOVA procedure showed that the mean NDVI values across the benchmark periods in Permit AOI 1 were not the same (df = 2, F =513.67, p < 0.001) (Table A-7).

Using the General Linear Model (GLM) procedure, Tukey's Studentized Range (HDS) Test was used to compare the NDVI means between the three benchmark periods in Permit AOI 1. From 1986 to 1996, 1996 to 2007, and 1986 to 2007 there was a significant increase of mean NDVI by 0.2510 ($p < 0.05$; CI: [0.2321, 0.2699]), a decrease by 0.0736 ($p < 0.05$; CI: [0.0547, 0.0925]), and an increase by 0.1774 ($p < 0.05$; CI: [0.1585, 0.1963]), respectively (Table 12).

The mean NDVI value in 1996 was on the upper range of NDVI values for Permit AOI 1, while that of 2007 was relatively low. For this reason, there was a large increase of NDVI from 1986 to 1996 and a relatively smaller increase from 1986 to 2007. Also, it was expected that the mean NDVI from 1996 to 2007 would be similar or slightly increased, however this was not observed. Statistical analysis implies a significant decrease of NDVI from 1996 to 2007. Although statistically significant, the decrease of mean NDVI between the two years was not extreme. With the majority of values between 0.50 and 0.60 from 1996 to 2007, the trend suggests suggest a stable mean NDVI, as seen in Figure 12.

Table 12: Tukey's Studentized Range Test for mean NDVI Permit AOI 1

Benchmark Period Comparisons	Difference Between Means	Simultaneous 95% Confidence Limits		Significant at 0.05 level: ***
1986 vs. 1996	-0.2510	-0.2699	-0.2321	***
1996 vs. 2007	0.0736	0.0547	0.0925	***
1986 vs. 2007	-0.1774	-0.1963	-0.1585	***

Permit Area of Interest 2

The dates with maximum average NDVI for each growing season from 1984 to 2010 in the Reference AOI were used to observe temporal NDVI change in Permit AOI 2. Permit AOI 2 had a mean NDVI of 0.02 corresponding to a barren, low vegetation area in 1990 when the area was mined. Previous to the year it was mined, year-to-year NDVI values were comparable to those in the Reference AOI (Table 13).

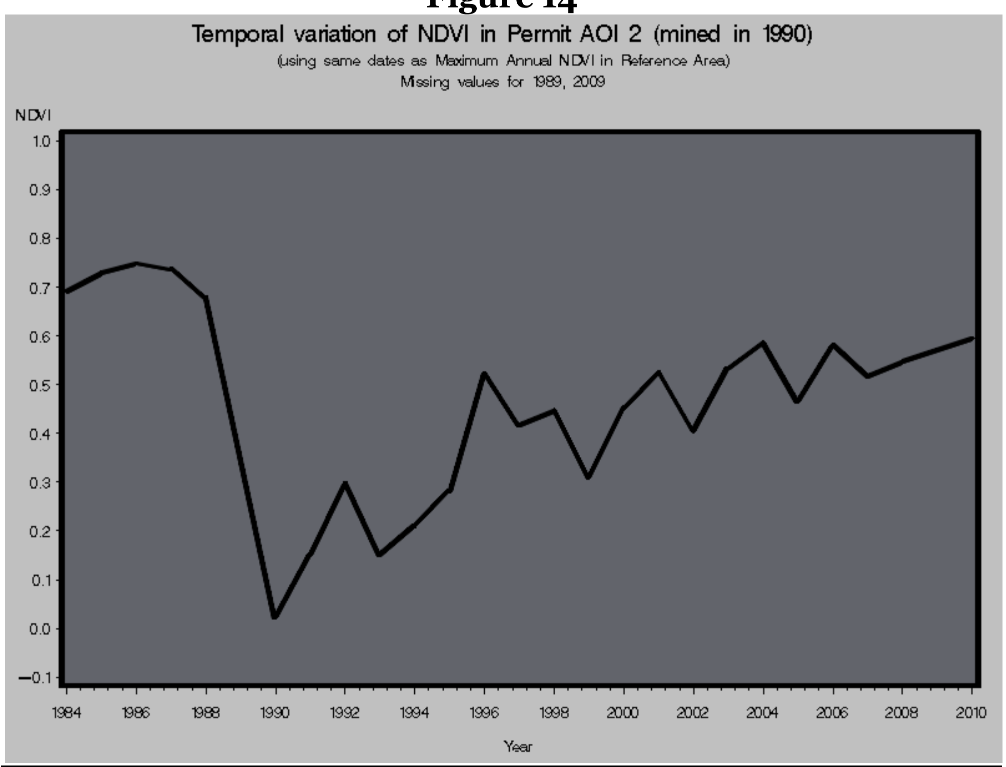
Table 13: Pre-mining NDVI values at Permit AOI 2

Year	Reference AOI	Permit AOI 2
1984	0.67	0.69
1985	0.72	0.73
1986	0.74	0.75
1987	0.72	0.74
1988	0.70	0.68
1990*	0.68	0.02

*indicates year of mining on AOI

Post-mining, reclamation procedures increased the vegetation productivity in the area to 0.52 in 1996. NDVI values increased over time reaching 0.59 by 2010 (Figure 14). The exact dates and corresponding summary statistics of the maximum average NDVI of Permit AOI 2 during the growing season from 1984 to 2010 can be found in Table A-4.

Figure 14



Descriptive statistics were obtained to examine NDVI change by-pixel for each benchmark period in Permit AOI 2. Table 14 provides a summary of statistics for Permit AOI 2, while Figure 15 and Table 15 provide a graphical visualization and a quantitative representation of the interquartile range of NDVI, respectively.

Table 14:
Summary NDVI Statistics of Permit AOI 2 in 1986, 1996, and 2007

Date	Minimum	Maximum	Mean	St. Dev
June 19, 1986	0.71	0.78	0.75	0.01
June 14, 1996	0.18	0.65	0.52	0.07
June 13, 2007	0.28	0.71	0.52	0.10

Figure 15: Boxplots of NDVI in Permit AOI 2

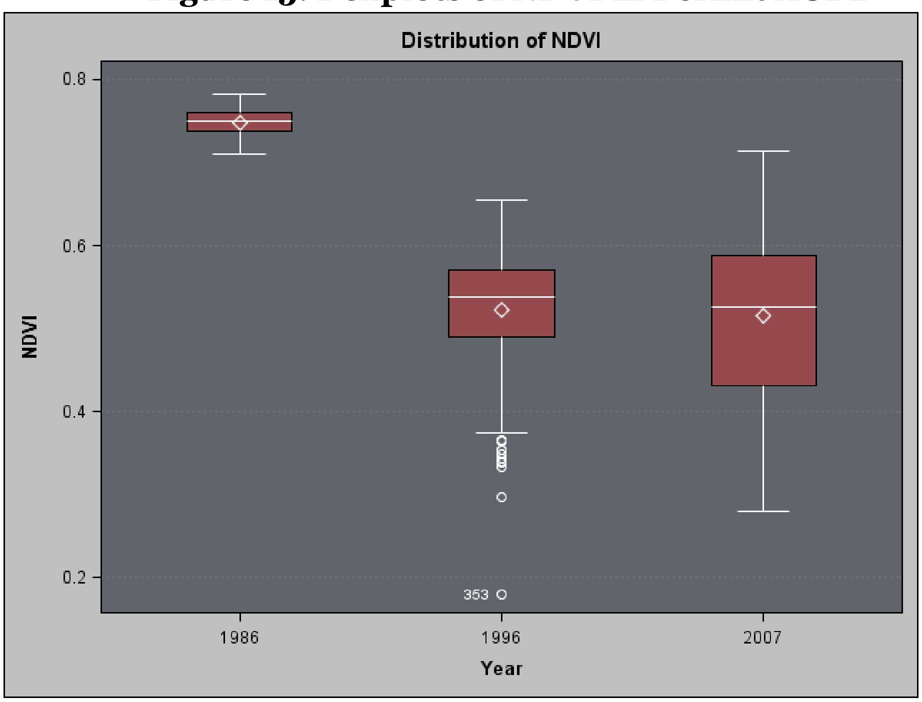


Table 15: Percentile Values and Interquartile Range (IQR) of NDVI in Permit AOI 2

June 19, 1986		June 14, 1996		June 13, 2007	
Percentile	***NDVI***	***Percentile***	***NDVI***	***Percentile***	***NDVI***
100	0.78	100	0.65	100	0.71
75	0.76	75	0.57	75	0.59
50	0.75	50	0.54	50	0.53
25	0.74	25	0.49	25	0.43
0	0.71	0	0.18	0	0.28
IQR	0.22	IQR	0.08	IQR	0.16

The ANOVA procedure showed that the mean NDVI values across the benchmark periods in Permit AOI 2 were not the same (df = 2, F = 1324.72, $p < 0.001$) (Table A-8).

Using the General Linear Model (GLM) procedure, Tukey's Studentized Range (HDS) Test was used to compare the NDVI means between the three benchmark periods in Permit AOI 2. The test showed that there was a significant decrease of mean NDVI from 1986 to 1996 and 1986 to 2007 by 0.2263 ($p <0.5$; CI: [0.2143, 0.2383]) and 0.2321 ($p <0.5$; CI: [0.2200, 0.2442]), respectively. The 0.0059 decrease of mean NDVI from 1996 and 2007 was not a significant ($p >0.5$; CI: [-0.0062, 0.0179]) (Table 16).

Analysis suggests that surface mining in Permit AOI 2 was responsible for the decrease of vegetation productivity from 1986 to 1996. Also, statistical tests imply that the mean NDVI difference from 1996 and 2007 was not significant, suggesting that vegetation productivity may have stabilized, or at least slowed in growth, between the two years. However, graphical trends suggest that mean NDVI in Permit AOI 2 may be increasing slightly with time.

Table 16: Tukey's Studentized Range Test for mean NDVI Permit AOI 2

Benchmark Period Comparisons	Difference Between Means	Simultaneous 95% Confidence Limits		Significant at 0.05 level: ***
1986 vs. 1996	0.2263	0.2142	0.2383	***
1996 vs. 2007	0.0059	-0.0062	0.0179	
1986 vs. 2007	0.2321	0.2200	0.2442	***

Permit Area of Interest 3

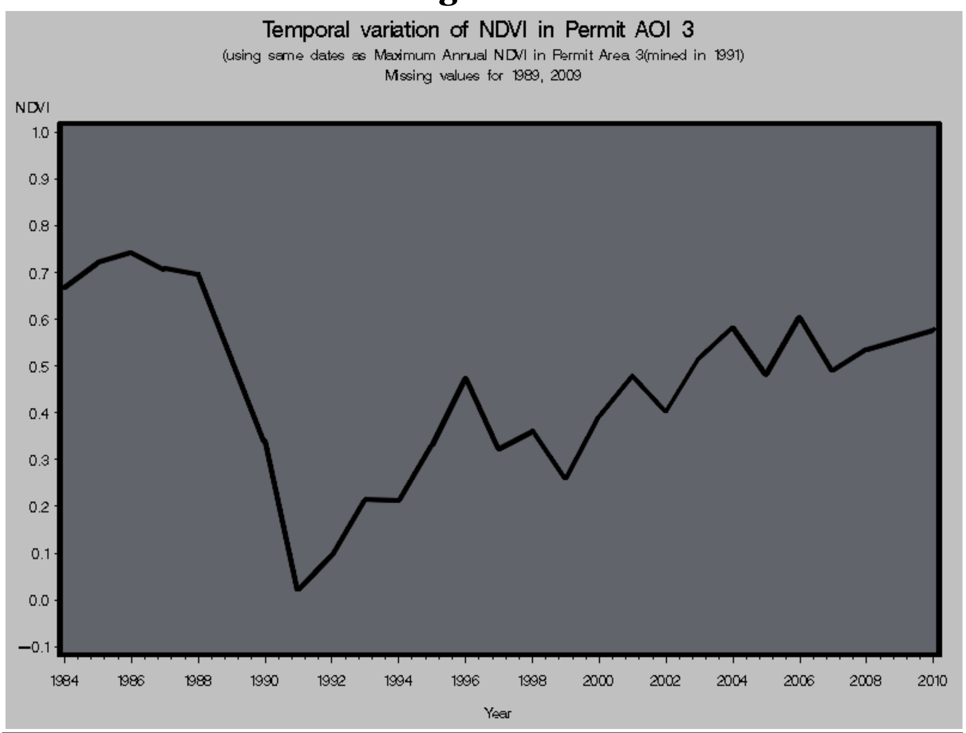
The dates with maximum average NDVI for each growing season from 1984 to 2010 in the Reference AOI were used to observe temporal NDVI change in Permit AOI 3. The average maximum NDVI during the growing season was lowest in 1991, when the areas was mined, with a value of 0.02, and peaked at 0.74 on June 19, 1986 (Figure 16). In the years previous to mining, the year-to-year NDVI values were comparable to those in the Reference AOI, specifically from 1984 to 1988 (Table 17). In 1990, the AOI was partially altered due to mining activities, yielding a moderate NDVI (0.34) for that year. By 1991, the entire AOI was altered, resulting in a mean NDVI of 0.02. From 1991 to 1996 the mean NDVI increased to 0.47, and by the end of the study period, mean NDVI in the area reached 0.58. The exact dates and corresponding summary statistics of the maximum average NDVI of Permit AOI 3 during the growing season from 1984 to 2010 can be found in Table A-5.

Table 17: Pre-mining NDVI values at Permit AOI 3

Year	Reference AOI	Permit AOI 3
1984	0.67	0.67
1985	0.72	0.72
1986	0.74	0.74
1987	0.72	0.71
1988	0.70	0.70
1990*	0.68	0.34
1991**	0.61	0.02

*year of partial AOI alteration due to mining
**year of entire AOI alteration due to mining

Figure 16



Descriptive statistics were obtained to examine NDVI change by-pixel for each benchmark period in Permit AOI 3. Table 18 provides a summary of statistics for Permit AOI 3, while Figure 17 and Table 19 provide a graphical visualization and a quantitative representation of the interquartile range of NDVI, respectively.

**Table 18:
Summary NDVI Statistics of Permit AOI 2 in 1986, 1996, and 2007**

Date	Minimum	Maximum	Mean	St. Dev.
June 19, 1986	0.63	0.78	0.74	0.02
June 14, 1996	0.07	0.78	0.47	0.10
June 13, 2007	0.08	0.72	0.49	0.13

Figure 17: Boxplots of NDVI in Permit AOI 3

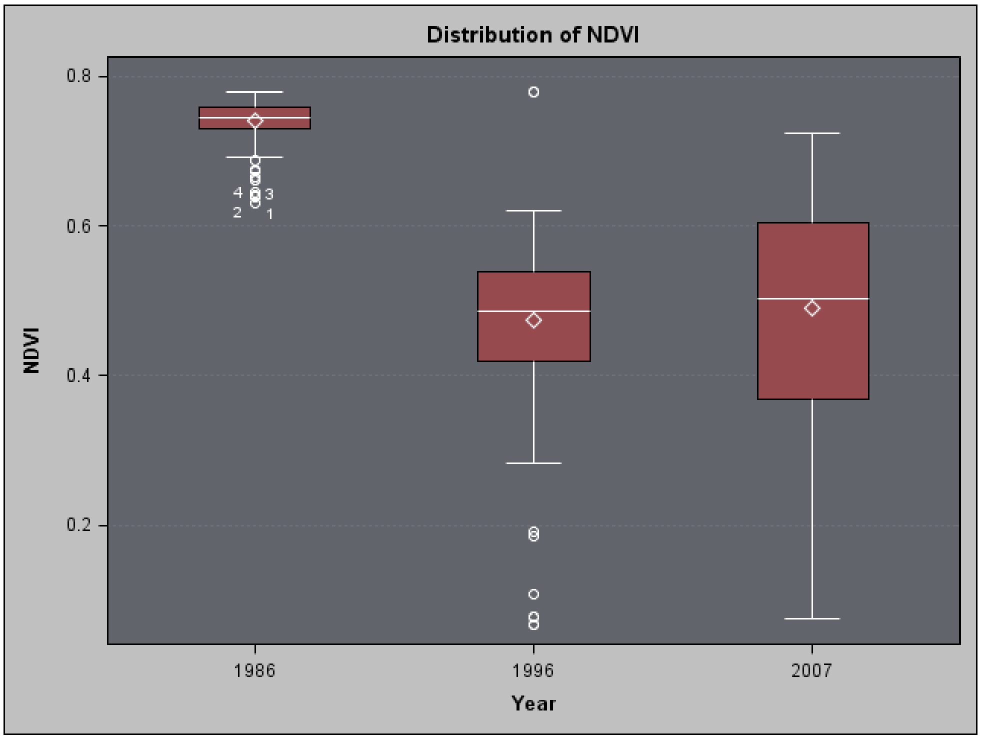


Table 19: Percentile Values and Interquartile Range (IQR) of NDVI in Permit AOI 3

June 19, 1986		June 14, 1996		June 13, 2007	
Percentile	***NDVI***	***Percentile***	***NDVI***	***Percentile***	***NDVI***
100	0.78	100	0.78	100	0.72
75	0.76	75	0.54	75	0.60
50	0.74	50	0.49	50	0.50
25	0.73	25	0.42	25	0.37
0	0.63	0	0.08	0	0.08
IQR	0.03	IQR	0.12	IQR	0.24

The ANOVA procedure showed that the mean NDVI values across the benchmark periods in Permit AOI 3 were not the same (df = 2, F = 767.02, p < 0.001) (Table A-9).

Using the General Linear Model (GLM) procedure, Tukey's Studentized Range (HDS) Test was used to compare the NDVI means between the three benchmark periods in Permit AOI 3. From 1986 to 1996 and 1986 to 2007, there was a significant decrease of mean NDVI by 0.2671 (p <0.05; CI: [0.2492, 0.2851]) and 0.2517 (p <0.05; CI: [0.2517, 0.2697], respectively. There was not a significant difference between mean NDVI from 1996 to 2007, with a change of 0.0154 (p >0.05; CI: [-0.0334, 0.0025]) (Table 20).

Similar to Permit AOI 2, analysis of Permit AOI 3 shows a significant decrease of vegetation productivity from 1986 to 1996 due to surface mining activities. Also, statistical tests imply that the mean NDVI difference from 1996 and 2007 was not significant, suggesting that vegetation productivity may have stabilized, or at least slowed in growth, between the two years. However, the trend between the two years, as seen in Figure 16, implies that mean NDVI was increasing slightly with over time.

Table 20: Tukey's Studentized Range Test for mean NDVI Permit 3 AOI

Benchmark Period Comparisons	Difference Between Means	Simultaneous 95% Confidence Limits		Significant at 0.05 level: ***
1986 vs. 1996	0.2671	0.2492	0.2851	***
1996 vs. 2007	-0.0154	-0. 0334	0.0025	
1986 vs. 2007	0.2517	0.2337	0.2697	***

Permit AOIs versus Reference AOI

The ANOVA procedure was used to determine if the mean NDVI values across each AOI on each benchmark period were similar. A summary of the ANOVA test results are in Table 21, while complete results can be viewed in the Appendix (Table A-10, A-11, and A-12).

Table 21: Tukey's Studentized Range Test for Mean NDVI in 1986, 1996, and 2007

Year	Null Hypotheses	Degrees of Freedom	F-Statistic	P-value
1986	Mean NDVI of: Ref AOI = AOI 1 = AOI 2 = AOI 3	2	2496.21	<0.001
1996		2	719.27	<0.001
2007		2	581.20	<0.001

Tukey's Studentized Range (HSD) Test was executed to compare the Reference mean NDVI values for each benchmark period in 1986, 1996, and 2007, to those in the Permit AOIs.

In 1986, Permit AOI 2 and 3 were not yet altered by surface mining activity, thus the mean NDVI differences between the Reference AOI and the two AOIs, 0.0083 ($p > 0.05$; CI: [-0.0226, 0.061]) and 0.0014 ($p > 0.05$; CI: [0.0163, 0.0136]), respectively, were not significant (Figure 18 and Table 22). By 1986, Permit AOI 1 had been recovering from mining for twelve years; there was a significant difference of 0.3909 ($p < 0.05$; CI: [0.3770, 0.4051]) between the mean NDVI of the Reference AOI and that of Permit AOI 1.

Figure 18: Boxplots of NDVI for each AOI in 1986

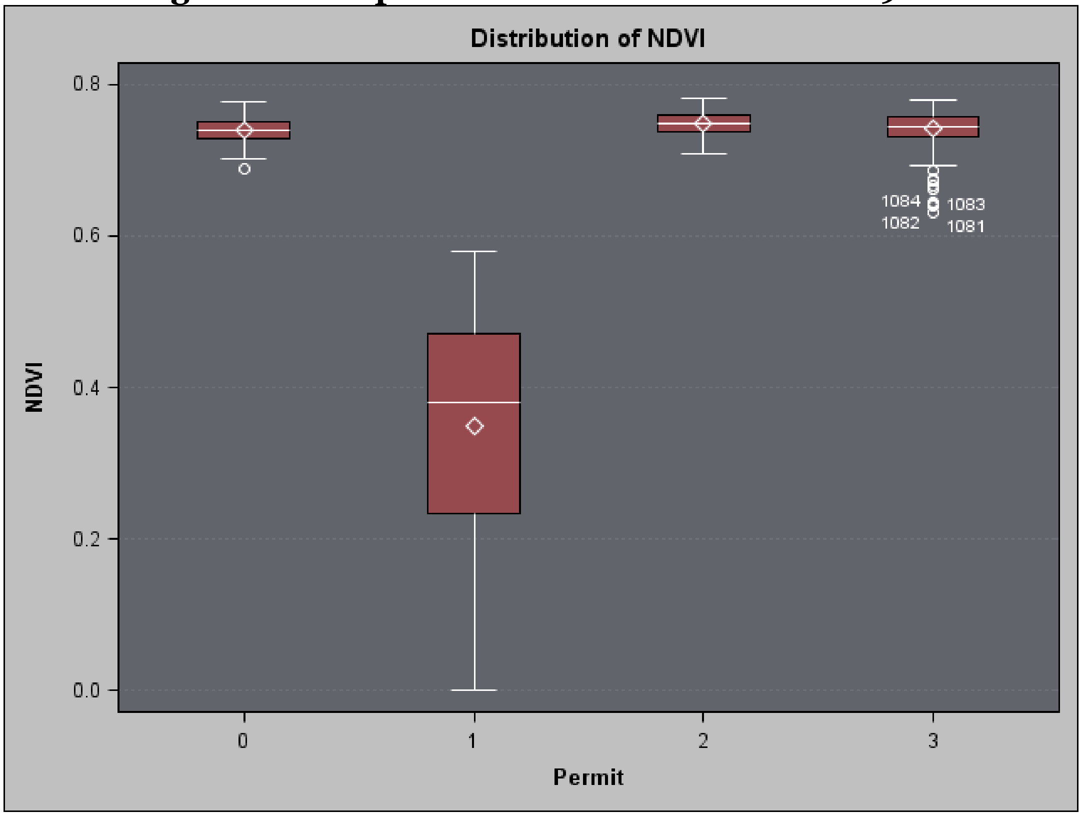


Table 22: Tukey's Studentized Range Test for mean NDVI in 1986

Comparison AOIs	Difference Between Means	Simultaneous 95% Confidence Limits		Significant at 0.05 level: ***
Ref vs. AOI 1	0.3909	0.3767	0.4051	***
Ref vs. AOI 2	-0.0083	-0.0226	0.0061	
Ref vs. AOI 3	-0.0014	-0.0164	0.01356	

By 1996, Permit AOI 1, 2, and 3, had been recovering from mining activities for 12, 6, and 5 years, respectively. There was a significant difference between mean NDVI of the Reference AOI and Permit AOI 1, 2, and 3 with differences of 0.1019 ($p < 0.05$; CI: [0.0889, 0.1150]), 0.1800 ($p < 0.05$; CI: [0.0.1669, 0.1932]), and 0.2278 ($p < 0.05$; CI: [0.2141, 0. 2415]), respectively (Figure 19 and Table 23). Even though there was a significant difference between the mean NDVI in the Permit AOIs and the Reference AOI, the quantity of difference decreased with greater recovery time, suggesting that vegetation productivity approached that of the Reference AOI, though had not yet reached it.

Figure 19: Boxplots of NDVI for each AOI in 1996

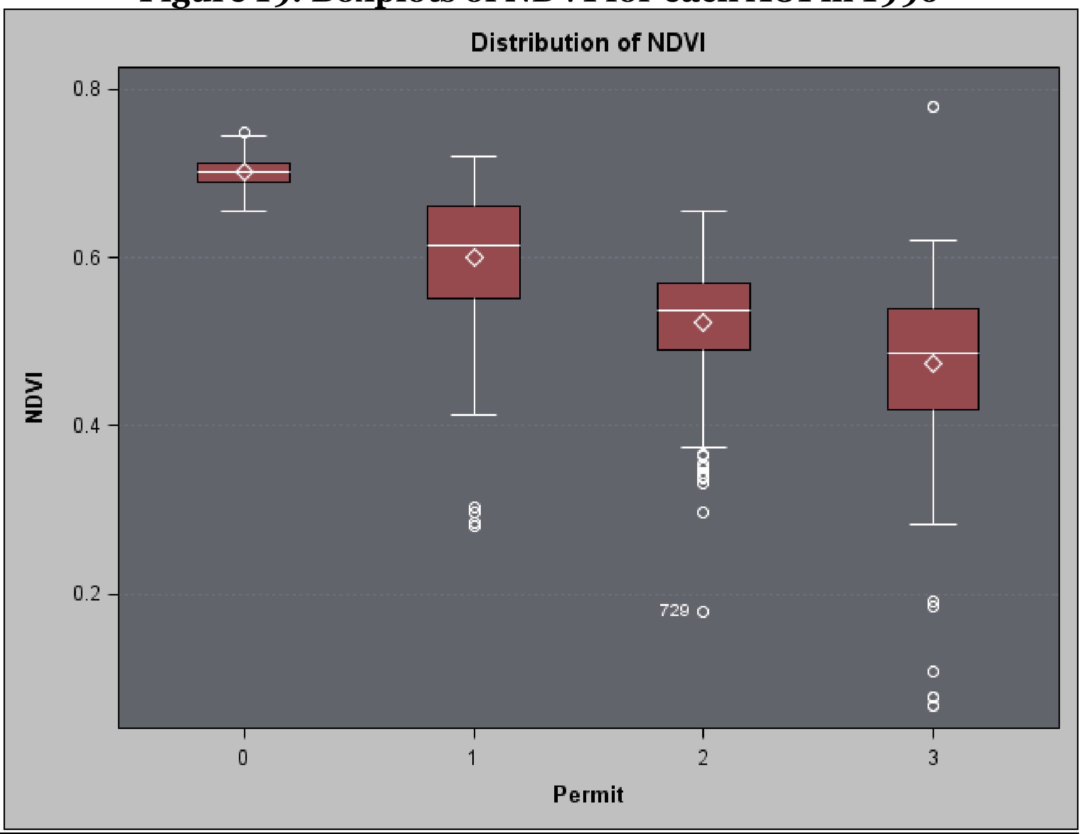


Table 23: Tukey's Studentized Range Test for mean NDVI in 1996

Comparison AOIs	Difference Between Means	Simultaneous 95% Confidence Limits		Significant at 0.05 level: ***
Ref vs. AOI 1	0.1019	0.0889	0.1150	***
Ref vs. AOI 2	0.1800	0.1669	0.1932	***
Ref vs. AOI 3	0.2278	0.2141	0.2415	***

By 2007, Permit AOI 1, 2, and 3 had 23, 17, and 16 years to recover from surface mining activities, respectively. However, Permit AOI 1, 2, and 3, still had a significantly different mean NDVI from that of the Reference AOI value with differences of 0.2200 ($p < 0.05$; CI: [0.2023, 0. 2376]), 0.2303 ($p < 0.05$; CI: [0.2125, 0. 2481]), and 0.2568 ($p < 0.05$; CI: [0.2382, 0. 2753]), respectively (Figure 20 and Table 24). Similar to the findings from 1996, the quantity of mean difference decreased with greater recovery time; however the differences were all greater in 2007 compared to those in 1996. This suggests that mean NDVI for the Permit AOIs may have nearly stabilized by 2007, with mean NDVI well below that of the Reference AOI.

Figure 20: Boxplots of NDVI for each AOI in 2007

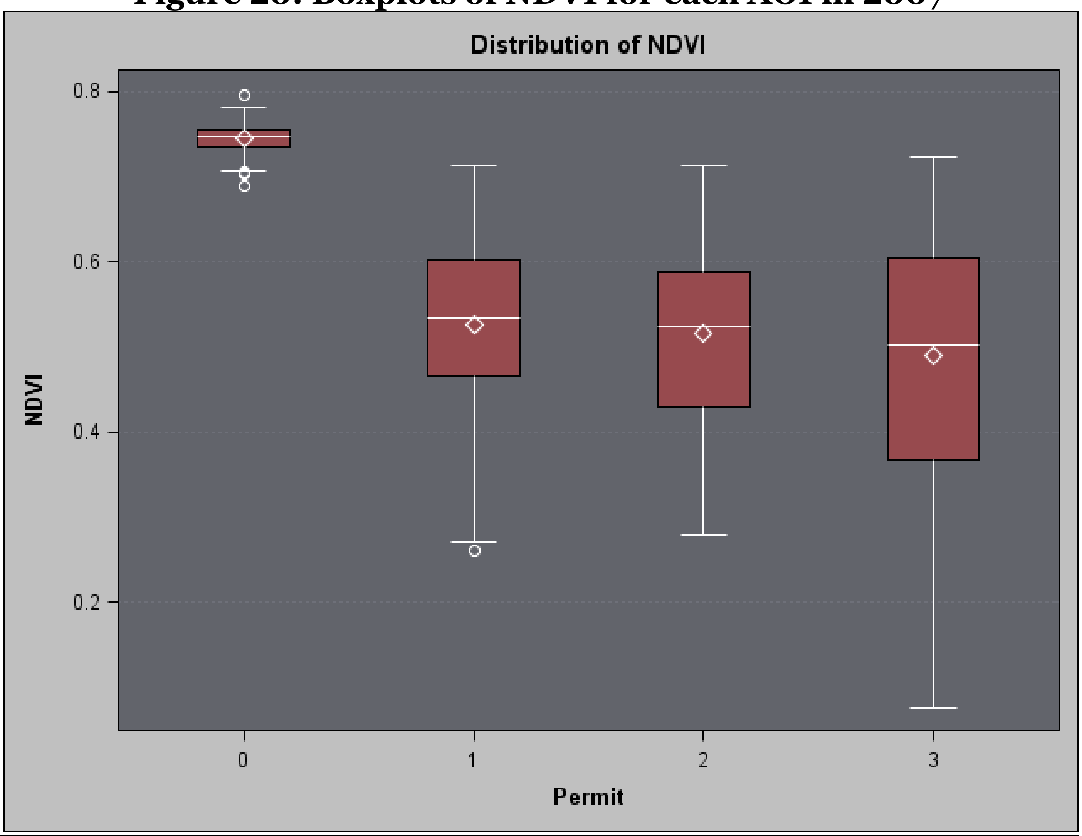


Table 24: Tukey's Studentized Range Test for mean NDVI in 2007

Comparison AOIs	Difference Between Means	Simultaneous 95% Confidence Limits		Significant at 0.05 level: ***
Ref vs. AOI 1	0.2200	0.2023	0.2376	***
Ref vs. AOI 2	0.2303	0.2125	0.2481	***
Ref vs. AOI 3	0.2568	0.2382	0.2753	***

Aim 2: Evaluate whether vegetation productivity on mining-permitted lands have properly recovered the vegetation to equal or greater productivity to the natural vegetation cover

Hobet Mine Land Cover Classification

Approximately 60,000 pixels were classified into Barren, Sparse Vegetation, and Dense Vegetation (Figure 21). Overall mining activity, signified by the total area of barren land, increased from 6% to 25% on the study site from 1986 to 2007. In 1986, 85% of the land was classified as dense vegetation. Due to mining activities, dense vegetation decreased to approximately 39% of the land by 2007 (Table 25). Visual inspection of the land cover classification maps showed that barren land converted to sparse vegetation from 1986 to 1996 and 1996 to 2007. It was also apparent that much of the barren land in 1986 converted to sparse or dense vegetation by 2007. To further evaluate vegetation reclamation progress, the aforementioned Areas of Interest were examined.

Figure 21

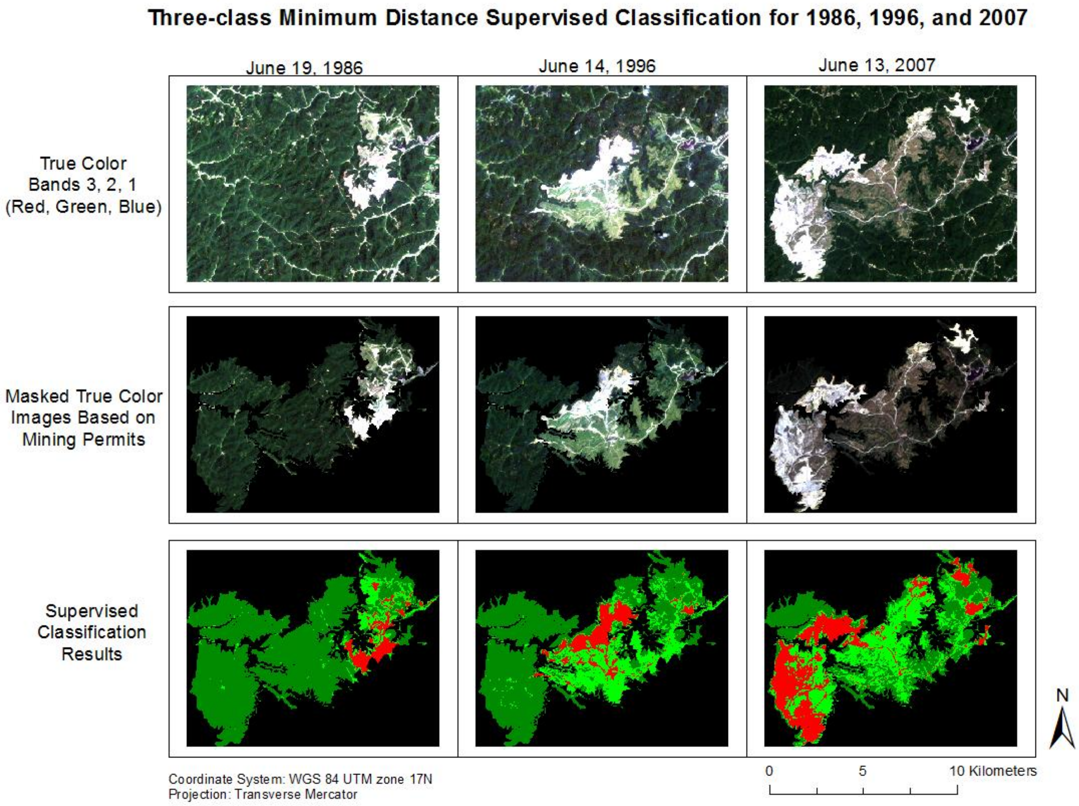


Table 25:
Land Cover Classification in 1986, 1996, and 2007 on Hobet Mine

Classification	Date	Pixels (30x30 m)	Percentage of Hobet Mine
Barren	1986	3,559	6%
	1996	6,122	10%
	2007	15,5516	25%
Sparse Veg	1986	5,246	9%
	1996	15,187	25%
	2007	21,707	36%
Dense Veg	1986	52,098	85%
	1996	39,594	65%
	2007	23,680	39%

AOI Land Cover Classification

The Reference AOI consisted of 390 pixels. As expected through visual interpretation of the true color images, 100% of the pixels were classified as dense vegetation in 1986, 1996, and 2007 (Figure 22 and Table 26).

Permit AOI 1, which was mined in 1984, had 25% and 75% of the pixels classified as barren and sparse vegetation, respectively in 1986. By 1996, all of the barren-classified pixels of 1986 were reclassified as sparse or dense vegetation. The percentage of dense vegetation in 1996 was 66%, while that in 2007 decreased to 51% (Figure 23 and Table 27).

In 1986, all pixels of Permit AOI 2 were classified as dense vegetation; this AOI was not mined until 1990. In 1996, 76% and 24% were classified as sparse and dense vegetation, respectively. By 2007, many of the sparse vegetation pixels in 1996 converted to dense vegetation, as dense vegetation increased from 24% to 47% (Figure 24 and Table 28).

Because Permit AOI 3 was not mined until 1991, all of the pixels were classified as dense vegetation in 1986. By 1996, though, 12% of the pixels were barren, while 85% and 2% were classified as sparse and dense vegetation, respectively. By 2007, sparse vegetation classification decreased to 53%, while dense vegetation increased to 46% (Figure 25 and Table 29).

Figure 22

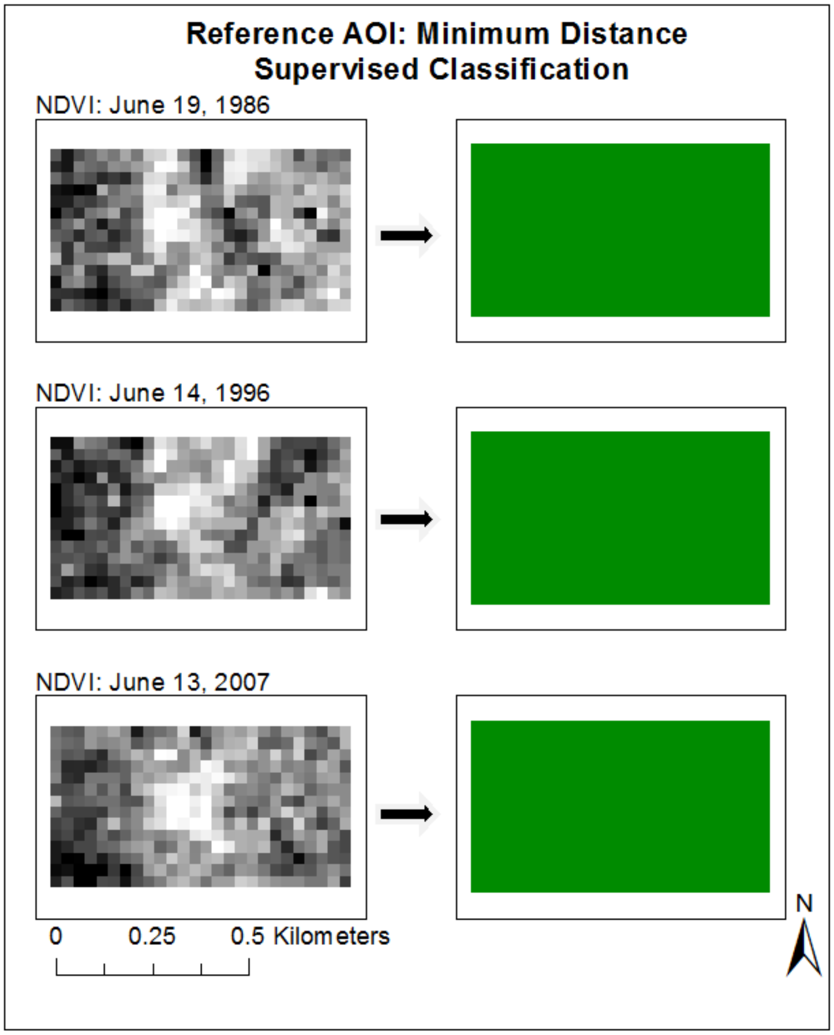


Table 26:
Land Cover Classification in the Reference AOI

Classification	Date	Pixels (30x30 m)	Percentage of AOI
Barren	1986	0	0%
	1996	0	0%
	2007	0	0%
Sparse Veg	1986	0	0%
	1996	0	0%
	2007	0	0%
Dense Veg	1986	390	100%
	1996	390	100%
	2007	390	100%

Figure 23

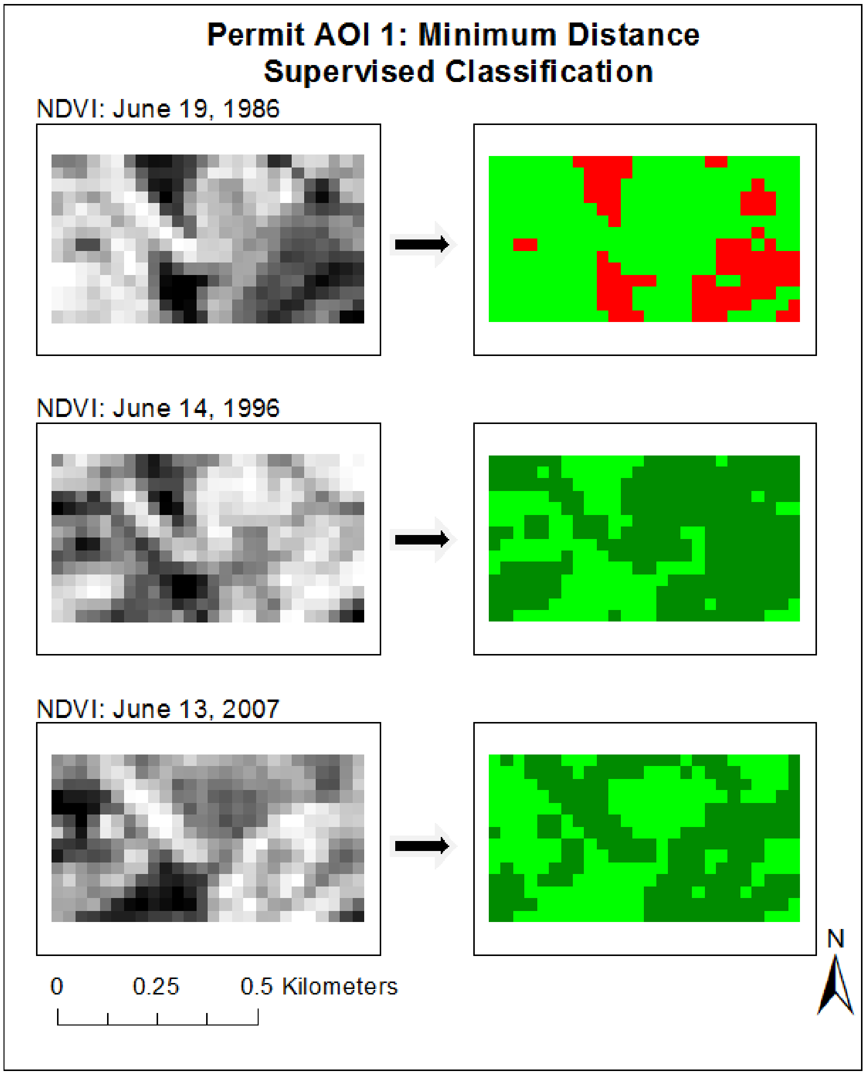


Table 27:
Land Cover Classification in Permit AOI 1

Classification	Date	Pixels (30x30 m)	Percentage of AOI
Barren	1986	90	25%
	1996	0	0%
	2007	0	0%
Sparse Veg	1986	274	75%
	1996	123	34%
	2007	178	49%
Dense Veg	1986	0	0%
	1996	241	66%
	2007	186	51%

Figure 24

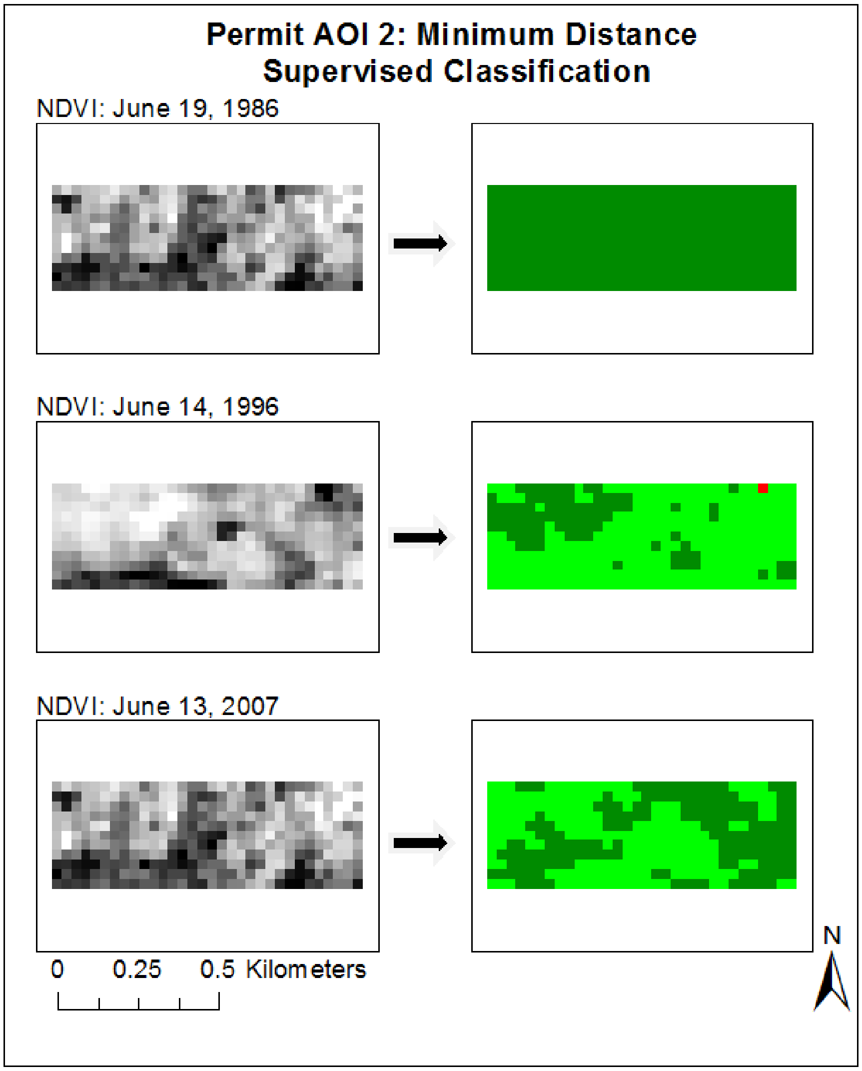


Table 28:
Land Cover Classification in Permit AOI 2

Classification	Date	Pixels (30x30 m)	Percentage of AOI
Barren	1986	0	0%
	1996	1	0%
	2007	0	0%
Sparse Veg	1986	0	0%
	1996	266	76%
	2007	188	53%
Dense Veg	1986	352	100%
	1996	85	24%
	2007	164	47%

Figure 25

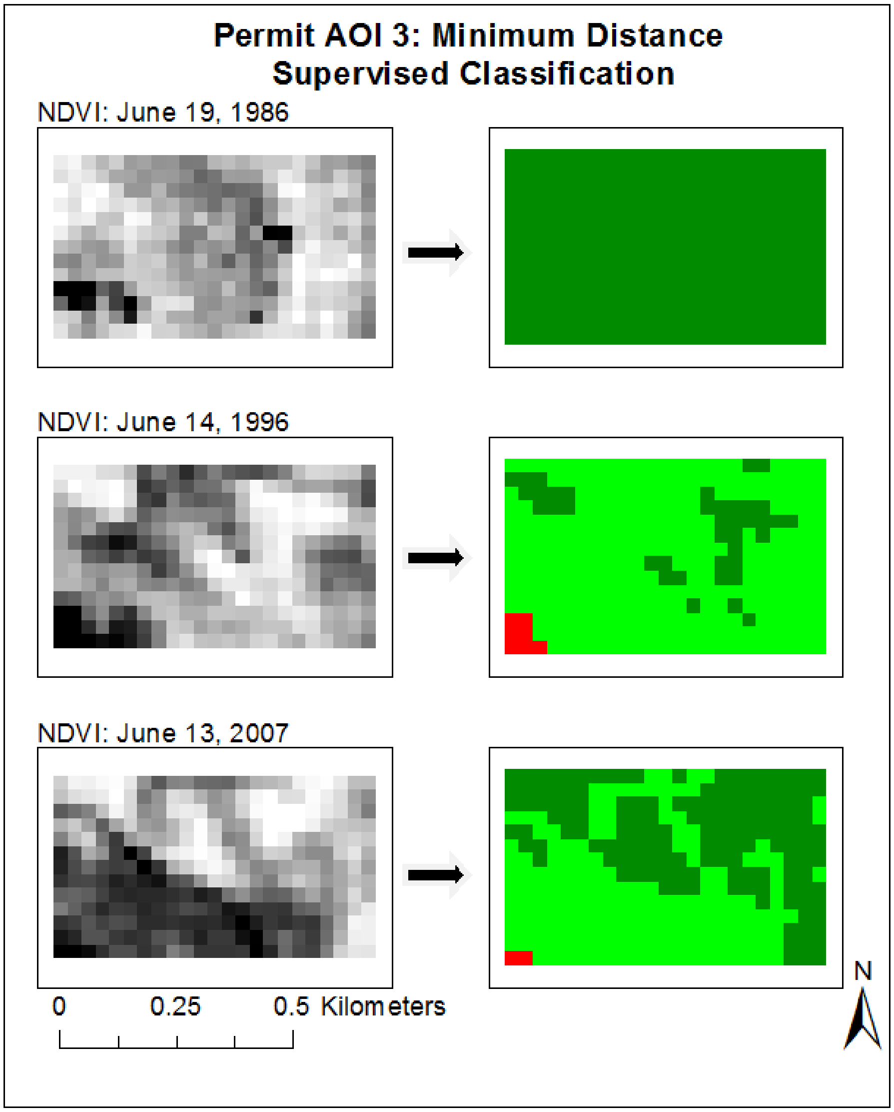


Table 29:
Land Cover Classification in Permit AOI 3

Classification	Date	Pixels (30x30 m)	Percentage of AOI
Barren	1986	0	0%
	1996	39	12%
	2007	2	1%
Sparse Veg	1986	0	0%
	1996	276	86%
	2007	171	53%
Dense Veg	1986	322	100%
	1996	7	2%
	2007	149	46%

Summary

Changes of mean NDVI values in the AOIs in 1986, 1996, and 2007 were associated to the changes of pixel-count classified as dense vegetation for those years.

Mean NDVI and percentage of dense vegetation increased from 1986 to 2007 in Permit AOI 1. The decrease of mean NDVI and dense vegetation from 1996 to 2007, although slight, can be attributed to the presence of a vegetation pest or disease affecting certain species in that AOI. Otherwise, this decrease can be explained by degrading soil properties important for vegetation cover, such as decreased moisture or nutrient retention.

Mean NDVI in Permit AOI 2 and 3 increased from 1996 to 2007, with values stabilizing below that of the Reference AOI. The percentage of pixels classified as dense vegetation also increased between those two years, while less than 50% were classified as dense vegetation by 2007. The decrease of mean NDVI and dense vegetation, as seen in Permit AOI 1, was not observed in Permit AOI 2 and 3. This may not have been apparent on these AOIs because these areas were mined around 6 years later, and the vegetation growth was still on a slight upward trend between 1996 and 2007, as verified by their mean NDVI values for those years. Alternatively, these areas may not have been exposed to a pest or disease.

After mining activities ceased in the Permit AOIs, mean NDVI values increased with time. However, by 2007, mean NDVI in each Permit AOI was significantly below that of the Reference AOI. Furthermore, in terms of NDVI, land classification analysis suggests that at Permit AOI 1, 2, and 3, approximately

51%, 47%, and 46% of area was successfully revegetated, respectively, to equal or greater productivity by 2007.

Limitations

Remote sensing can be advantageous because data acquisition occurs remotely. However, processing and extracting information from these data can contribute to variability in measurements that wouldn't be apparent from data collected in the field. The main limitation of this study was the lack of field-based data. Field data collection allows for validation of results obtained through remote sensing, while also providing more descriptive information of vegetation cover.

Another limitation of this study was the use of medium-resolution data. Data were acquired from the Thematic Mapper (TM) sensor on the Landsat 5 platform, yielding six spectral bands with 30 m resolution. With this resolution, community-level vegetation classification in our study was possible. However, with higher resolution images, such as the 2.4 m resolution images provided by Quickbird, species-level vegetation cover classification could have been evaluated (Shank 2009). Secondly, six spectral bands only allowed for the calculation of one index for vegetation productivity, NDVI. Hyperspectral imagery would have allowed for the calculation of multiple vegetation indices which could have provided more meaningful information regarding vegetation recovery (Exelis 2012).

Gaining species-level classification, either through the use of high-resolution remote sensing imagery or field-based species censusing, can provide vital information for revegetation monitoring and evaluation. With regards to this study, where vegetation reclamation included planting non-native, invasive species, mapping the prevalence of these species can greatly explain the changes of vegetation cover and biodiversity on post-mined lands. Also, quantifying temporal vegetation productivity using multiple vegetation indices can yield a more complete evaluation of vegetation reclamation.

Because hyperspectral and high-resolution imagery are privately-owned and relatively new technologies, these data can be expensive. Landsat 5 TM images are publically available with no charge. Also, Landsat 5 has been acquiring data since 1984, allowing for temporal analysis of vegetation change that cannot be evaluated with hyperspectral and/or high-resolution imagery.

Conclusion

Using remote sensing techniques, this study aimed to monitor and evaluate vegetation reclamation in mined areas on Hobet Mine in southwestern West Virginia from 1984 to 2010. Surface mining in Appalachia has been a large contributor to land-use change in the region. Reclaiming these lands have the potential to partially abate the negative consequences of mining, which can influence many aspects of vital ecosystem function, including carbon storage, water quality, and wildlife habitat protection.

The Normalized Difference Vegetation Index (NDVI) was used to quantify vegetation productivity in this study. NDVI is associated with high chlorophyll abundance, therefore is related to plant vigor and growth. On mined regions, NDVI drastically increased 6 to 8 years following mining activities, however the rate of increase tended to diminish following this period. In the three mining-permitted areas observed in this study, none had comparable NDVI values to natural vegetation cover by the end of the study period.

These results were further supported by those found using Land Cover Classification techniques and observing pixel-by-pixel vegetation change. Dense vegetation was the dominant land cover on Hobet Mine in 1986, however mining activities largely transformed this land to barren or sparsely vegetated land. In addition, there was inadequate recovery from barren or sparsely vegetated land to dense vegetation by the end of the study period.

Land classification trends in the three mining-permitted AOIs indicate that reclamation activities have successfully revegetated approximately 50% of the areas by 2007. From 1996 to 2007, conversion from sparse vegetation to dense vegetation was observed, suggesting that reclamation activities may fully restore vegetation productivity, in terms of NDVI, over a longer period of time.

Results from this study suggest that vegetation reclamation has not restored surface-mined lands to equal or greater productivity to the natural vegetation cover on Hobet Mine in West Virginia. Because surface mining in Appalachia is wide-spread, the lack of proper vegetation reclamation can have vast impacts on ecosystem function.

References

Angel, P. N., Davis, V. M., Burger, J. A., Graves, D., & Zipper, C. E. (2005). *The Appalachian Regional Reforestation Initiative*. US Office of Surface Mining.

Bloomberg Businessweek. (n.d.). *Coil, Gas, and Consumable Fuels: Company Overview of Hobet Mining, LLC*. Retrieved March 25, 2012, from Bloomberg Businessweek: http://investing.businessweek.com/research/stocks/private/snapshot.asp?privcapId=4271553

Chander, G., Markham, B. L., & Barsi, J. A. (2007). Revised Landsat-5 THematic Mapper Radiometric Calibration. *IEEE Geoscience and Remote Sensing Letters* , 490-494.

DOE. (2011). *Coal Production and Number of Mines by State, County, and Mine Type, 2010*. Washington, DC: US Department of Energy/Energy Information Administration.

Eastern Forest Environmental Threat Assessment Center. (n.d.). *Threat Summary: West Virginia*. Retrieved April 4, 2012, from Eastern Forest Environmental Threat Assessment Center: http://threatsummary.forestthreats.org/browse.cfm?stateSearch=WV

EPA. (2011, September 1). *Mid-Atlantic Mountaintop Mining*. Retrieved March 24, 2012, from US Environmental Protection Agency: http://www.epa.gov/Region3/mtntop/

EPA. (2005). *Mountaintop Mining/VF Final Programmatic Environmental Impact Statement*. Philadelphia: EPA Region 3.

Exelis . (2012). *ENVI Tutorial: Vegetation Analysis*. Exelis Visual Information Solutions.

Exelis. (2012). *ENVI Tutorial: Classificatoin Methods*. Exelis Visual Information Solutions.

Exelis. (2012). *Introducing ENVI 4.8*. Retrieved March 26, 2012, from Exelis Visual Information Solutions: http://www.exelisvis.com/ProductsServices/ENVI/ENVILatestRelease.aspx

ITT Visual Information Solutions. (2008). *ENVI Feature Extraction Module User's Guide*. ITT Visual Information Solutions.

Linli, C., & Jun, S. (2010). Temporal and spatial response of vegetation NDVi to temperature and precipitation in eastern China. *Journal of Geographical Sciences* , 163-176.

NASA. (2012, March 15). *Landsat 5*. Retrieved March 25, 2012, from National Aeronautics and Space Administration: http://landsat.gsfc.nasa.gov/about/landsat5.html

NASA. (2012, March 15). *The Thematic Mapper*. Retrieved March 25, 2012, from National Aeronautics and Space Administration: http://landsat.gsfc.nasa.gov/about/tm.html

Negley, T. L., & Eshleman, K. N. (2006). LOOK UP ONLINE. *Hydrol. Process.* , 3467.

Pond, G. J., Passmore, M. E., Borsuk, F. A., Reynolds, L., & Rose, C. J. (2008). Downstream effects of mountaintop coal mining: comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools. *J. N. Am. Benthol. Soc.* , 717-737.

Ricketts, T. H., Dinerstein, E., Olson, D. M., Loucks, C. J., Eichbaum, W., DellaSalla, D., et al. (1999). Terrestrial ecoregions of North America: a conservation assessment. *Island Press* .

Sayler, K. L. (2011, May 19). *Land Cover Trends Project: Central Appalachians*. Retrieved March 25, 2012, from USGS: http://landcovertrends.usgs.gov/east/eco69Report.html

Shank, M. (2009). *Mapping Vegetation Change on a Reclaimed Surface Mine Using Quickbird*. Charleston: West Virginia Department of Environmental Protection.

SMRE. (1977). *Public Law 95-87: Surface Mining Control and Reclamation Act of 1977*. Washington, DC: US Department of the Interior/Office of Surface Mining Reclamation and Enforcement.

Soofi, K. (2005, May 5). *Remote Sensing Lecture: Image Classification*. Retrieved March 26, 2012, from UCSD: Satellite Remote Sensing - SIO 135/SIO 236: http://topex.ucsd.edu/rs/classification.pdf

TEEIC. (n.d.). *Surface Mining Control and Reclamation Act (SMCRA)*. Retrieved January 15, 2012, from Tribal Energy and Environmental Information: http://teeic.anl.gov/lr/dsp_statute.cfm?topic=12&statute=238

Townsend, P. A., Helmers, D. P., Kingdon, C. C., McNeil, B. E., de Beurs, K. M., & Eshleman, K. N. (2009). Changes in the extent of surface mining and reclamation in the Central Appalachians detected using 1976-2006 Landsat time series. *Remote Sensing of Environment* , 62-72.

USEIA. (2011). *Annual Energy Outlook 2011 with Projections to 2035*. Washington, DC: US Department of Energy/Energy Information AAdministration.

USEIA. (2011, May 27). *U.S. Energy Information Adminisration*. Retrieved January 14, 2012, from Energy in Brief: What is the role of coal in the United States?: http://www.eia.gov/energy_in_brief/role_coal_us.cfm

USGS. (2010, January). *Greenness of the Conterminous US: What is NDVI?* Retrieved March 26, 2012, from USGS: http://ivm.cr.usgs.gov/whatndvi.php

USGS. (2011, December 23). *LPGS and NLAPS Processing Systems Comparision*. Retrieved March 26, 2012, from USGS Landsat Missions: http://landsat.usgs.gov/products_IP_LPGSvsNLAPS.php

WCI. (2009). *The Coal Resource: A Comprehensice Overview of Coal*. London: World Coal Institute.

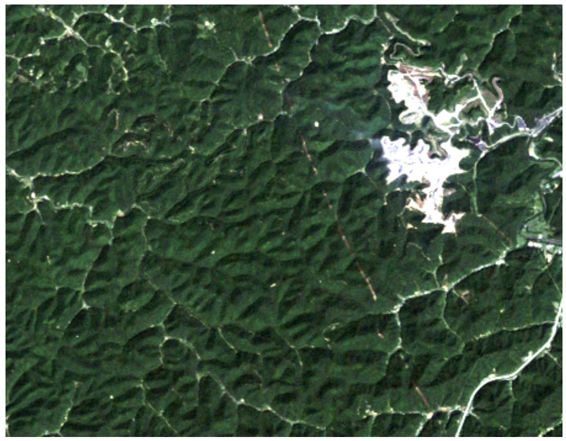
Weier, J., & Herring, D. (n.d.). *Measuring Vegetation (NDVI & EVI)*. Retrieved March 26, 2012, from NASA Earth Observatory: http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php

WVDEP. (n.d.). *Technical Applicatoins and GIS Unit*. Retrieved March 26, 2012, from ArcGIS Services Directory: http://gis.dep.wv.gov/index.html

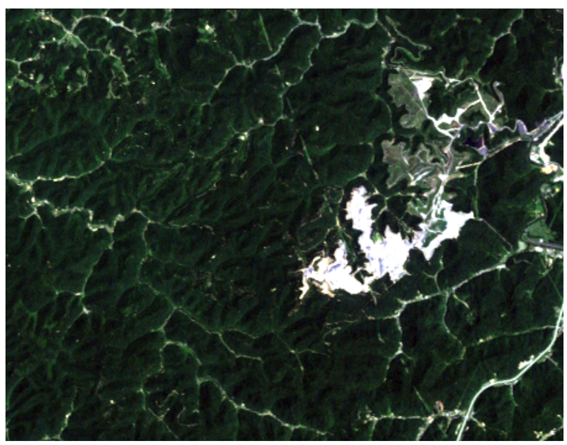
WVDEP. (n.d.). *West Virginia DEP Technical Applications and GIS Unit*. Retrieved March 25, 2012, from West Virginia Department of Environmental Protection: http://gis.dep.wv.gov/

Appendix

Figure A-1: Temporal Land Change on Hobet Mine in West Virginia: True Color Imagery from Landsat 5 TM

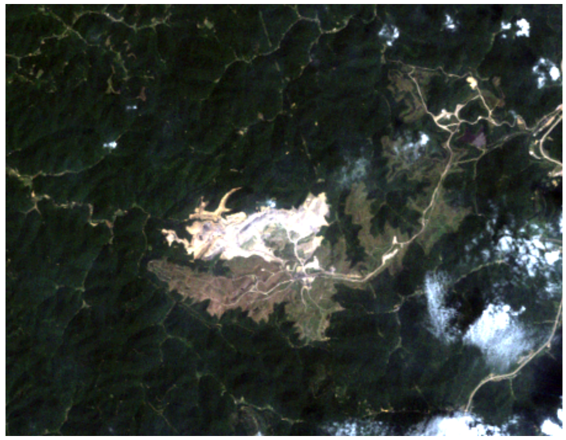


Sept. 17, 1984

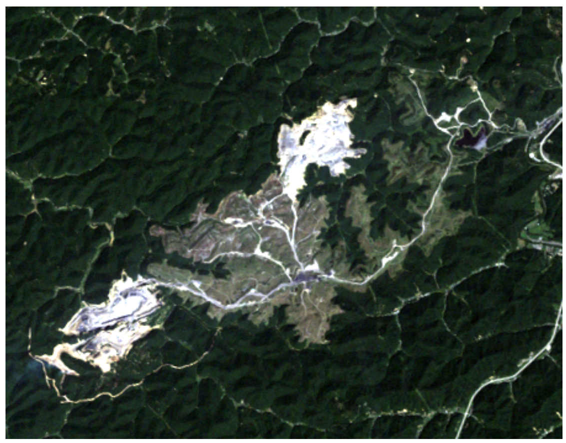


June 6, 1987

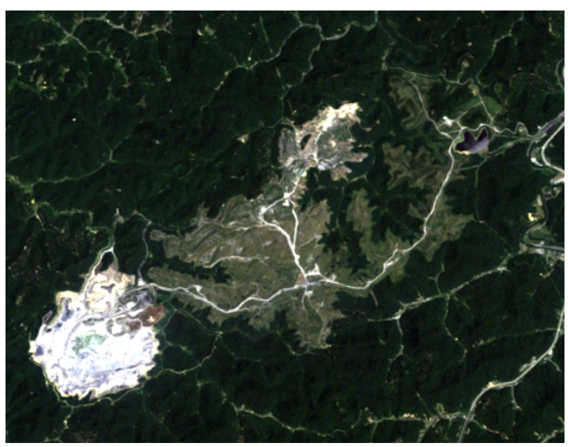
Sept. 21, 1991



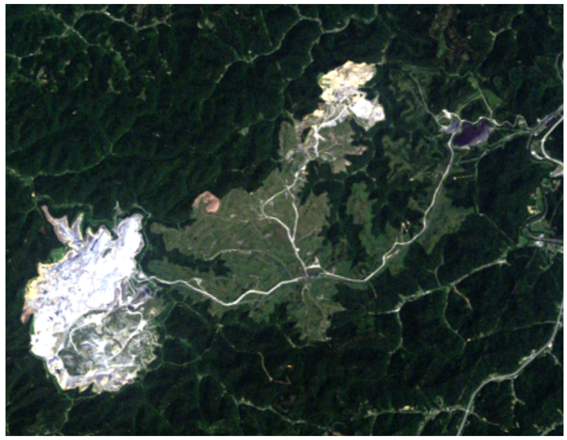
Aug. 12, 1994



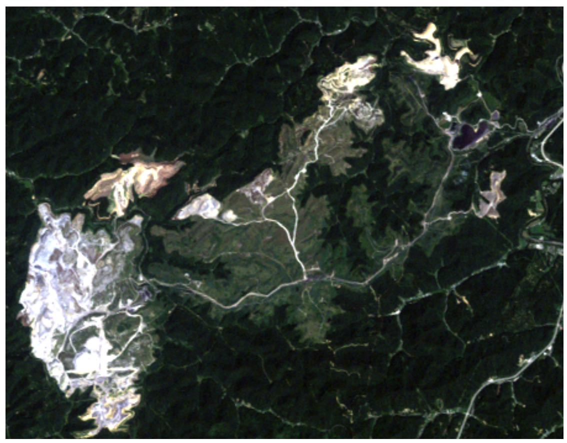
Sept. 5, 1997



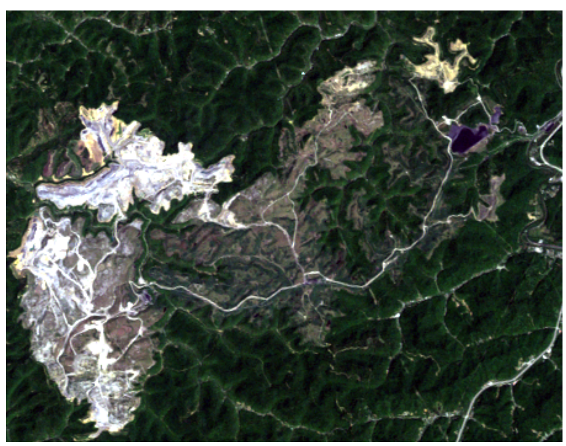
June 9, 2000



June 2, 2003



Aug. 13, 2006



May 4, 2010

Table A-1:
All Landsat 5 TM Data Products Used and NDVI Summary Statistics

ID	YearMonthDay	Min	Max	Mean	Std. Deviation
1	19840816	0.5556	0.6855	0.6170	0.0208
2	19840917	0.5821	0.7344	0.6737	0.0248
3	19841003	0.4754	0.6881	0.5988	0.0366
4	19841222	-0.0588	0.2632	0.1331	0.0729
5	19850429	0.4336	0.6522	0.5457	0.0399
6	19850718	0.6376	0.7401	0.6806	0.0174
7	19850803	0.6699	0.7793	0.7207	0.0187
8	19850920	0.4286	0.6262	0.5416	0.0362
9	19860603	0.6744	0.7532	0.7176	0.0145
10	19860619	0.6885	0.7778	0.7402	0.0156
11	19860705	0.5902	0.6966	0.6499	0.0176
12	19860822	0.5745	0.6935	0.6358	0.0230
13	19861009	0.4182	0.6939	0.5982	0.0510
14	19870113	-0.0833	0.2500	0.0888	0.0663
15	19870419	0.1351	0.3010	0.1917	0.0270
16	19870521	0.4222	0.6420	0.5815	0.0369
17	19870606	0.6637	0.7762	0.7242	0.0176
18	19870724	0.5146	0.6515	0.5888	0.0272
19	19870809	0.4845	0.6290	0.5632	0.0269
20	19870910	0.3556	0.5126	0.4409	0.0308
21	19871113	0.0345	0.2727	0.1723	0.0556
22	19880116	-0.0476	0.2364	0.1190	0.0582
23	19880421	0.1605	0.3895	0.2304	0.0355
24	19880523	0.6589	0.7407	0.6993	0.0144
25	19880608	0.6489	0.7333	0.6944	0.0162
26	19880811	0.4783	0.5766	0.5336	0.0196
27	19880828	0.5778	0.7188	0.6591	0.0244
28	19880928	0.4186	0.6147	0.5376	0.0350
29	19881014	0.4340	0.6863	0.5953	0.0500
30	19881115	0.0000	0.2800	0.1742	0.0537
31	19891018	-0.0400	0.2258	0.1230	0.0567
32	19900427	0.2039	0.4231	0.3296	0.0474
33	19900716	0.6239	0.7386	0.6798	0.0194
34	19900817	0.5048	0.6296	0.5617	0.0226
35	19901020	0.2973	0.6000	0.4957	0.0548
36	19901121	-0.0526	0.1864	0.0934	0.0438
37	19910921	0.4921	0.6909	0.6085	0.0314
38	19920111	-0.0370	0.2157	0.0910	0.0509
39	19920705	0.5424	0.6730	0.6041	0.0232

40	19920721	0.4000	0.5238	0.4678	0.0247
41	19920806	0.5577	0.6842	0.6168	0.0231
42	19921110	0.0000	0.2364	0.1415	0.0469
43	19930809	0.5439	0.6301	0.5838	0.0177
44	19940116	-0.0909	0.0769	0.0119	0.0265
45	19940305	0.0455	0.2222	0.1488	0.0310
46	19940812	0.5670	0.6748	0.6219	0.0189
47	19941015	0.3000	0.6629	0.4928	0.0725
48	19941202	-0.0476	0.2581	0.1354	0.0666
49	19950324	0.1020	0.2857	0.1858	0.0248
50	19950730	0.6383	0.7519	0.6928	0.0207
51	19950831	0.5181	0.6636	0.5943	0.0257
52	19951018	0.3000	0.6591	0.5269	0.0604
53	19960122	-0.0149	0.2000	0.0675	0.0356
54	19960310	-0.0185	0.0488	0.0128	0.0127
55	19960326	0.1064	0.2432	0.1721	0.0195
56	19960411	0.1014	0.2308	0.1590	0.0183
57	19960614	0.6563	0.7484	0.7023	0.0161
58	19961004	0.4737	0.7143	0.6103	0.0443
59	19970108	-0.0370	0.2000	0.0943	0.0517
60	19970225	0.0526	0.2308	0.1538	0.0344
61	19970905	0.6484	0.7813	0.7150	0.0211
62	19971007	0.4154	0.6538	0.5644	0.0451
63	19971023	0.3478	0.6533	0.5464	0.0571
64	19980519	0.6923	0.7753	0.7378	0.0134
65	19980807	0.5929	0.7083	0.6368	0.0188
66	19980823	0.5686	0.6800	0.6278	0.0202
67	19980924	0.5082	0.7308	0.6482	0.0345
68	19981111	0.0370	0.3506	0.2259	0.0515
69	19981127	0.0000	0.2667	0.1600	0.0567
70	19990623	0.5606	0.7195	0.6769	0.0260
71	19990725	0.2137	0.7237	0.5798	0.1316
72	19990810	0.6071	0.7429	0.6962	0.0229
73	20000117	0.0000	0.2632	0.1605	0.0518
74	20000305	0.0204	0.2000	0.1389	0.0287
75	20000609	0.6290	0.7500	0.7025	0.0160
76	20000727	0.5556	0.6643	0.6188	0.0188
77	20001015	0.2889	0.6154	0.4868	0.0585
78	20001031	0.1000	0.3968	0.2548	0.0579
79	20001218	-0.0667	0.1304	0.0487	0.0381
80	20010103	-0.0833	0.0769	0.0171	0.0280
81	20010425	0.3208	0.6239	0.4977	0.0664
82	20010815	0.5957	0.7206	0.6567	0.0221

83	20011002	0.4182	0.6404	0.5620	0.0388
84	20011018	0.2558	0.5556	0.4394	0.0529
85	20011103	0.0909	0.3333	0.2325	0.0484
86	20011205	-0.0435	0.2364	0.1307	0.0571
87	20011221	-0.0435	0.2414	0.1239	0.0618
88	20020122	-0.0909	0.2121	0.0648	0.0513
89	20020428	0.0541	0.5254	0.3047	0.1047
90	20020802	0.3543	0.5238	0.4287	0.0379
91	20020903	0.5000	0.6607	0.5968	0.0269
92	20030109	-0.0526	0.2340	0.1123	0.0587
93	20030125	-0.0698	0.0769	0.0197	0.0246
94	20030602	0.5932	0.7178	0.6636	0.0195
95	20031008	0.3469	0.6264	0.5146	0.0515
96	20031024	0.1892	0.5385	0.3766	0.0644
97	20031109	0.0370	0.3462	0.1866	0.0536
98	20031125	0.0286	0.2632	0.1371	0.0506
99	20031227	-0.0909	0.2364	0.0713	0.0576
100	20040112	-0.0857	0.1429	0.0203	0.0382
101	20040620	0.6034	0.7255	0.6730	0.0209
102	20040706	0.6250	0.7500	0.6973	0.0219
103	20040807	0.6044	0.7424	0.6810	0.0257
104	20041010	0.3810	0.6818	0.5641	0.0535
105	20041026	0.0811	0.4211	0.2720	0.0598
106	20041127	-0.0370	0.2203	0.0940	0.0507
107	20050404	0.1045	0.2683	0.1699	0.0255
108	20050506	0.4528	0.6403	0.5722	0.0343
109	20050726	0.5424	0.6821	0.6102	0.0232
110	20050911	0.5062	0.6529	0.5878	0.0289
111	20060423	0.2952	0.5842	0.4430	0.0598
112	20060712	0.3587	0.4907	0.4141	0.0276
113	20060813	0.6082	0.7518	0.6894	0.0220
114	20061219	-0.0833	0.2542	0.1111	0.0626
115	20070104	-0.0323	0.1786	0.0879	0.0473
116	20070309	0.0370	0.1807	0.1223	0.0259
117	20070410	0.1351	0.3725	0.2057	0.0343
118	20070512	0.5313	0.6774	0.6120	0.0270
119	20070613	0.6889	0.7966	0.7468	0.0160
120	20070731	0.5702	0.6986	0.6504	0.0190
121	20070816	0.4242	0.5970	0.5547	0.0215
122	20070917	0.5248	0.7213	0.6491	0.0299
123	20080208	0.0000	0.2113	0.1257	0.0423
124	20080717	0.6068	0.7397	0.6778	0.0227
125	20080818	0.5800	0.7097	0.6531	0.0228

126	20080903	0.5500	0.6814	0.6234	0.0244
127	20080919	0.5281	0.6774	0.6048	0.0294
128	20081005	0.4915	0.6731	0.5955	0.0371
129	20091008	0.4583	0.6889	0.5945	0.0446
130	20100317	0.1064	0.2113	0.1620	0.0197
131	20100418	0.2830	0.5963	0.4409	0.0673
132	20100504	0.4951	0.7500	0.6895	0.0408
133	20100707	0.5906	0.7083	0.6512	0.0168
134	20100909	0.5733	0.7228	0.6605	0.0242
135	20101112	0.0556	0.2542	0.1563	0.0445
136	20101128	0.0000	0.2759	0.1443	0.0540

Table A-2: Reference AOI
Maximum Average NDVI in the Growing Season (May to Sept.)

YearMonthDay	Min	Max	Mean	Std. Deviation
19840917	0.5821	0.7344	0.6737	0.0248
19850803	0.6699	0.7793	0.7207	0.0187
19860619	0.6885	0.7778	0.7402	0.0156
19870606	0.6637	0.7762	0.7242	0.0176
19880523	0.6589	0.7407	0.6993	0.0144
19900716	0.6239	0.7386	0.6798	0.0194
19910921	0.4921	0.6909	0.6085	0.0314
19920806	0.5577	0.6842	0.6168	0.0231
19930809	0.5439	0.6301	0.5838	0.0177
19940812	0.5670	0.6748	0.6219	0.0189
19950730	0.6383	0.7519	0.6928	0.0207
19960614	0.6563	0.7484	0.7023	0.0161
19970905	0.6484	0.7813	0.7150	0.0211
19980519	0.6923	0.7753	0.7378	0.0134
19990810	0.6071	0.7429	0.6962	0.0229
20000609	0.6290	0.7500	0.7025	0.0160
20010815	0.5957	0.7206	0.6567	0.0221
20020903	0.5000	0.6607	0.5968	0.0269
20030602	0.5932	0.7178	0.6636	0.0195
20040706	0.6250	0.7500	0.6973	0.0219
20050726	0.5424	0.6821	0.6102	0.0232
20060813	0.6082	0.7518	0.6894	0.0220
20070613	0.6889	0.7966	0.7468	0.0160
20080717	0.6068	0.7397	0.6778	0.0227
20100504	0.4951	0.7500	0.6895	0.0408

Table A-3: Permit AOI 1
Maximum Average NDVI in the Growing Season (May to Sept.)

YearMonthDay	Min	Max	Mean	Std. Deviation
19840917	-0.0741	0.0337	-0.0057	0.0160
19850803	-0.0357	0.5478	0.1886	0.1486
19860619	0.0000	0.5798	0.3503	0.1419
19870606	0.0169	0.6541	0.4895	0.0989
19880523	0.0508	0.5887	0.3485	0.0885
19900716	0.2712	0.5724	0.4435	0.0517
19910921	0.3333	0.5429	0.4726	0.0369
19920806	0.2941	0.6389	0.5235	0.0515
19930809	0.2121	0.5410	0.3700	0.0754
19940812	0.2967	0.6094	0.4797	0.0527
19950730	0.1852	0.7143	0.5151	0.1216
19960614	0.2807	0.7207	0.6010	0.0755
19970905	0.4021	0.6947	0.5541	0.0508
19980519	0.3962	0.7143	0.5889	0.0721
19990810	0.3462	0.6320	0.4857	0.0572
20000609	0.3984	0.6933	0.5685	0.0644
20010815	0.4023	0.6691	0.5731	0.0453
20020903	0.2917	0.6094	0.4821	0.0642
20030602	0.4688	0.6886	0.6073	0.0505
20040706	0.5161	0.7290	0.6161	0.0368
20050726	0.4127	0.6084	0.5043	0.0357
20060813	0.4393	0.6986	0.6160	0.0439
20070613	0.2605	0.7124	0.5274	0.0977
20080717	0.0484	0.7301	0.6126	0.0909
20100504	0.1250	0.7317	0.6305	0.0785

Table A-4: Permit AOI 2
Maximum Average NDVI in the Growing Season (May to Sept.)

YearMonthDay	Min	Max	Mean	Std. Deviation
19840917	0.5714	0.7458	0.6917	0.0286
19850803	0.6727	0.7761	0.7292	0.0200
19860619	0.7097	0.7818	0.7485	0.0140
19870606	0.6885	0.7697	0.7377	0.0155
19880523	0.3571	0.7436	0.6789	0.0721
19900716	-0.0380	0.1636	0.0237	0.0277
19910921	0.0000	0.4699	0.1518	0.1027
19920806	0.0210	0.4790	0.2975	0.1123
19930809	0.0352	0.2593	0.1509	0.0552
19940812	0.0286	0.3137	0.2102	0.0379
19950730	0.0609	0.4286	0.2825	0.0744
19960614	0.1795	0.6543	0.5230	0.0665
19970905	0.2000	0.6036	0.4171	0.0637
19980519	0.1613	0.6000	0.4467	0.0632
19990810	0.1807	0.5714	0.3107	0.0547
20000609	0.1515	0.6512	0.4524	0.0712
20010815	0.2581	0.6541	0.5250	0.0511
20020903	0.1818	0.5906	0.4054	0.0567
20030602	0.2771	0.6564	0.5340	0.0476
20040706	0.3277	0.7161	0.5854	0.0559
20050726	0.3279	0.5946	0.4662	0.0474
20060813	0.4000	0.6944	0.5809	0.0539
20070613	0.2800	0.7143	0.5170	0.0967
20080717	0.3675	0.7089	0.5475	0.0863
20100504	0.3580	0.7255	0.5946	0.0663

Table A-5: Permit AOI 3
Maximum Average NDVI in the Growing Season (May to Sept.)

YearMonthDay	Min	Max	Mean	Std. Deviation
19840917	0.5625	0.7345	0.6675	0.0299
19850803	0.6391	0.7698	0.7211	0.0235
19860619	0.6316	0.7792	0.7418	0.0241
19870606	0.5075	0.7821	0.7083	0.0438
19880523	0.5965	0.7439	0.6963	0.0259
19900716	0.0128	0.7059	0.3400	0.2301
19910921	-0.0137	0.1750	0.0221	0.0167
19920806	0.0172	0.3934	0.0950	0.0631
19930809	0.1238	0.3675	0.2143	0.0401
19940812	0.1224	0.3333	0.2122	0.0317
19950730	0.1111	0.5102	0.3318	0.0872
19960614	0.0667	0.6224	0.4734	0.0926
19970905	0.0392	0.4375	0.3231	0.0525
19980519	0.0884	0.4884	0.3613	0.0475
19990810	0.0667	0.4495	0.2601	0.0453
20000609	0.0921	0.5683	0.3924	0.0638
20010815	0.1515	0.6290	0.4775	0.0596
20020903	0.1167	0.5636	0.4042	0.0686
20030602	0.1644	0.6433	0.5174	0.0580
20040706	0.1298	0.7047	0.5816	0.0647
20050726	0.1875	0.5949	0.4821	0.0503
20060813	0.1597	0.6993	0.6036	0.0614
20070613	0.0759	0.7237	0.4910	0.1290
20080717	0.1233	0.7073	0.5351	0.1002
20100504	0.1690	0.7031	0.5782	0.0866

Table A-6: ANOVA Test: GLM Procedure
Reference AOI Differences of NDVI Means

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.41962476	0.20981238	829.30	<.0001
Error	1089	0.27551655	0.00025300		
Corrected Total	1091	0.69514131			

R-Square	Coeff Var	Root MSE	NDVI Mean
0.603654	2.180205	0.015906	0.729563

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Year	2	0.41962476	0.20981238	829.30	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	2	0.41962476	0.20981238	829.30	<.0001

Table A-7: ANOVA Test: GLM Procedure
Permit AOI 1 Differences of NDVI Means

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	12.12168067	6.06084034	513.67	<.0001
Error	1089	12.84923587	0.01179911		
Corrected Total	1091	24.97091654			

R-Square	Coeff Var	Root MSE	NDVI Mean
0.485432	22.07990	0.108624	0.491957

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Year	2	12.12168067	6.06084034	513.67	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	2	12.12168067	6.06084034	513.67	<.0001

Table A-8: ANOVA Test: GLM Procedure
Permit AOI 2 Differences of NDVI Means

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	12.33150479	6.16575239	1324.72	<.0001
Error	1053	4.90105895	0.00465438		
Corrected Total	1055	17.23256374			

R-Square	Coeff Var	Root MSE	NDVI Mean
0.715593	11.45553	0.068223	0.595546

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Year	2	12.33150479	6.16575239	1324.72	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	2	12.33150479	6.16575239	1324.72	<.0001

Table A-9: ANOVA Test: GLM Procedure
Permit AOI 3 Differences of NDVI Means

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	13.46750482	6.73375241	767.02	<.0001
Error	896	7.86606983	0.00877910		
Corrected Total	898	21.33357464			

R-Square	Coeff Var	Root MSE	NDVI Mean
0.631282	16.48670	0.093697	0.568318

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Year	2	13.46750482	6.73375241	767.02	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Year	2	13.46750482	6.73375241	767.02	<.0001

Table A-10: ANOVA Test: GLM Procedure
AOI Mean NDVI Differences in 1986

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	41.64680051	13.88226684	2496.21	<.0001
Error	1375	7.64685405	0.00556135		
Corrected Total	1378	49.29365456			

R-Square	Coeff Var	Root MSE	NDVI Mean
0.844871	11.66520	0.074574	0.639290

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Permit	3	41.64680051	13.88226684	2496.21	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Permit	3	41.64680051	13.88226684	2496.21	<.0001

Table A-11: ANOVA Test: GLM Procedure
AOI Mean NDVI Differences in 1996

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	10.11598903	3.37199634	719.27	<.0001
Error	1377	6.45548345	0.00468808		
Corrected Total	1380	16.57147248			

R-Square	Coeff Var	Root MSE	NDVI Mean
0.610446	11.81124	0.068470	0.579698

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Permit	3	10.11598903	3.37199634	719.27	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Permit	3	10.11598903	3.37199634	719.27	<.0001

Table A-12: ANOVA Test: GLM Procedure
AOI Mean NDVI Differences in 2007

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	14.94991766	4.98330589	581.20	<.0001
Error	1375	11.78954370	0.00857421		
Corrected Total	1378	26.73946135			

R-Square	Coeff Var	Root MSE	NDVI Mean
0.559096	16.13140	0.092597	0.574018

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Permit	3	14.94991766	4.98330589	581.20	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Permit	3	14.94991766	4.98330589	581.20	<.0001