# Data Report for the Scoping Study on Metal Contaminant Levels in Forest Soils and Concurrent Habitat Evaluation for the Palmerton Zinc Natural Resource Damage Assessment, Palmerton, Pennsylvania

**Prepared by**

## The Palmerton Natural Resource Trustee Council

**Commonwealth of Pennsylvania**
Department of Environmental Protection
Department of Conservation and Natural Resources
Fish and Boat Commission
Game Commission

**U.S. Department of Commerce**
National Oceanic and Atmospheric Administration

**U.S. Department of the Interior**
National Park Service
Fish and Wildlife Service

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## Introduction

During more than ninety years of smelting operations, large quantities of metals were emitted from the Palmerton Zinc Pile Superfund Site (Site), carried by the wind, and deposited over the Palmerton Valley and surrounding areas (USEPA 1987). Within these areas, Federal and State agencies are responsible for the natural resources and the services these resources provide. Agencies such as the National Park Service (NPS) and the Pennsylvania Game Commission (PGC) own and manage land within the affected area. NPS owns and manages approximately 800 acres of land that has been acquired to protect the Appalachian National Scenic Trail along the Blue Mountain ridgeline. The PGC owns several thousand acres of potentially affected State Game Lands on Blue Mountain that would be used for wildlife management and hunting. Other agencies are trustees for fish and wildlife resources, and are concerned with the quality of habitat in the area.

Many site-specific investigations have documented soil concentrations of cadmium, lead, and zinc greater than in surrounding areas, with concentrations in the top few inches of litter orders of magnitude greater than in the underlying mineral soils (Buchauer 1973; Beyer et al. 1984; REWAI 1988; USEPA 1993; Storm et al. 1994; USEPA 2001). Several investigators noted direct acute toxicity to soil dwelling organisms (Beyer et al. 1984; USEPA 2001), while others noted conspicuously absent or reduced abundance of terrestrial flora and fauna (e.g., vegetation, bacteria, fungi, soil microbes, salamanders, and birds) in areas closest to the smelters where metal concentrations were elevated (Jordan 1975; Jordan and Lechevalier 1975, Nash 1975; Beyer et al. 1985; Strojan 1978; Storm et al. 1993). Despite these and other studies, little data exist on the current concentration and extent of soil metals contamination on public and private lands supporting natural resources.

This report documents the results of a soils scoping study conducted in the fall of 2004 to provide information on the concentration and extent of soil metals on public and private lands supporting natural resources. The soils scoping study was planned and implemented by the Palmerton Trustee Council in cooperation with CBS Operations Inc. (formerly Viacom Inc.) as part of the Palmerton Zinc Natural Resource Damage Assessment.

## Objectives

The objectives of the soils study were to:

- Measure total soil concentrations[1] of arsenic, copper, cadmium, lead, and zinc (metals) in samples collected from Stony Ridge, State Game Lands 217 and 168, and National Park Service land, to characterize the concentration and extent of soil metals on public and private lands supporting Trustee resources within and adjacent to the Site;
- Measure total soil metals concentrations in samples from a reference (uncontaminated) area on Blue Mountain to characterize baseline total soil metal levels;

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[1] Total soil metals concentration is operationally defined as measured following standard methods for acid digest (SW846 Method 3051B) and ICP analysis ( SW846 Method 6010B).

- Measure the total organic content[2] of soil samples to better characterize metals bioavailability; and
- Characterize the habitat in the immediate vicinity of the soil sampling sites to preliminarily evaluate the effects of soil metals on vegetation.

# Methods

## Soil sampling methods

Standard operating procedures were followed as detailed in the Palmerton Trustee Council Soil Sampling and Analysis Plan (2004). Sample locations were predetermined based on a 500 $ft^2$ sample grid design and located using hand-held GPS units. Due to the difficult terrain and challenging weather conditions, a subset of the initially proposed sample locations were prioritized and sampled. Highest priority was given to public lands between Furnace Gap and Little Gap due to the proximity of this area to the Site and the paucity of existing soil metals data. Samples were collected from a total of 359 locations on public and private lands within and adjacent to the Site and 10 reference locations on State Game Lands 106 (Figure 1, Appendix A). This sampling effort encompassed approximately 1,400 acres of NPS land, 2200 acres of State Game land, and 800 acres of private land.

Multiple teams composed of a combination of Trustee and CBS representatives performed sampling activities. Three sub-samples were collected from separate pits at each location and combined. Obvious leaf litter and herbaceous cover were first removed and soils samples collected from the upper 3 inches of the soil profile. Supplemental soil pit information and a photograph were documented for each location. Chain-of-custody documentation was also performed. Soils were analyzed for total arsenic, cadmium, copper, lead, zinc, and percent mineral content by the Pennsylvania Department of Environmental Protection's Mobile Analysis Unit (MAU-2) following standard procedures. Split samples were taken to represent about 10% of the total number of samples and sent to an independent lab of CBS's choice for comparative metals analysis.

## Habitat assessment methods

A habitat assessment was performed at each soil sampling location by the same teams conducting the soil sampling following standard operating procedures as detailed in the Soil Sampling and Analysis Plan (Palmerton Trustee Council, 2004). Vegetation and ground cover data were recorded using a habitat check list. Photographs were also taken at each site to document the observed conditions.

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[2] Total organic content is operationally defined as measured following a standard method for loss upon ignition (USDA Method 8F1).

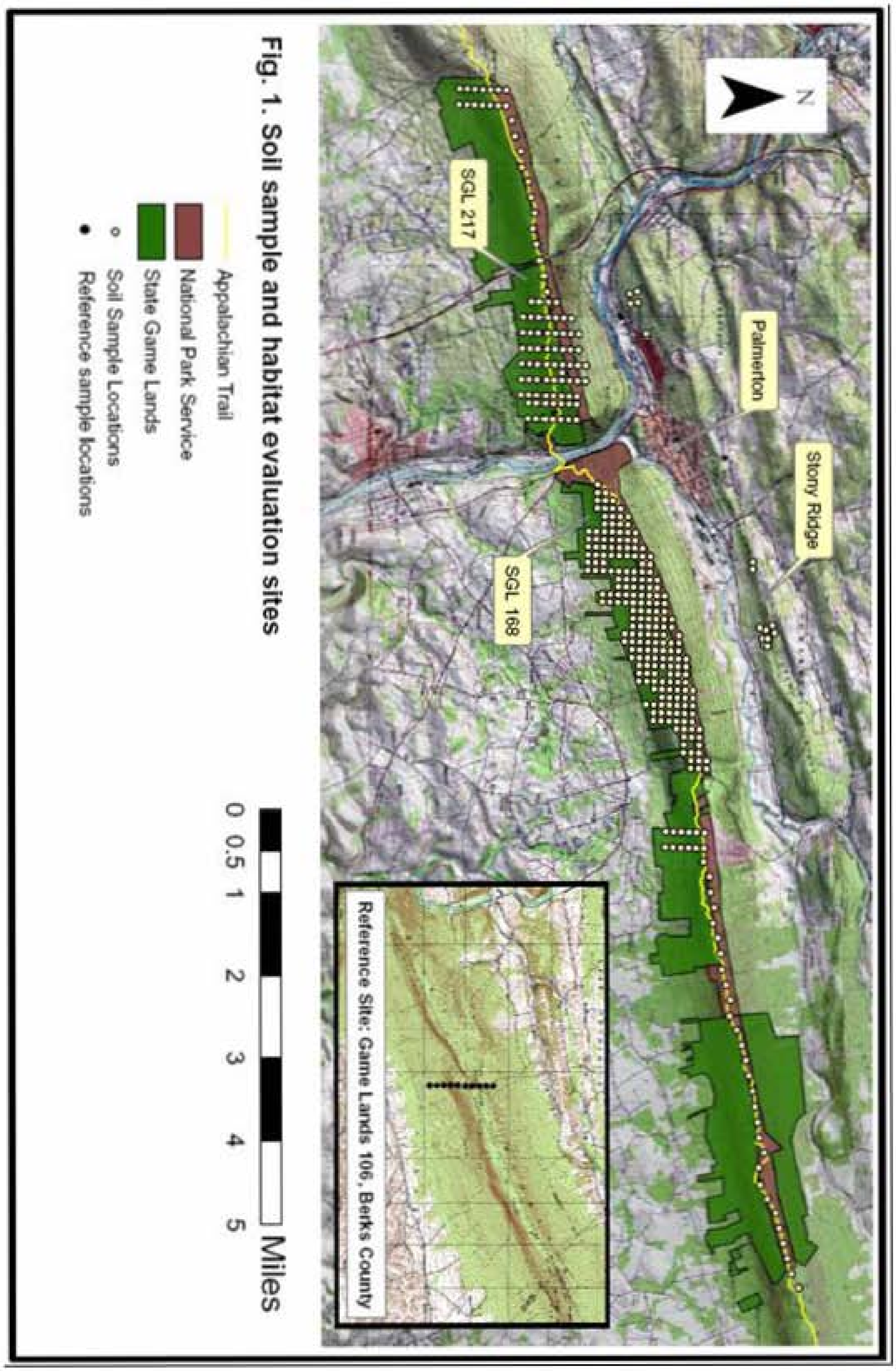

Figure 1. **Soil Sample and Habitat Evaluation Sites**

## Results

### Soils Analysis

Concentrations of all five metals of concern were elevated in soils collected near the Site relative to reference soils (Tables 1-3). Maximum levels for all metals on Blue Mountain, especially cadmium (527 mg/kg) and zinc (22,280 mg/kg), were extremely high[3] relative to reference and similar to those previously reported (Beyer et.al., 1985, Storm et. al., 1994, USEPA 1993, USEPA 2001). Average levels for all metals on Blue Mountain, especially cadmium (75 mg/kg) and zinc (2,962 mg/kg) were very high relative to reference concentrations and similar to those previously reported (Beyer et.al., 1985, Storm et. al., 1994, USEPA 1993, USEPA 2001). Average levels for arsenic, copper, lead, and especially zinc (6,040 mg/kg) were higher on Stony Ridge than on Blue Mountain. The Stony Ridge sampling was from a relatively small area in close proximity to the smelters. Reference soil metals were generally low and similar to background levels for the region (Table 3).

The average percent organic content (16 %) for Blue Mountain was relatively low considering the samples included litter and organic soil layers (0-3 inch depth). Approximately 75 % of the sites sampled had an organic soil content of 20% or less. The average organic content of Stony Ridge samples was even lower (9 %).

A total of 38 samples were split in the field and analyzed for metals by a separate lab for quality assurance purposes. The average relative percent differences were all less than or equal to 10 % except arsenic (Table 4). Overall, the split analysis does not suggest any problems with the metals analysis conducted at either lab.

**Table 1.** Summary statistics for soils collected on Blue Mountain (n = 342)

| | As mg/kg | Cd mg/kg | Cu mg/kg | Pb mg/kg | Zn mg/kg | Organic Content % |
|---|---|---|---|---|---|---|
| **Maximum** | 110 | 527 | 390 | 3345 | 22280 | 68 |
| **Average** | 33 | 75 | 70 | 516 | 2818 | 16 |
| **Minimum** | 11 | 4 | 6 | 26 | 36 | 2 |
| **Standard deviation** | 18 | 73 | 66 | 528 | 3185 | 13 |
| **Detection Limits** | 10 | 2 | 1 | 6 | 2 | NA |

NA: not applicable

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[3] Palmerton area soil contamination previously referred to as “highly contaminated” (Li et al., 2000), “heavily contaminated” (Beyer et al., 1985), “extremely contaminated” (Beyer and Storm, 1995), “grossly contaminated” (Sileo and Beyer , 1985), “grossly elevated” Ketterer et al., 2001), and “abnormally high” (Strojan, 1978).

**Table 2. Summary statistics for soils collected on Stony Ridge (n = 16)**

| | As mg/kg | Cd mg/kg | Cu mg/kg | Pb mg/kg | Zn mg/kg | Organic Content % |
|---|---|---|---|---|---|---|
| **Maximum** | 134 | 259 | 238 | 1991 | 26530 | 26 |
| **Average** | 55 | 74 | 96 | 653 | 6040 | 9 |
| **Minimum** | 13 | 5 | 19 | 154 | 371 | 2 |
| **Standard deviation** | 33 | 77 | 58 | 476 | 8057 | 6 |
| **Detection Limits** | 10 | 2 | 1 | 6 | 2 | NA |

**Table 3. Summary statistics for soils collected from the reference area (n = 10)**

| | As* mg/kg | Cd mg/kg | Cu mg/kg | Pb mg/kg | Zn mg/kg |
|---|---|---|---|---|---|
| **Maximum** | 21 | ND | 27 | 295 | 71 |
| **Average** | 18 | ND | 11 | 130 | 33 |
| **Minimum** | 14 | ND | 4 | 58 | 16 |
| **Standard deviation** | 5 | ND | 6 | 69 | 15 |
| **Detection Limits** | 10 | 2 | 1 | 6 | 2 |
| **Average Eastern U.S.** [†] | 5 | 0.22[‡] | 13 | 14 | 40 |

* Eight out of ten samples were non-detect for arsenic

ND: not detected

[†] USGS (USDOE 1997)

[‡] Oak Ridge Reservation (USDOE 1997)

**Table 4. Summary statistics for split samples (n = 38)**

| | Relative Percent Differences (%) | | | | |
|---|---|---|---|---|---|
| | As | Cd | Cu | Pb | Zn |
| **Maximum** | 54 | 40 | 38 | 56 | 43 |
| **Average** | 24 | 10 | 2 | 8 | 10 |
| **Minimum** | -17 | -37 | -33 | -28 | -32 |
| **Standard deviation** | 16 | 14 | 13 | 15 | 13 |

## Habitat Assessment

On average, contaminated sites had less tree cover and a lower diversity of trees than the reference area (Fig. 2). Average shrub cover was similar on Blue Mountain and the reference area but lower on Stony Ridge. Average herbaceous cover was much higher on the contaminated sites and was predominantly grass and fern (Figs. 2 & 3). Blue Mountain, Stony Ridge and the reference area all had very rocky soil surface layers but a lower percentage of contaminated sites were covered with leaf litter, and erosion had exposed the subsoil at many of them (Fig. 4). Tree seedlings, resprouted trees, moss and fungi were all more prevalent in the reference area than in contaminated areas (Fig. 5). Seedlings and saplings of many species (e.g., oak, sassafras, and chestnut) typically resprout following damage of the primary stem as a result of herbivory, wind, fire, or other stress. Lichen was only observed on Blue Mountain sites. The presence of chlorotic vegetation (i.e., yellowing leaves) was also limited to Blue Mountain. Summary data for the habitat assessment is provided in the appendix (Tables A1-A4).

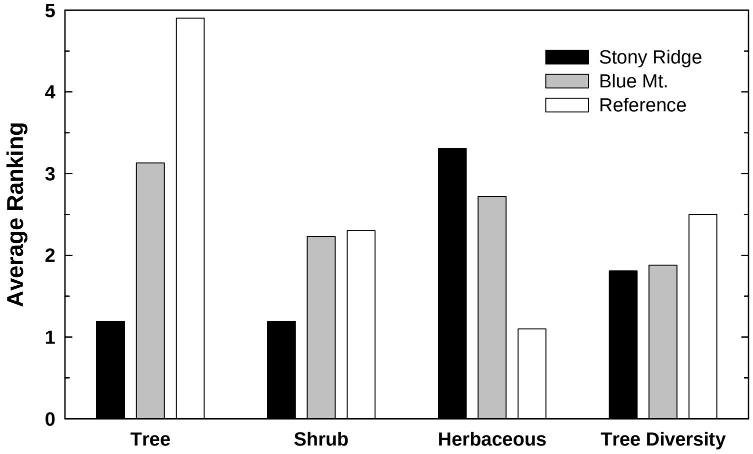

**Figure 2. Average vegetative cover rankings and tree diversity. Cover rankings: 1-scant (≤5 %); 2-sparse (≤25 %); 3-low (≤50%); 4-medium (≤75 %); 5-closed (> 75%). Relative tree diversity is the average number of different tree families per site (not identified to species level).**

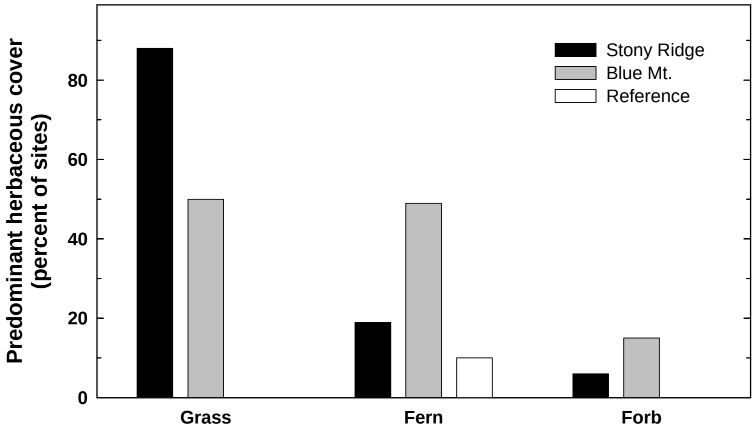

**Figure 3. Percentage of sites where the herbaceous cover was predominantly (≥ 33%) grass, fern and/or forb. Note that sites may have none, or more than one, cover type.**

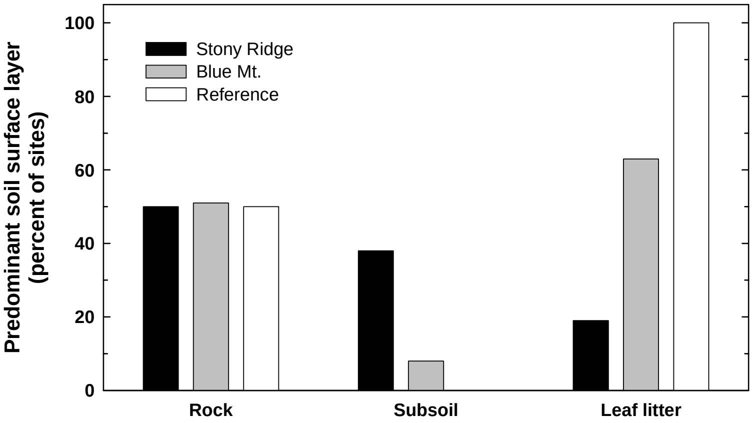

**Figure 4. Percentage of sites where the soil surface layer was predominantly (≥ 33%) rock, subsoil, and/or leaf litter. Note that sites may be comprised of more than one cover type.**

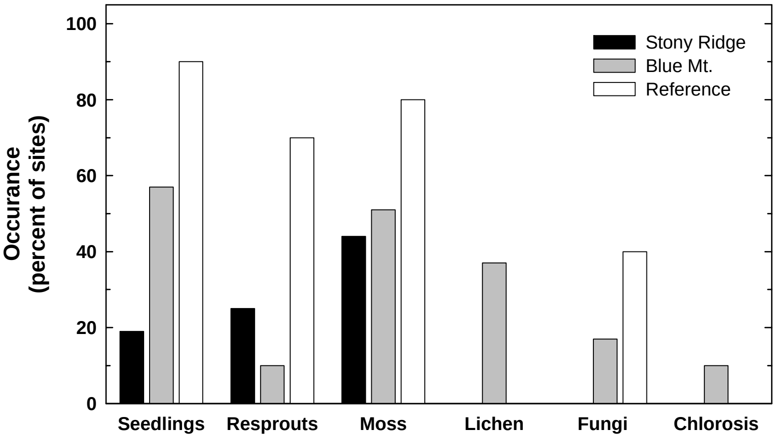

**Figure 5. Percentage of sites with presence of seedlings, resprouts, moss, lichen and chlorotic vegetation (yellow leaves).**

## Discussion

The results show that after more than 25 years after the primary smelting operations ceased, surface soils throughout the sampling area on Blue Mountain and Stony Ridge remain highly elevated in metals, especially zinc and cadmium, as compared to reference concentrations[4]. The results also show a decline in the forest habitat conditions throughout these contaminated areas relative to reference areas.

The toxic effects of metals on soil fauna and flora, subsequent decreased litter decomposition rates and erosional losses have all strongly affected the composition and function of metals-contaminated soils on Blue Mountain (Buchauer 1973, Jordan and

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[4] Based on a variety of source identification methods, EPA's National Enforcement Investigations Center attributed greater than 90% of the cadmium, lead, and zinc contamination on Blue Mountain, Stony Ridge and surrounding areas, to zinc smelting (USEPA 1994).

Lechevalier 1975, Strojan, 1978 a,b, Beyer et al. 1984, Beyer 2001). Our results show that soil zinc concentration was positively correlated with soil percent organic content for Blue Mountain soils (Fig. 6). A similar correlation existed for all five metals and organic content in Stony Ridge soils (not shown). This finding is consistent with previous studies and has been attributed to the aerial deposition of contaminants on the soil surface and sorption to the organic soil layer (Beyer et al. 1984, USEPA 1993, USEPA 2001). Metals have leached into the underlying mineral soils over time, but remain more highly concentrated in the surface organic soil layers (Buchauer 1973, Jordan 1975, USEPA 2001).

Earlier studies reported the deposition of Site-related metals up to 100 km away and a linear relationship of decreasing soil metal concentration with increasing distance from the smelters along an east-west axis (Buchauer 1973, Beyer et al. 1984, USEPA 1994, USEPA 2001). Our data show a similar overall relationship but indicate soil zinc concentrations in the upper three inches of the soil profile are elevated at relatively uniform levels (1500-2500 mg/kg) throughout much of the sampling area on Blue Mountain within 6 km of the smelters (Fig. 6). Hot spots with higher soil zinc levels (4000-25,000 mg/kg) were found scattered throughout this area but tended to be closer to the smelters (within 2 km) and associated with high organic soil deposits. A similar relationship was observed with cadmium and to a lesser extent lead, copper, and arsenic.

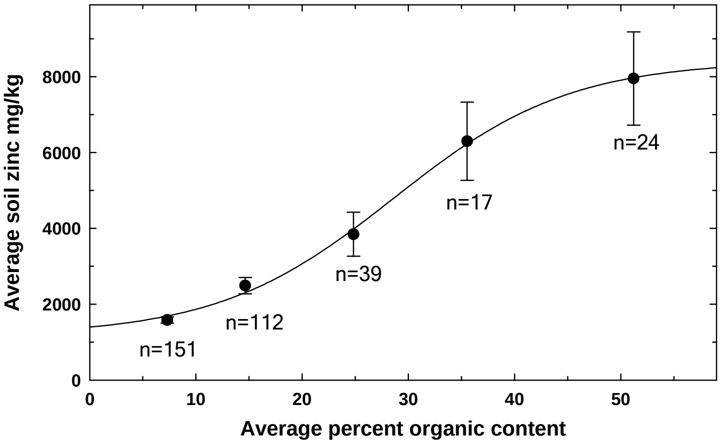

**Figure 6. Soil zinc concentration as a function of percent organic content for Blue Mountain soils (n=342). Soil data were combined into five groups based on percent organic content (0-10, 10-20, 20-30, 30-40, >40) and averaged. Error bars represent standard errors about the mean.**

The range of zinc levels in the more commonly found low-organic soils samples (1500-2500 mg Zn/kg) were much higher than the reference area (16-71 mg Zn/kg) and well above literature based threshold plant toxicity (phytotoxicity) levels (70-400 mg/kg) (Kabata-Pendias and Pendias 1992, Alloway 1990). The decreased tree cover, tree diversity, tree seedlings, tree resprouts, moss and fungi, and increased grass cover are consistent with previous studies and have been attributed to a combination of phytotoxic responses to the metal contaminated soils[5] and the cascading deleterious effects of increased soil erosion, reduced litter decomposition rates, and altered soil nutrient dynamics (Jordan 1975, Beyer 1988, Beyer and Storm 1995).

A comparison of Blue Mountain data between areas that were either mostly barren or forested as of 1992, based on 1992 orthorectified aerial photography (PASDA 2004, see appendix), is provided in Figs. 7-10. This comparison suggests that the previously barren areas remain relatively devoid of tree, shrub and herbaceous cover. The previously forested areas have lower tree cover and higher herbaceous cover, predominantly in the form of grass and fern, as compared to reference. The observation of tree seedlings was low in barren areas (20 %), and reduced in forested areas (61 %) as compared to reference (90 %). Photographs of three example sites are provided in Figure 11.

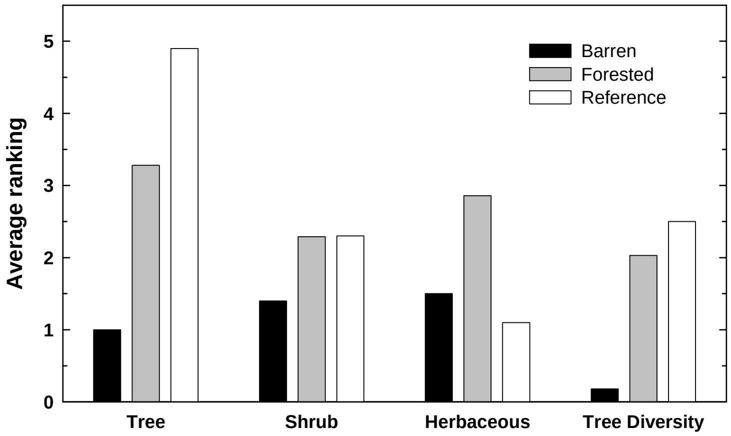

**Figure 7. Average vegetative cover rankings in areas that were either mostly barren or forested in 1992 as compared to reference. Cover rankings: 1-scant (≤5 %); 2-sparse (≤25 %); 3-low (≤50%); 4-medium (≤75 %); 5-closed (> 75%). Relative tree diversity is the average number of different tree families per site (not identified to species level).**

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[5] Nash (1972) concluded that the abnormally high soil zinc levels were a significant factor in causing a 90% reduction in the richness and abundance of lichen in the barren areas of Blue Mountain. Jordan (1975) documented reduced tree and tree seedling, richness and abundance, and demonstrated that soil zinc levels at Palmerton inhibited root elongation of tree seedlings. In EPA's second five-year review report (2002), zinc toxicity symptoms and elevated tissue concentrations were reported for a wide range of trees growing in the Ecoloam treated area. The highest zinc concentrations were reported for Birch leaves (853-2696 mg/kg), resulting in recommendations for removal of birch, poplar, and others to reduce migration of metals through plants to the soil surface (USEPA 2002).

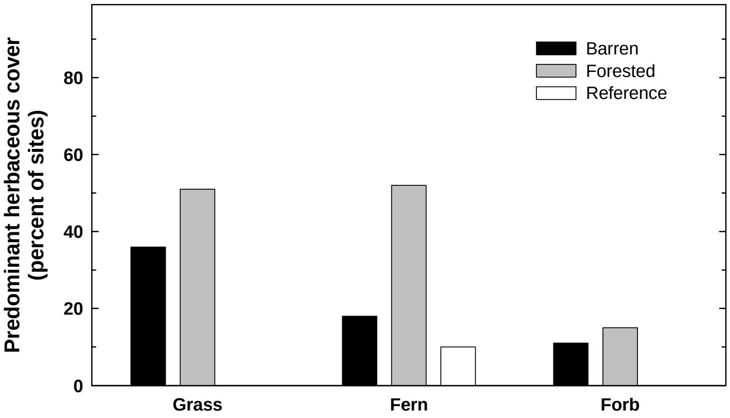

**Figure 8. Percentage of sites where the herbaceous cover was predominantly (≥ 33%) grass, fern and/or forb, in areas that were either mostly barren or forested in 1992 as compared to reference.**

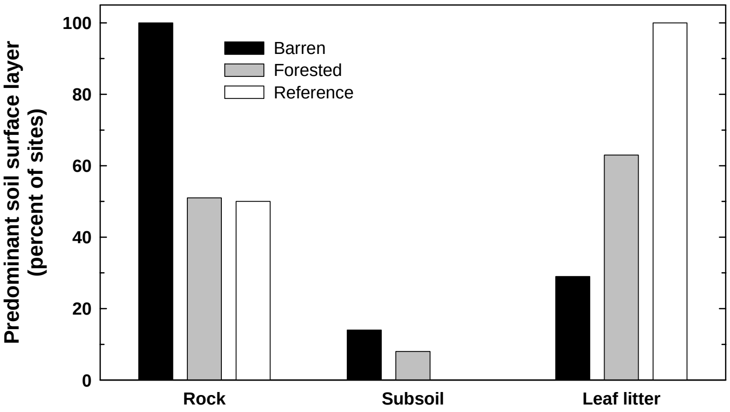

**Figure 9. Percentage of sites where the soil surface was predominantly (≥ 33%) rock, subsoil, and/or leaf litter, in areas that were either mostly barren or forested in 1992 as compared to reference.**

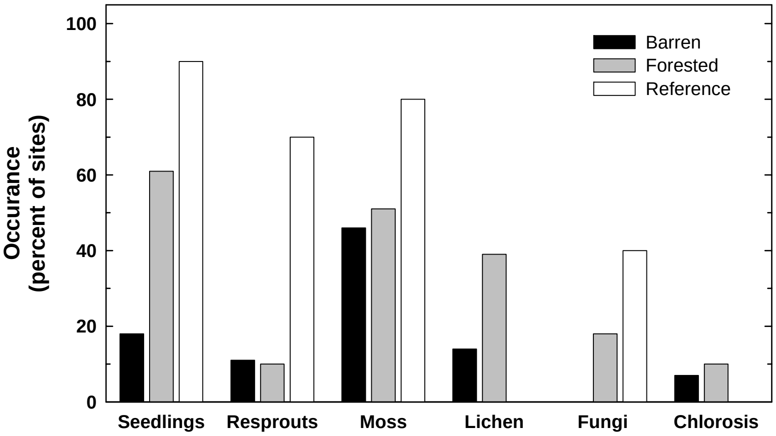

**Figure 10. Percentage of sites with presence of seedlings, resprouts, moss, lichen and chlorotic vegetation (yellow leaves), in areas that were either mostly barren or forested in 1992 as compared to reference.**

**Figure 11. Photographs of a mostly barren site, a forested site on Blue Mountain, and a reference site, respectively.**

A comparison to literature-based phytotoxicity levels provides information for estimating the relative phytotoxicity of site soils. This approach is especially helpful for mapping the potential extent of injury to the forest as a whole and focusing future, more detailed studies. Such maps can be revised as additional site-specific data is acquired. Maps were developed showing soil sample locations and metals results based on the five relative phytotoxicity ranges shown for each metal in Table 9. The lowest relative phytotoxicity level was assigned to the threshold effects concentration (TEC) range, within which phytotoxic effects are typically first observed (Kabata-Pendias and Pendias 1992, Alloway 1990). Subsequently higher relative phytotoxicity levels were assigned to ranges based on multiples of the maximum TEC ($TEC_{max}$) concentration as indicated in the criteria column of Table 9. Figures 12-16 are maps showing the sample locations and estimated relative phytotoxicity for the five metals of concern. Actual phytotoxicity varies depending on soil characteristics[6], plant species, and other factors and will require further study to determine site specific-toxicity thresholds (Chaney 1993).

The maps suggest that soil zinc and cadmium are elevated at levels estimated to be phytotoxic throughout much of the sampling area on Blue Mountain and Stony Ridge (Figures 12-13). Soil lead, copper, and arsenic levels are also elevated at levels estimated to be phytotoxic but to a lesser extent than zinc and cadmium (Figures 14-16). Similar to the general trend for soil metals, the estimated relative phytotoxicity of soils tends to decline with increasing distance from the smelters in an east-west direction. The western extent of potentially phytotoxic soil levels appears to be in the vicinity of Lehigh Furnace Gap, which is about 5 miles west of Lehigh Gap. The eastern extent is not as clearly discernable since even the most eastern locations had potentially phytotoxic zinc and cadmium levels.

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[6] The bioavailability of metals in soil depends on the solubility of the source material, soil chemical processes, and sorbtion by organic matter (McBride 1994). Despite substantial differences in the total concentration of zinc between surface and subsurface soil layers collected from the Site, Roberts et al. (2002) reported that zinc was largely available in both layers and at similar levels.

**Table 5**. Soil metal concentration ranges used for mapping estimated relative phytotoxicity

| Relative | Soil Concentration Ranges mg/kg | | | | | |
|---|---|---|---|---|---|---|
| **Phytotoxicity** | **As** | **Cd** | **Cu** | **Pb** | **Zn** | **Criteria** |
| None | ND-20 | ND-3 | ND-60 | ND-100 | ND-70 | < TEC |
| Low | 21-50 | 3-8 | 61-125 | 101-400 | 71-400 | TEC range |
| Moderate | 51-100 | 9-16 | 126-250 | 401-800 | 401-800 | 1-2 x TEC$_{max}$ |
| High | 101-500 | 17-80 | 251-1260 | 801-4000 | 801-4000 | 2-10 x TEC$_{max}$ |
| Very High | NA | 81+ | NA | NA | 4001+ | > 10x TEC$_{max}$ |

ND: not detected
NA: not applicable
TEC: threshold effects concentration (Kabata-Pendias and Pendias 1992, Alloway 1990)

## Conclusions

The results of this study confirm that concentrations of metals of concern in the soils throughout the approximate 4,400 acres assessed are elevated as compared to reference. Zinc was on average about 100 times higher in assessment area soils than the reference area. Zinc is of particular concern since it one of the most commonly phytotoxic microelements (Chaney 1993). The results of the habitat assessment indicate areas that were mostly barren in 1992 remain largely devoid of all vegetative cover and are primarily covered with rock. Within the assessment area, areas that were mostly forested in 1992 were found to be reduced in tree cover, leaf litter, and the presence of tree seedlings and had a greater predominance of grass and fern as compared to reference.

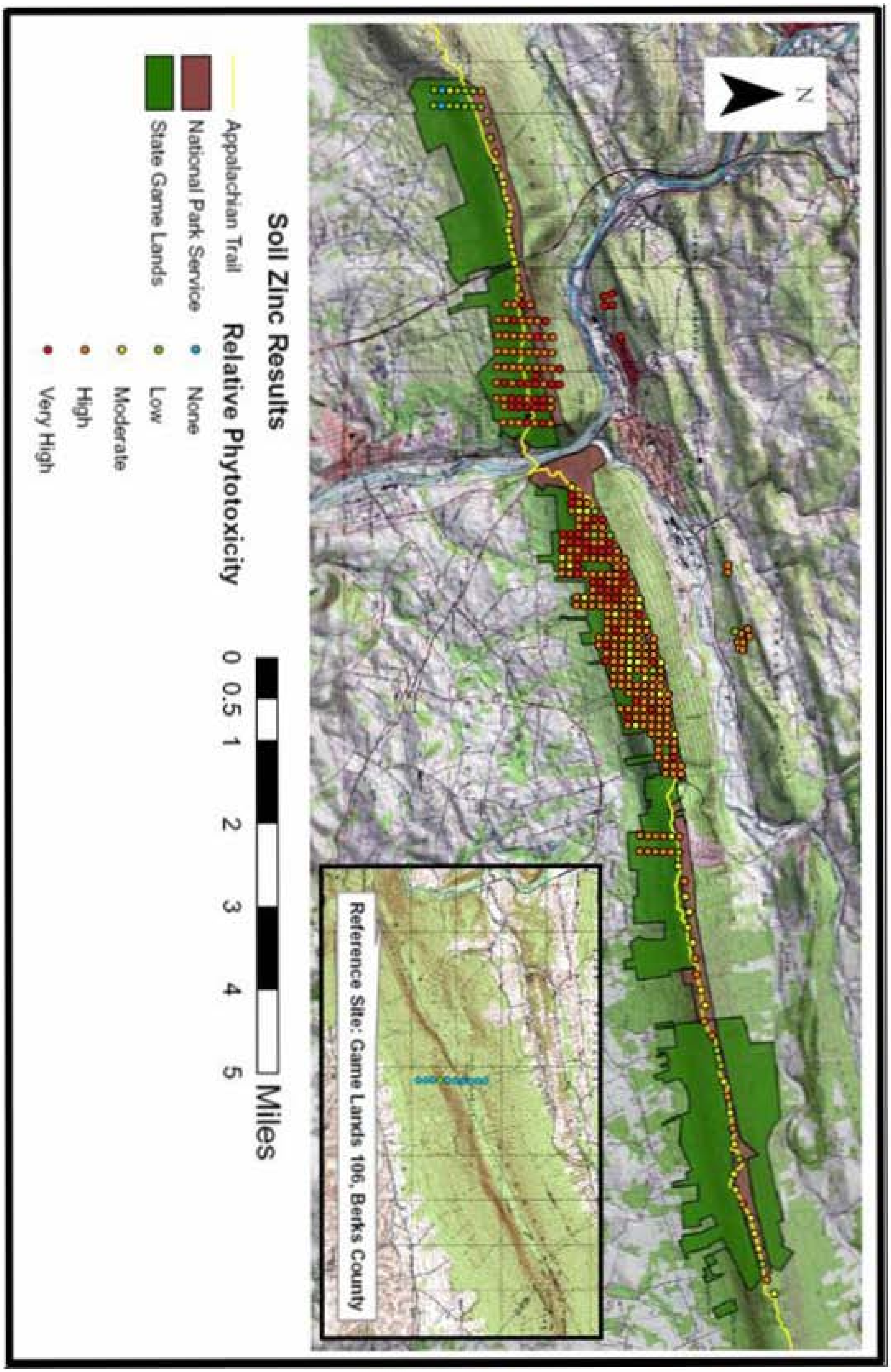


**Figure 12. Zinc relative phytotoxicity map**

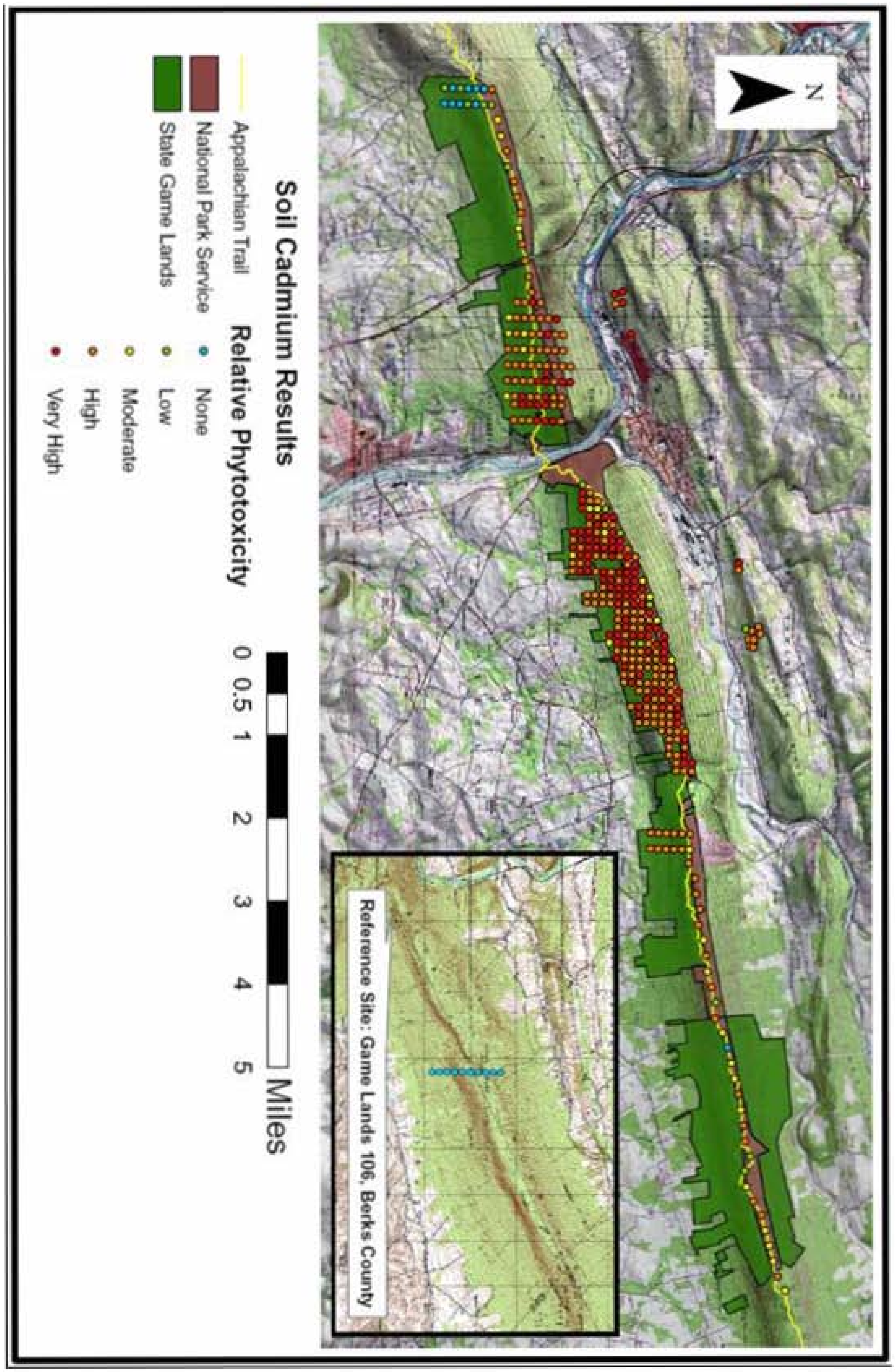


**Figure 13. Cadmium relative phytotoxicity map**

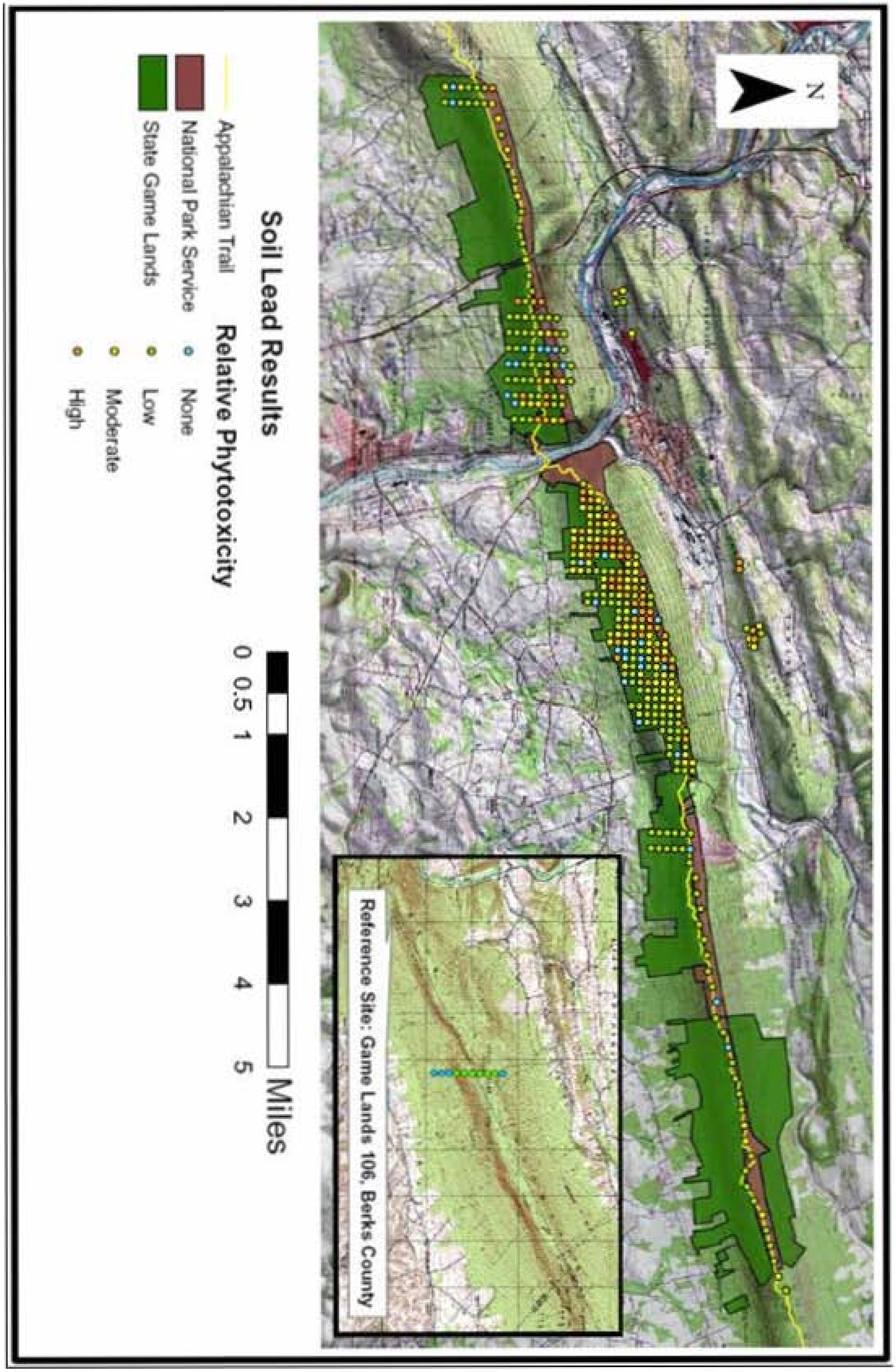


**Figure 14. Lead relative phytotoxicity map**

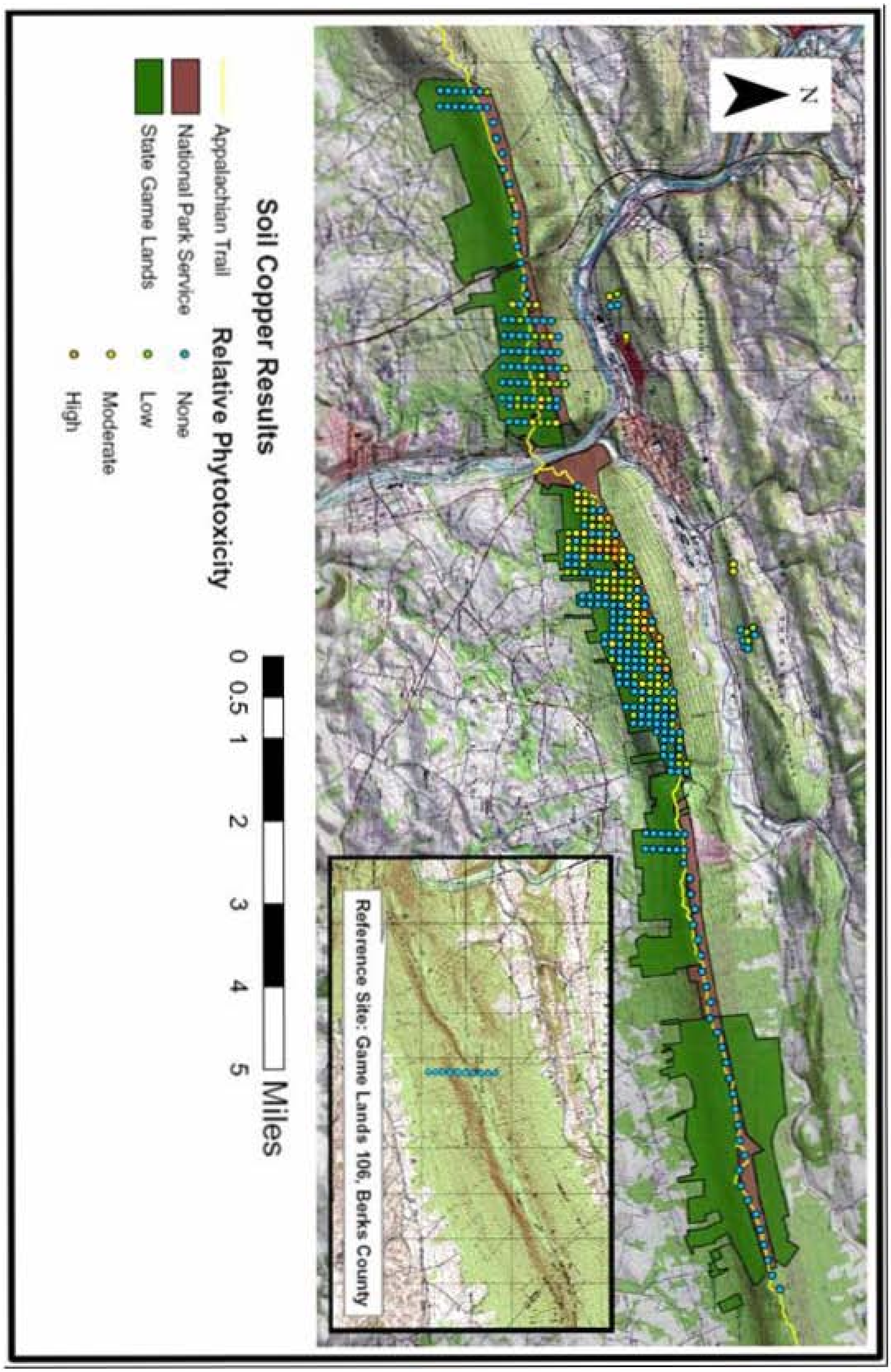


Figure 15. Copper relative phytotoxicity map

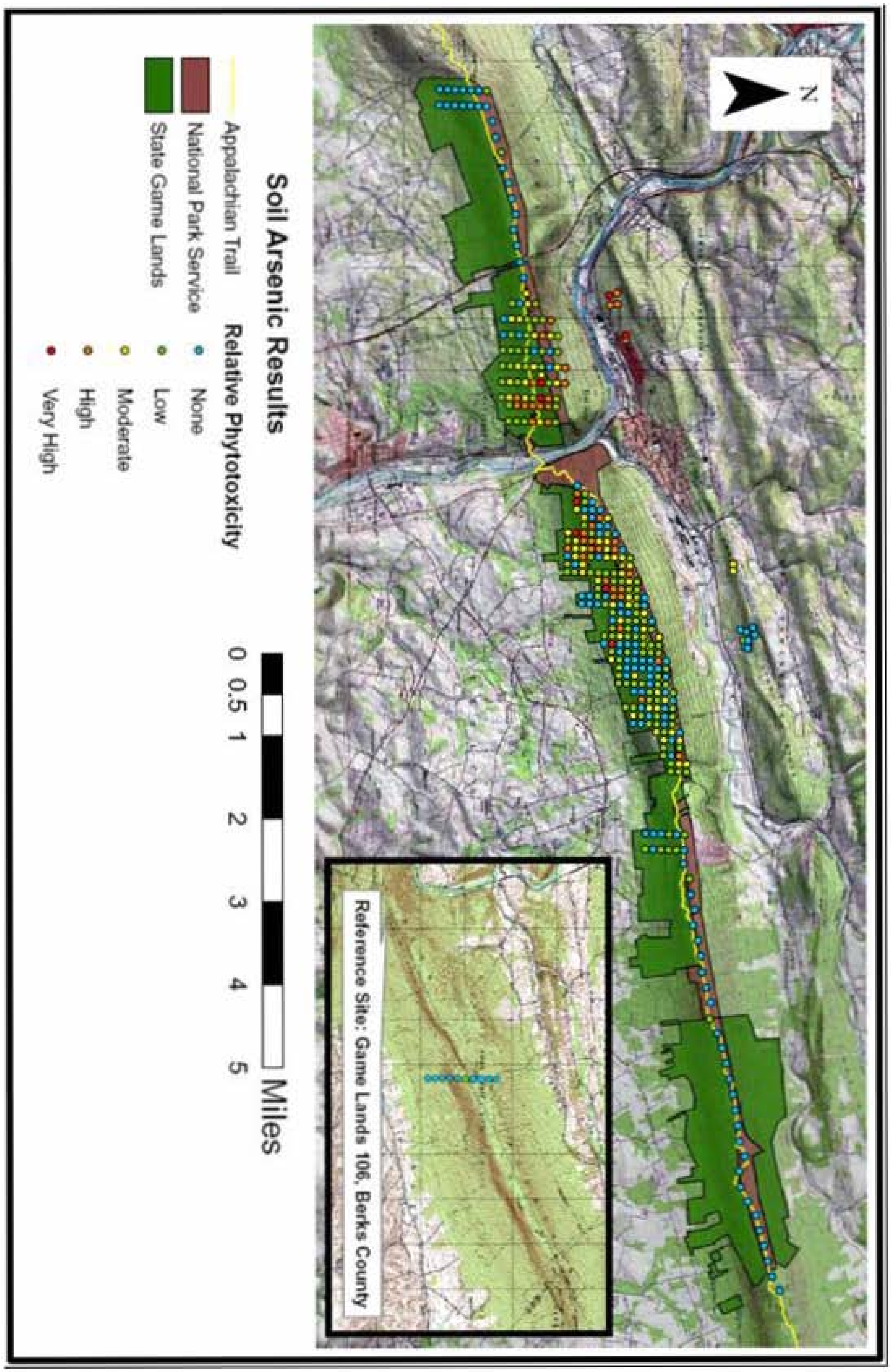


Figure 16. Arsenic relative phytotoxicity map

## Appendix

**Table A1. Average vegetative cover rankings and tree diversity.**

| Location | Tree Cover | Shrub Cover | Herbaceous Cover | Relative Tree Diversity |
|---|---|---|---|---|
| **Blue Mountain** | 3.13 | 2.23 | 2.72 | 1.88 |
| **Stony Ridge** | 1.19 | 1.19 | 3.31 | 1.81 |
| **Reference** | **4.90** | **2.30** | **1.10** | **2.50** |

Cover rankings: 1scant (≤5 %); 2 sparse (≤25 %); 3 low (≤50%); 4 medium (≤75 %); 5 closed (> 75%)
Relative tree diversity: number of different tree families per site (not identified to species level).

**Table A2. Percentage of sites where the herbaceous cover was predominantly (≥ 33%) grass, fern and/or forb*.**

| | Grass | Fern | Forb |
|---|---|---|---|
| **Blue Mountain** | 50% | 49% | 15% |
| **Stony Ridge** | 88% | 19% | 6% |
| **Reference** | **0%** | **10%** | **0%** |

*Rows need not add to 100% since a site may have none, or more than one, cover type

**Table A3. Percentage of sites where the soil surface was predominantly covered (≥ 33%) by rock, subsoil, and leaf litter***

| | Rock | Subsoil | Leaf litter |
|---|---|---|---|
| **Blue Mountain** | 51% | 8% | 63% |
| **Stony Ridge** | 50% | 38% | 19% |
| **Reference** | **50%** | **0%** | **100%** |

*Rows need not add to 100% since a site may be comprised of more than one cover type

**Table A4. Percentage of sites with presence of seedlings, resprouts, moss, lichen and chlorotic vegetation (yellow leaves)**

| Location | Tree seedlings | Tree resprouts | Moss | Lichen | Fungi | Chlorosis |
|---|---|---|---|---|---|---|
| **Blue Mountain** | 57% | 10% | 51% | 37% | 17% | 10% |
| **Stony Ridge** | 19% | 25% | 44% | 0% | 0% | 0% |
| **Reference** | **90%** | **70%** | **80%** | **0%** | **40%** | **0%** |

**Table A5. Average vegetative cover rankings, and tree diversity.**

| Location | Tree Cover | Shrub Cover | Herbaceous Cover | Relative Tree Diversity |
|---|---|---|---|---|
| **Denuded (as of 1992)** | 1.00 | 1.33 | 1.52 | 0.18 |
| **Forested (as of 1992)** | 3.32 | 2.31 | 2.86 | 2.05 |
| **Reference** | **4.90** | **2.30** | **1.10** | **2.50** |

Cover rankings: 1scant (≤5 %); 2 sparse (≤25 %); 3 low (≤50%); 4 medium (≤75 %); 5 closed (> 75%)
Relative tree diversity: number of different tree families per site (not identified to species level).

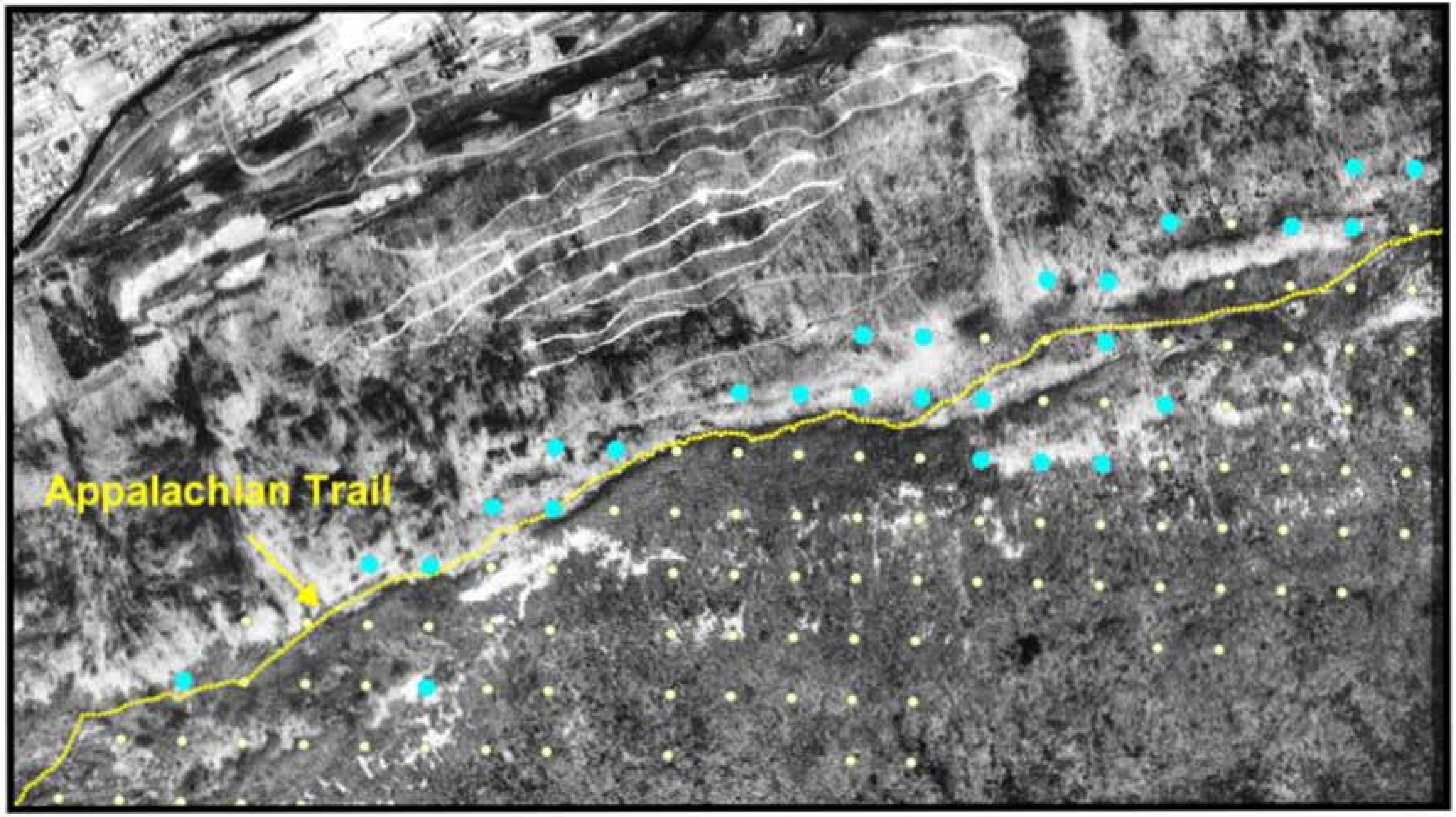
**Table A6. Percentage of sites where the herbaceous cover was predominantly (≥ 33%) grass, fern and/or forb*.**

| Location | Grass | Fern | Forb |
|---|---|---|---|
| **Denuded (as of 1992)** | 33% | 19% | 11% |
| **Forested (as of 1992)** | 51% | 52% | 15% |
| **Reference** | **0%** | **10%** | **0%** |

*Rows need not add to 100% since a site may none, or more than one, cover type

**Table A7. Percentage of sites with presence of seedlings, resprouts, moss, lichen and chlorotic vegetation (yellow leaves)**

| Location | Tree seedlings | Tree resprouts | Moss | Lichen | Fungi | Chlorosis |
|---|---|---|---|---|---|---|
| **Denuded (1992)** | 19% | 11% | 48% | 15% | 0% | 7% |
| **Forested (1992)** | 61% | 10% | 51% | 39% | 18% | 10% |
| **Reference** | **90%** | **70%** | **80%** | **0%** | **40%** | **0%** |



Aerial digital orthoquad showing the extent of the barren areas on Blue Mountain as of 1992. Sampling locations corresponding with mostly barren areas (light colored) are highlighted in blue.

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