

**VEGETATION, EDAPHIC, AND HISTORICAL
ANALYSIS OF CHARCOAL HEARTHS AT
HOPEWELL FURNACE
NATIONAL HISTORIC SITE, PENNSYLVANIA**

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Technical Report NPS/MARHOFU/NRTR-94/056

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Cooperative Agreement
4000-9-8004
Supplemental Agreement 15

Final Report
February 1994

National Park Service
Mid-Atlantic Regional Office
Division of Resource Management and Visitor Protection
143 South Third Street
Philadelphia, PA 19106-2878

Summary

This study related the age structure and composition of forests at Hopewell Furnace National Historic Site (HOFU) in southeastern Pennsylvania to soil properties associated with disturbances caused by a local charcoal iron furnace. Physical and chemical properties of charcoal hearth soils, created by the recurring production of charcoal in earthmound kilns from the late 18th to the early 20th century, were examined to understand the lack of woody vegetation relative to surrounding sites after nearly a century of forest recovery. Reconnaissance located 105 previously unidentified charcoal hearths and the remains of 13 colliers' huts in wooded portions of the site. The age structure and composition of plant communities on charcoal hearths suggest that soil and site factors have continuously inhibited the reintroduction of woody vegetation relative to surrounding forests. Destruction of belowground vegetative structures and the soil seed bank by the heat of charcoal production delayed recolonization of hearth sites. In the period after hearth abandonment in the late 19th century, the primary factors creating a severe soil environment were likely the deposition of toxic amounts of soluble salts and elevated surface soil temperatures caused by exposure of a blackened soil surface. Significant differences in the chemical properties of charcoal hearth soils still exist today and may be responsible for the continued inhibition of woody vegetation. Additional results of this study include construction of a 367-year living tree-ring chronology which may be used in the future dating of historic structures at HOFU, and characterization of the area's presettlement forest, based on witness tree information collected by land surveyors from 1733 to 1794.

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Introduction

The charcoal iron industry remains an underappreciated aspect of land-use history in Pennsylvania, and in the mid-Atlantic region in general. At the industry peak in 1840, Pennsylvania led 24 other states in production, accounting for over a third of the nation's charcoal iron (Scrivenor 1854). Since a single charcoal iron furnace could consume several hundred acres of forest per year, the industry has frequently been depicted as a despoiler of the land, although its role as a conservator of the forest during a period of intense clearing for agriculture has been offered as an alternative viewpoint (Birkinbine 1896, Day 1929).

Whichever interpretation one favors, the physical and temporal extent of the charcoal iron industry in Pennsylvania has had widespread and long-lasting effects on the state's forest resource. Large-scale effects include the presence of valuable, even-aged, mixed-oak stands currently nearing maturity in nearly all counties of the state. Small-scale effects remain in the numerous hearths still evident within historic charcoal forests. A century or more since their last use, charcoal hearths exhibit unique vegetation and soil properties related to the repeated use of earthmound kilns in the production of charcoal from the late 18th century to the late 19th or early 20th century.

Previous studies have identified 45 historic charcoal hearths and the remains of 10 colliers' huts in 153 hectares of Hopewell Furnace National Historic Site (HOFU), information vital to the understanding and management of the park's cultural and natural resources (Heite 1988, 1989). The primary objectives of this study were to locate hearths and related features in the remaining unsurveyed portions of HOFU forests, understand the altered successional response of hearth vegetation, and study

site and soil properties in the context of ecology and preservation. Other objectives included description of the present age structure of hearth and non-hearth control forests, construction of a tree-ring chronology for future dating of historic structures at HOFU, and characterization of presettlement forest composition based on 18th century documents housed in the park archives.

Study Area

Hopewell Furnace National Historic Site is located in the Upland Section of the Piedmont Physiographic Province of southeastern Pennsylvania (Fenneman 1938). The climate is described as humid or temperate continental, with short mild winters and an average frost free period of 190 days (Kunkle 1963, Ackerman 1970). The mean monthly winter and summer temperatures are 0.3 °C and 23 °C, respectively, and precipitation is well distributed throughout the year with an average annual total of 113 cm. Upland soils of the park which supported charcoal forests are primarily sandy loams, channery loams, and channery silt loams of low to moderate water-holding capacity and low fertility. Most soils are derived from red sandstone conglomerate, gneiss, schist, or quartzite parent material, are highly leached, and are strongly acid (pH 5.1 to 5.5) to very strongly acid (pH 4.5 to 5.0), although small areas underlain by dolomite have a more basic soil reaction (Kunkle 1963, Ackerman 1970). The present diverse assemblage of forest associations has been influenced by geology, topography, drainage and, most prominently, local land use history (Russell and Schuyler 1988). Most upland forests of the park were initiated by charcoal clearcuts in the late 19th century and were further affected by selective logging until acquisition by the federal government in 1935.

The 350-ha park forms the nucleus of a 2000-ha charcoal iron plantation which was in operation from 1771 to 1883. The park has been divided into seven cultural resource areas by park staff to facilitate periodic inventories of historic features (Roger Stone 1993, personal communication; Figure 1). Six of the seven areas contain charcoal features; neither this study nor a previous one (Heite 1989) discovered any charcoal features in area D. Forests of this section, much of which is poorly drained, appear to be early successional communities which recolonized land used for agriculture and other purposes during the period of interest.

Methods

Pedestrian Surveys

Wooded areas within all seven cultural resource areas were surveyed to locate previously unidentified charcoal features during June and July of 1991, and May, June and July of 1992. The surveys were begun at the northernmost corner of each area. Charcoal hearths are flat, rockless, elliptical areas of about 150 m², having a surface layer composed of a mixture of charcoal and mineral soil. Hearths can often be recognized at a distance by the increased light reaching the forest floor caused by canopy gaps. Collier hut remains are low, circular platforms of soil about 30 m² in area and are usually surrounded by a single circular, shallow trench. Hearths and huts were numbered, flagged, and the location noted as they were found along parallel east-west transects. When a transect intersected the boundary of a forest or cultural resource area, a new transect was established 30 m to the south and the survey resumed in the reverse direction until the opposite boundary was reached.

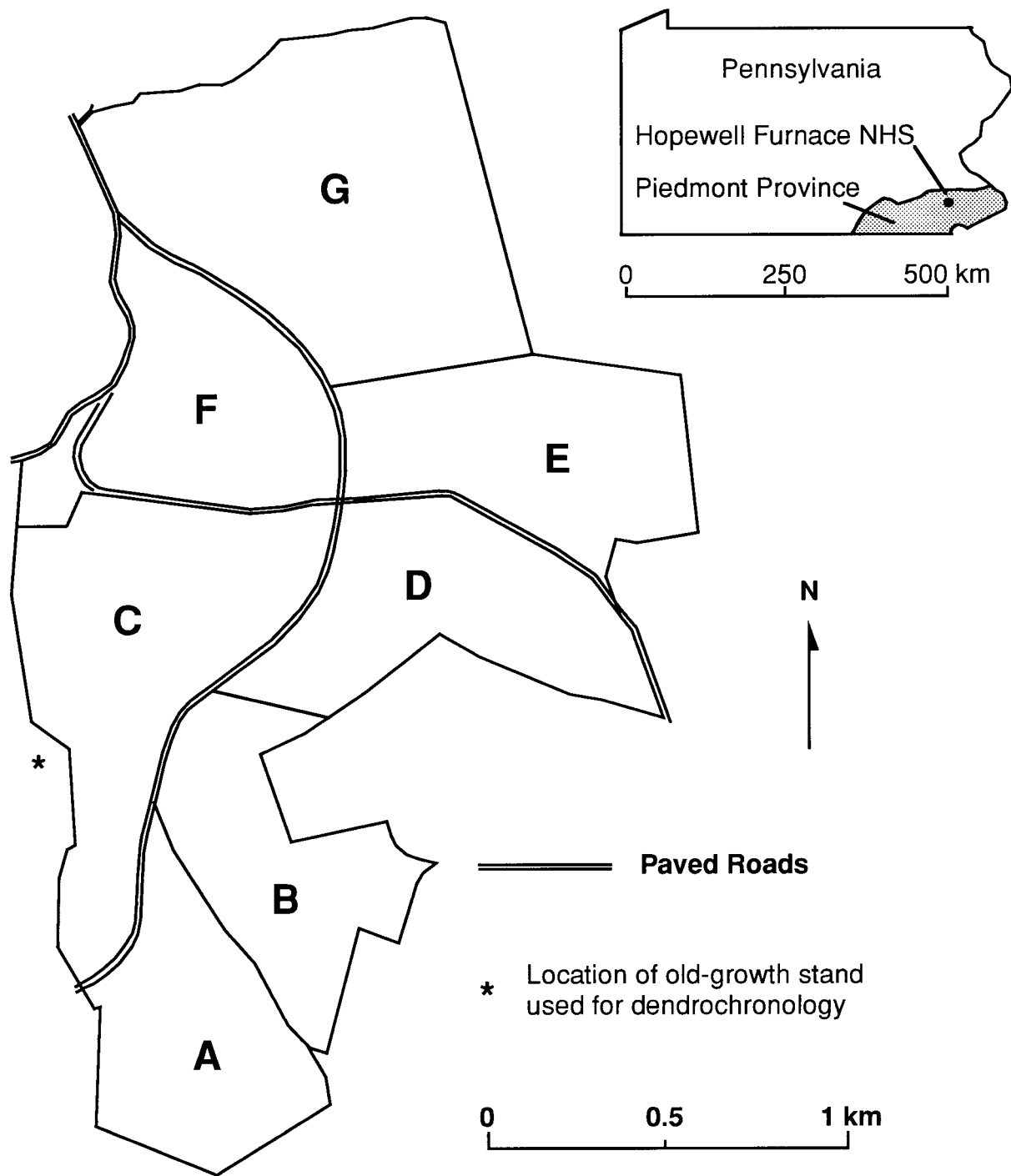


Figure 1. Cultural Resource Areas at Hopewell Furnace National Historic Site.

After this initial reconnaissance was complete, each previously unidentified feature was revisited for the collection of more detailed information. The location of each feature in relation to each other, park boundaries, and permanent points of reference were determined as accurately as possible with an orienteering compass and a measuring tape. Long and short axes were measured to the nearest half meter on each charcoal hearth. Also noted were hearth characteristics such as aspect, profile, flatness, absence of rocks, the presence of charcoal fragments, charcoal soil and dust rings, and the general amount and composition of vegetation. Since hearths varied widely in their ease of identification, the general condition and appearance of each hearth was given a subjective rating from zero to three in 0.5 increments. A rating of zero represented the most poorly defined hearths, confirmed only by examination of the soil profile with a soil probe, and a rating of three represented hearths having all the characteristic features of a well defined hearth. These criteria included a flat, rockless profile, well-defined margins such as sharp relief on slopes or the presence of a dust ring (cf. Heite 1988), and an open, relatively under-vegetated appearance. Ratings from 0.5 to 2.5 were subjectively assigned to hearths having relatively better expression of, and more of, these characteristics. The diameter of collier hut remains was taken by measuring across the raised platforms from the center of shallow trenches which circle hut perimeters. Remains of stone fireplaces associated with huts were noted.

Vegetation Surveys

Comparisons of hearth and non-hearth control vegetation were conducted on 38 paired sites representing the mixed oak-black birch, mixed oak, and tuliptree-oak forest associations at HOFU (cf. Russell and Schuyler 1988). Fifteen sites were surveyed in cultural resource area A, five in area B, eight in area F, and ten in area G. A radius of 1/2 the length of the hearth short axis was used to establish a central circular overstory plot within the hearth. Species, diameter at 1.37 m (dbh), and crown class (cf. Smith 1986) were recorded for each tree (≥ 10 cm dbh) within the plot. All trees within each plot and several of the largest trees nearby were cored for age determinations. All saplings (< 10 cm dbh but ≥ 1.5 m in height) within the overstory plot were tallied by species. Seedlings (single stems < 1.5 m in height) were tallied by species on one circular 5 m² plot at the center of each overstory plot. Shrub cover (multiple-stemmed woody plants < 10 cm dbh) by species and total herbaceous cover (all non-woody vegetation excluding lichens) of the 5 m² plot were recorded as one of the following percentage classes: 0 %, 1 - 5%, 6 - 25%, 26 - 50%, 51 - 75 %, and 76 - 100%. Overstory and understory control plots of the same size were centered 30 m in a random direction from hearth centers, and all vegetation sampling methods were repeated.

Tree, sapling, and seedling densities by species were converted to numbers per hectare. Tree diameters were used to calculate species basal area (dominance) in m² per hectare. Relative measures of density and dominance for each tree species were calculated by expressing both values as a percentage of the totals for each site. A relative importance value was then calculated for each tree species by averaging

relative density and relative dominance (see Appendix A). All tree cores were dried, secured in wooden mounts, and aged with a dissecting microscope.

Diversity measures were calculated for the four woody components at each hearth and control plot. The heterogeneity index (H') follows Shannon and Weaver (1949), where $H' = -\sum p_i (\log_2(p_i))$. P_i for trees, saplings and seedlings, and shrubs were species relative importance, relative density, and relative cover, respectively. Evenness values (J') were determined by dividing H' by the maximum value possible with the given plot richness (S ; Pielou 1966). Importance, density, cover, and diversity measures for the 38 paired sites were averaged for each soil type. Nomenclature follows Gleason and Cronquist (1991).

Soil Properties

Depth of the charcoal layer was measured with a soil probe at 0 m, 1 m, 3 m, and 5 m from hearth center along a randomly directed radial transect on each of the 38 hearth sites used for vegetation surveys. Six of the 38 paired sites were chosen for comparisons of soil physical and chemical properties on charcoal hearth and control soils. Soil pits were dug near a midpoint between the center and perimeter of the six paired hearth and control plots to a 40 cm depth for examination of the soil profile and removal of soil samples. One samples was removed from each of four ten-cm segments of the soil, i.e. 0-10 cm, 10-20 cm, 20-30 cm, and 30-40 cm. The top two samples were removed with an Uhland sampler which cuts a soil core of known volume for determination of bulk density and calculation of percentage pore space. Since the amount of rock increased greatly with depth, the device could not be used below 20 cm, and the two deeper samples were collected with a trowel. Soil physical

properties tested included bulk and particle densities, pore space, texture, and organic content. One-time measurements of soil chemical properties included pH, exchangeable acidity, base saturation, cation exchange capacity (CEC) exchangeable Ca, Mg, and K, and available P. Plant-available N was estimated with a buried bag incubation technique (Pastor et al. 1984) over a 3-month period from mid-May to mid August at four points on each of 3 hearth/control pairs. In order to estimate the chemical conditions of hearth soils following 19th century charcoal making, several liters of charcoal were also collected from a park demonstration hearth where new charcoal is produced twice yearly. Approximately five liters of this fresh charcoal were collected from the top ten cm at each of six randomly chosen spots on the demonstration hearth. Each sample was mixed before analyses. Six measurements were averaged for hearth soil, six for control soil, and six for fresh charcoal. A more detailed description of the methods of soil analysis used in this study can be found in Mikan (1993).

Statistical Analysis

Field vegetation parameters on the 38 paired hearth and control sites were compared using dependent t-tests with a pooled variance. Overall mean values for chemical properties of hearth soil, control soil, and fresh charcoal were compared using one-way analysis of variance; differences were determined by Fisher's least significant difference procedure with an individual error rate of 0.05 (Fisher 1949). Mean values of soil chemical and physical properties at various depths were compared for hearth and control soils with pooled variance, independent t-tests.

Dendrochronology

Two avenues are open to researchers desiring to date historic wooden structures with tree rings. One approach is to cross-date structural timbers with timbers contained in buildings of a known construction date, given an adequate period of overlap between the two chronologies. Alternatively, chronologies can be compared to the growth records of living trees, if old enough trees of the same, or closely related species, can be found nearby. For example, previous research has tentatively dated construction of the north wing of the ironmaster's house at HOFU (Bldg. 0001) to no earlier than 1799, based on correlations with tree-ring chronologies from the Hudson Valley in New York (Dessauer 1980). The aim of this study was to assemble a chronology from local living trees which could be used in the future dating of historic structures at HOFU. Because of the intense harvesting practices during the period of interest, trees of sufficient age could not be found within the boundaries of HOFU. A suitable 3-ha stand of chestnut oak (Quercus prinus (L.)) trees was found, however, in French Creek State Park on the steep northeastern slope of Mount Pleasure overlooking Hopewell Village (Figure 1). It is ironic that a stand in which many canopy trees predate establishment of the furnace in 1771 exists near the center of a several thousand-ha historic charcoal forest; it appears that the steep, rocky terrain may have protected this small presettlement-origin remnant from harvest. Forty-two chestnut oaks were cored for age determination and radial growth analysis. Twenty-eight cores from seven of the oldest, relatively sound trees were used to compile a radial growth index spanning 367 years. Methods used to generate the index and a description of the age structure and successional status of this stand can be found in Mikan et al (1994).

Presettlement Forest Composition

Original 18th century witness tree data from properties in and around Union Township were compiled from surveyors' plats, deeds, and township maps housed at the HOFU archives. The materials had a range of dates between 1733 and 1794 but most were from the period 1740 to 1780. Trees were by far the most common markers of boundary corners used by colonial surveyors of the area, although rock piles and posts were occasionally used. Many of the more common trees, especially the oaks, were abbreviated or given two letter codes, such as W O for white oak (Quercus alba (L.)), but were written out in full often enough to be sure of their meaning.

Results and Discussion

Pedestrian Surveys

Field reconnaissance uncovered 103 previously unidentified charcoal hearths and the remains of 13 colliers' huts in previously unsurveyed areas C, E, and G (Figures 1, 2, 3, and 5). Two hearths, features 56 and 57, were added to the existing list of features in area F (Figure 4), but no new features were discovered in the other well-studied areas A, B, or D. Of the 55 features in areas A, B, and F described by Heite (1988, 1989), nine hearths and three huts could not be located, putting the total inventory of charcoal features in HOFU forests at 141 hearths and 20 huts by the results of this study, or 150 hearths and 23 huts if the 12 missing features are included

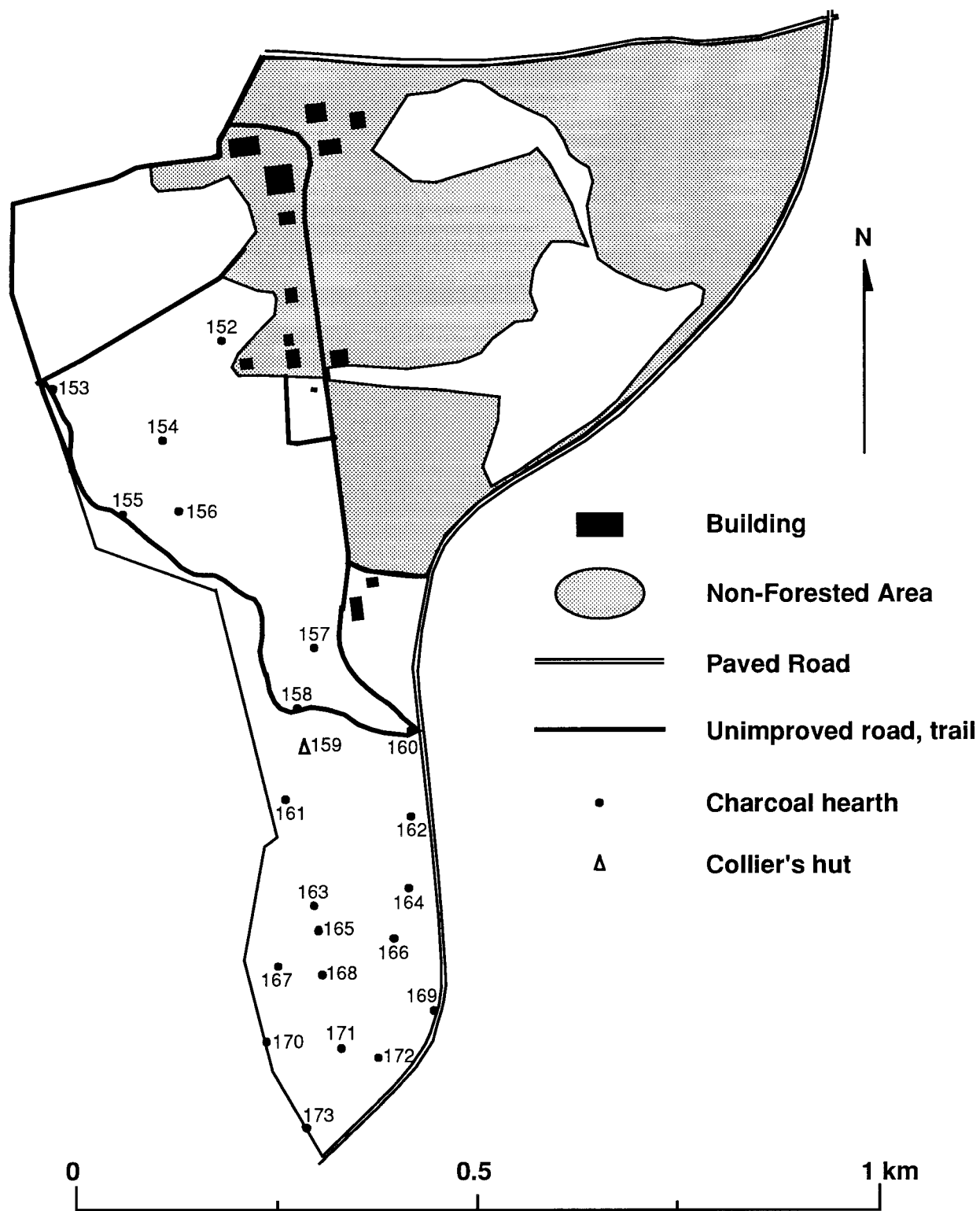


Figure 2. Charcoal Features in Area C, Hopewell Furnace National Historic Site.

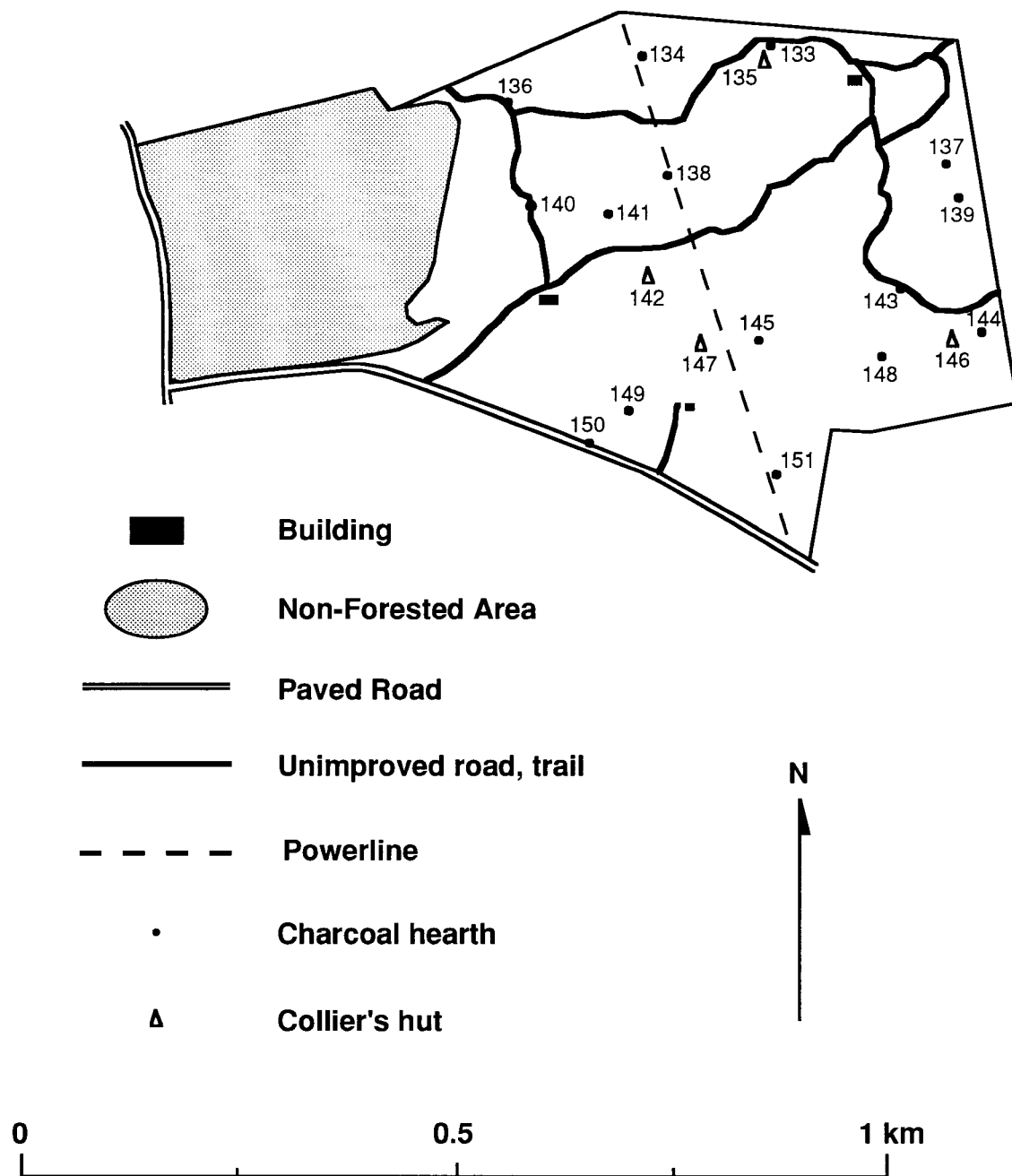


Figure 3. Charcoal Features in Area E, Hopewell Furnace National Historic Site

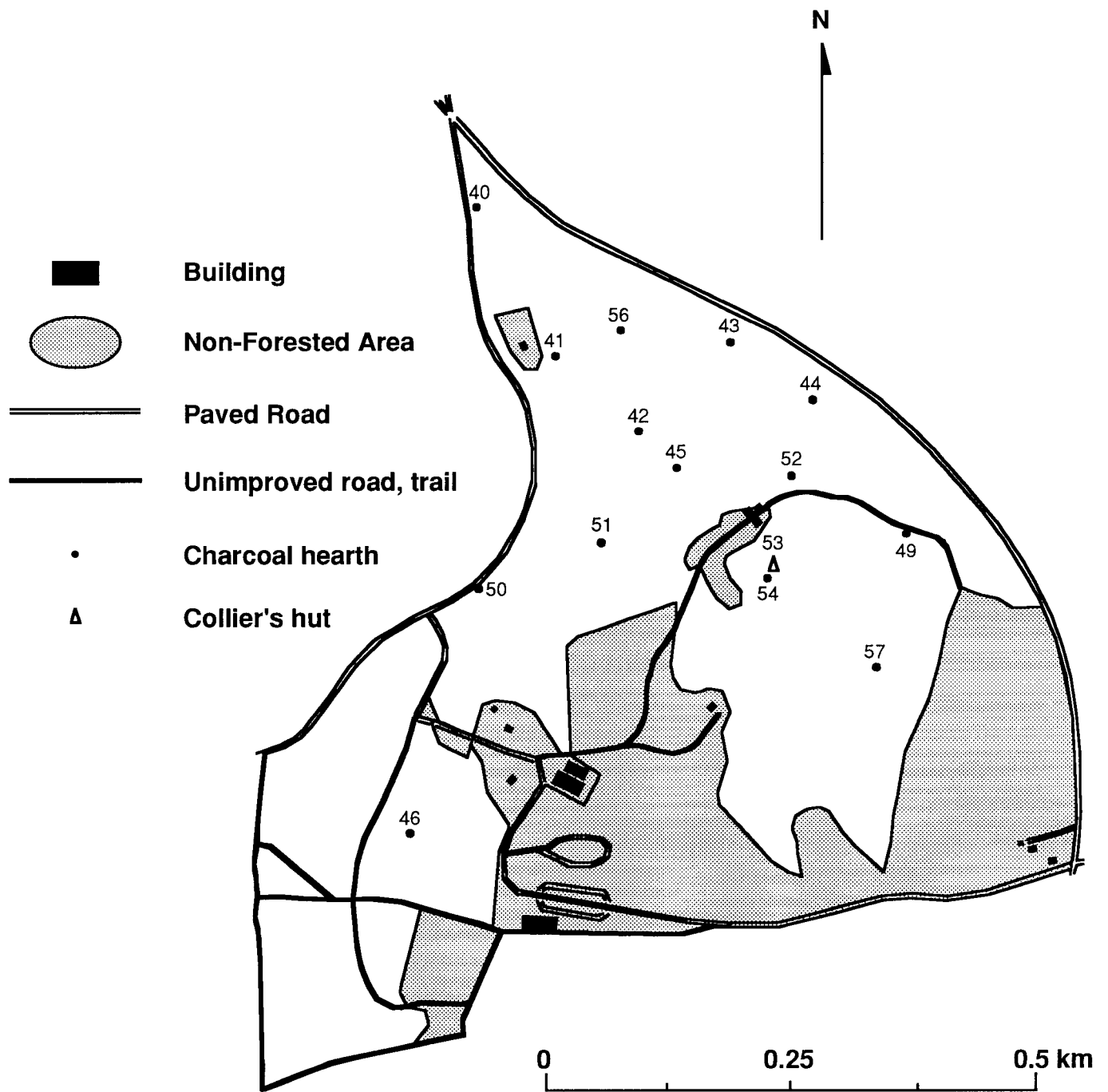


Figure 4. Charcoal Features in Area F, Hopewell Furnace National Historic Site

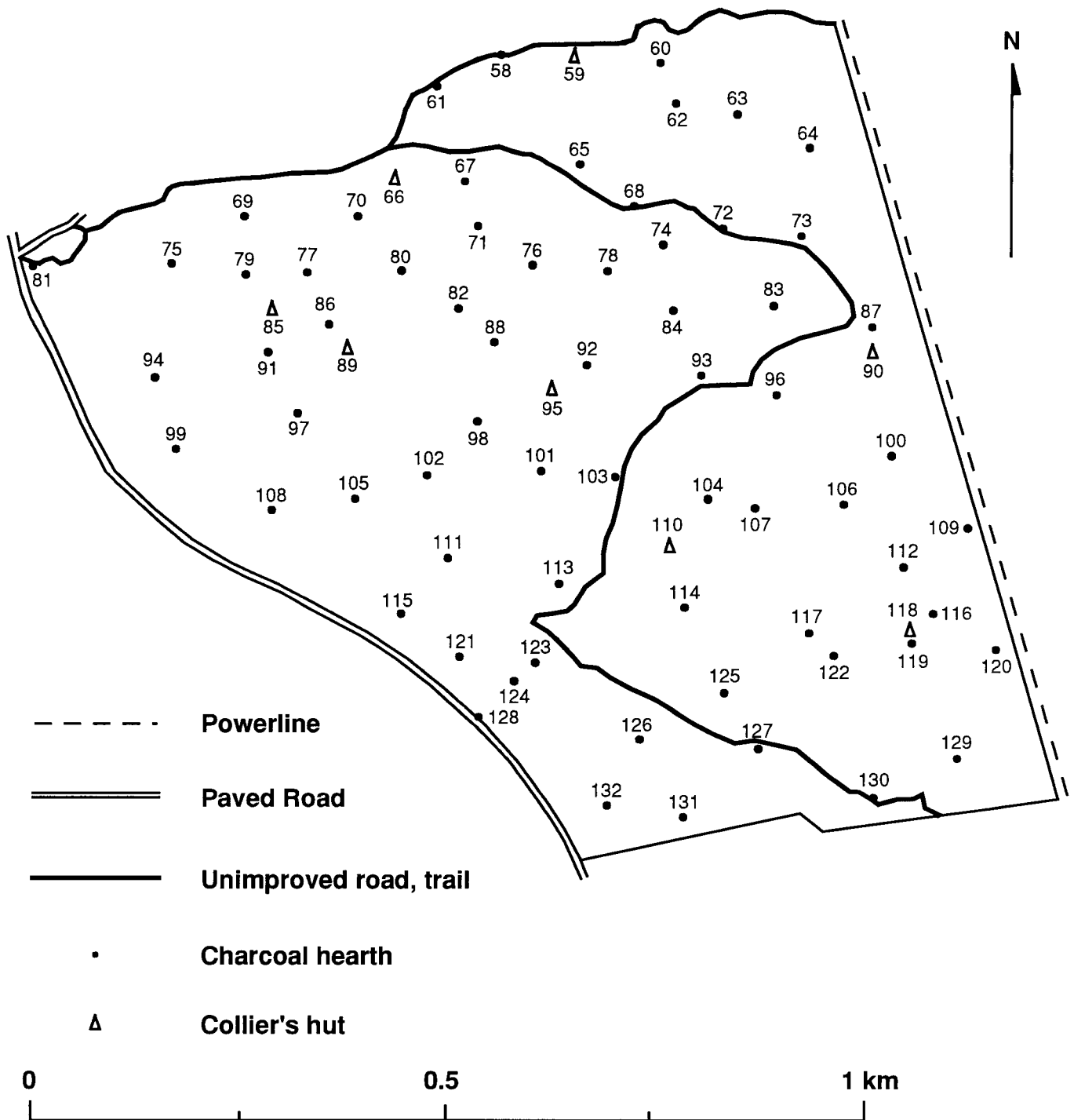


Figure 5. Charcoal Features in Area G, Hopewell Furnace National Historic Site

(Appendix B). Several factors may be responsible for the discrepancy in numbers of charcoal features. The principal reason is likely the definition of what constitutes a hearth. In this study the presence of a well-defined layer of charcoal soil in the surface 30 cm was considered to be a necessary criterion, as even small, poorly-shaped, or disturbed hearths would contain at least a thin layer of charcoal if they were ever used. Another factor may be that these surveys were conducted during the summer, as winter is judged a better time of year for the identification of surface features (Heite 1988). Although little time has passed since past surveys, natural disturbances such as tree uprooting may also be a factor obscuring previously identified features. Another difference is the placement of hearth F-49 (Figure 4); this study identified a large, disturbed charcoal hearth close to the Civilian Conservation Corps (CCC) road which may or may not be the same feature placed about 40 m to the south by Heite (1989). These differences, though small relative to the total number of features involved, emphasize the need for periodic inspection of these relatively remote features if they are important enough to be preserved for future study and interpretation of the charcoal iron industry at HOFU.

Hearths were best defined by their up- and downslope relief, although some hearths still retained a complete circular dust ring 10-15 cm high. Colliers probably created the dust rings by raking fine charcoal to the hearth perimeter after use as a courtesy and aid to colliers who would load wood piles during the next charcoal rotation (Heite 1989). Of the 141 hearths identified, 132 had borders sufficiently well defined for measurement. The smallest hearth had an area of 58 m² and the largest an area of 267 m². Hearths had average ($\pm$ standard error) long and short axes of 14.2 ± 0.17 m and 13.3 ± 0.15 m, respectively, with an average area of 150 ± 3 m² and an average ratio of long to short axes of 1.07 ± 0.01 . Thus, the typical hearth was

slightly elliptical with the longer axis oriented perpendicular to the slope. Regression analysis identified a weak but significant positive relationship between hearth ellipticity and percent slope ($r^2 = .11$; $p = .04$); hearths tend to be more elliptical as the degree of slope increased, with the ratio of long to short axes approaching one on flat terrain. Colliers may have recognized that narrow hearths perpendicular to slopes would have been more effective at preventing erosion, or the elliptical shapes may have simply been easier to construct on more steeply sloping sites. Results of the subjective rating of overall hearth condition and ease of identification showed a normal distribution with 72 % of the hearths (101 of 141) having an intermediate rating of 1.0, 1.5, or 2.0 (Appendix B). Poorly defined hearths with a rating of 0 or 0.5 comprised 15 % of the total (21 of 141) and hearths with excellent definition with a rating of 2.5 or 3.0 accounted for the remaining 13 % (19 of 141).

The 20 colliers' huts located in this study had minimum and maximum areas of 12.6 m² and 49.0 m², respectively, with average diameter of 6.3 ± 0.3 m and an average area of 31.7 ± 2.9 m². Five hut remains in section G showed several interesting features. The trench surrounding one hut, feature G-85, was interrupted by a raised area about 1m wide, suggesting a walkway to the hut entrance. From the raised platform of two huts, features G-59 and G-118, emerge concentrated stone piles, which may have formed a fireplace or chimney. Two other hut remains, features G-89 and G-90, have external U-shaped stone fire rings. These two structures do not resemble the fire rings made by the CCC in area E at HOFU, and probably date to the period of charcoal production.

The density of hearths in areas C and E (one hearth for every 2.7 ha and 2.6 ha, respectively) was very similar to results of previous studies at HOFU (Heite 1988, 1989) in areas A, B, and F. If only forested area is used in the analysis, the occurrence

increases to one hearth for every 1.7 ha (4.3 acres) in area C and one hearth for every 2.1 ha (5.2 acres) in area E. The completely forested area G showed a much higher density of charcoal hearths, with one hearth for every 1.1 ha (2.7 acres). The larger size of this area and its distance from the village probably make it a better representative of the density and distribution of hearths in forests managed by the furnace during its 112 years of operation.

Vegetation Comparisons

Vegetation differences between 38 paired hearth and control sites were present for the tree, sapling, shrub, and herbaceous strata (Table 1). Stocking of charcoal hearths was significantly reduced, with 62% of the average total tree density and 59% of the average total tree basal area of surrounding sites. Both density and basal area were also significantly reduced on charcoal hearths when the comparison was confined to trees which became established after the last year of iron production at Hopewell Furnace in 1883 (younger than 110 years old), or to trees 60 and younger. Sapling density and percentage shrub cover on charcoal hearths were also significantly reduced, averaging 72 % and 62 % that of controls, respectively. No significant difference was apparent in seedling density, but herbaceous cover on charcoal hearths was twice that of controls. Patterns of diversity reflected the overall reduction in woody vegetation on hearth soils, with both evenness and richness contributing to lower heterogeneity on hearths. Seedlings, which were not reduced in density, were also the only woody component not showing a significant decline in heterogeneity on hearths. Regression analysis identified a weak but highly significant negative relationship ($r^2 = .17$, $p < .01$) between seedling density and herbaceous

Table 1. Vegetation density, dominance, and diversity at Hopewell Furnace NHS¹. Means within a row ($\pm$ SE; n=38) having the same letter are not significantly different at $p < .05$. Densities are in no. ha⁻¹. Tree dominance is expressed as m² ha⁻¹. Shrub and herbaceous dominances are expressed as % cover. Diversity measures of heterogeneity and evenness follow Shannon and Weaver (1949) and Pielou (1966), respectively and were calculated using species importance values for trees, species densities for saplings and seedlings, and percentage covers for shrubs.

	Control	Hearth
<u>Density</u>		
Trees (all ages)	409 $\pm$ 32 a	252 $\pm$ 29 b
Trees (< 110 yrs.)	353 $\pm$ 34 a	250 $\pm$ 29 b
Trees ($\leq$ 60 yrs.)	47 $\pm$ 10 a	26 $\pm$ 8 b
Sapling Density	1051 $\pm$ 151 a	755 $\pm$ 168 b
Seedling Density	29053 $\pm$ 4065 a	33632 $\pm$ 4549 a
<u>Dominance</u>		
Trees (all ages)	28.3 $\pm$ 2.6 a	16.7 $\pm$ 2.1 b
Trees (< 110)	23.3 $\pm$ 2.3 a	16.6 $\pm$ 2.1 b
Trees ($\leq$ 60)	0.9 $\pm$ 0.2 a	0.4 $\pm$ 0.2 b
Shrub	48.0 $\pm$ 6.3 a	29.7 $\pm$ 5.0 b
Herbaceous	18.6 $\pm$ 3.9 a	37.4 $\pm$ 5.5 b
<u>Richness (S)</u>		
Tree	3.18 $\pm$ 0.16 a	1.87 $\pm$ 0.16 b
Sapling	3.16 $\pm$ 0.32 a	2.47 $\pm$ 0.34 a
Seedling	3.84 $\pm$ 0.32 a	4.21 $\pm$ 0.35 a
Shrub	2.74 $\pm$.021 a	1.87 $\pm$ 0.14 b
<u>Evenness (J')</u>		
Tree	0.68 $\pm$ 0.04 a	0.48 $\pm$ 0.07 b
Sapling	0.61 $\pm$ 0.06 a	0.48 $\pm$ 0.07 a
Seedling	0.72 $\pm$ 0.05 a	0.69 $\pm$ 0.05 a
Shrub	0.65 $\pm$ 0.05 a	0.47 $\pm$ 0.07 b
<u>Heterogeneity Index (H')</u>		
Tree	1.16 $\pm$ 0.08 a	0.59 $\pm$ 0.09 b
Sapling	1.17 $\pm$ 0.14 a	0.83 $\pm$ 0.15 b
Seedling	1.40 $\pm$ 0.13 a	1.46 $\pm$ 0.13 a
Shrub	0.96 $\pm$ 0.08 a	0.55 $\pm$ 0.08 b

1 Methods used to calculate these values are described in Appendix A.

cover on charcoal hearths; those hearths with increased herbaceous cover support fewer seedlings. This relationship was not present on control plots, nor were any other relationships between herbaceous and woody components present on either soil .

Charcoal hearth vegetation also differed in composition from surrounding control sites. On control plots, tree relative importance was shared nearly equally by black oak (Quercus velutina (Lam.)), white oak (Quercus alba (L.)), chestnut oak, red maple (Acer rubrum L.), tuliptree (Liriodendron tulipifera (L.)), black gum (Nyssa sylvatica (Marsh.)), and black birch (Betula lenta (L.))(Table 2). A significant decrease in importance of four of these overstory species is evident on hearth plots, with red maple and the three oaks showing only one third the relative importance of controls. Tuliptree was the only species in the tree class with a statistically significant increase in importance on hearth soils, although black birch also showed a sizeable increase. Among overstory species, black birch, black gum, tuliptree, and red maple dominated the sapling layer of control plots and, as elsewhere in the region, oaks were virtually absent from the sapling layer (Table 3). Non-canopy trees important to the sapling layer were witch hazel (Hamamelis virginiana L.), serviceberry (Amelanchier arborea (Michx. f.) Fern.), sassafras (Sassafras albidum (Nutt.) Nees), and flowering dogwood (Cornus florida L.). Red maple, serviceberry, and black gum saplings were significantly less common on charcoal hearths. Only flowering dogwood showed a significant increase in sapling density on charcoal hearths. Seedling densities between control and hearth plots were generally similar or, because of large variance, not statistically different; black oak seedlings, however displayed a significantly increased density on hearth soils (Table 4).

Table 2. Tree relative importance values on control and charcoal hearth soils at Hopewell Furnace NHS¹. Means within a row ($\pm$ SE; n=38) with the same letter are not significantly different at $p < .05$. Other species present included Betula alleghaniensis, Carya glabra, Carya tomentosa, Fraxinus pennsylvanica, and Populus grandidentata.

Species	Control	Hearth
<u>Acer rubrum</u>	14.1 $\pm$ 2.5 a	4.5 $\pm$ 2.0 b
<u>Betula lenta</u>	8.7 $\pm$ 2.9 a	14.2 $\pm$ 4.7 a
<u>Liriodendron tulipifera</u>	13.8 $\pm$ 4.0 a	34.7 $\pm$ 6.2 b
<u>Nyssa sylvatica</u>	10.6 $\pm$ 2.3 a	10.4 $\pm$ 3.8 a
<u>Quercus alba</u>	11.4 $\pm$ 3.3 a	3.5 $\pm$ 2.0 b
<u>Quercus coccinea</u>	5.1 $\pm$ 2.2 a	5.1 $\pm$ 3.1 a
<u>Quercus prinus</u>	10.1 $\pm$ 3.5 a	1.0 $\pm$ 1.0 b
<u>Quercus rubra</u>	5.7 $\pm$ 2.6 a	2.4 $\pm$ 1.4 a
<u>Quercus velutina</u>	16.7 $\pm$ 3.4 a	8.0 $\pm$ 3.5 b
<u>Sassafras albidum</u>	2.7 $\pm$ 1.3 a	2.6 $\pm$ 1.3 a
Others	1.1 $\pm$ 0.6 a	2.4 $\pm$ 1.0 a

¹ Methods used to calculate importance values are described in Appendix A.

Table 3. Sapling densities in no. ha⁻¹ on control and charcoal hearth soils at Hopewell Furnace NHS. Means within a row ($\pm$ SE; n=38) with the same letter are not significantly different at $p < .05$. Other species present, among which there were no significant differences, included Carpinus caroliniana, Carya glabra, Carya tomentosa, Castanea dentata, Fagus grandifolia, Fraxinus americana, Fraxinus pensylvanica, Prunus serotina, Prunus pensylvanica and Prunus virginiana.

Species	Control	Hearth
<u>Acer rubrum</u>	131 $\pm$ 32 a	41 $\pm$ 14 b
<u>Amelanchier arborea</u>	68 $\pm$ 29 a	27 $\pm$ 13 b
<u>Betula lenta</u>	206 $\pm$ 65 a	153 $\pm$ 54 a
<u>Cornus florida</u>	36 $\pm$ 14 a	94 $\pm$ 22 b
<u>Hamamelis virginiana</u>	74 $\pm$ 45 a	28 $\pm$ 12 a
<u>Liriodendron tulipifera</u>	153 $\pm$ 36 a	197 $\pm$ 52 a
<u>Nyssa sylvatica</u>	192 $\pm$ 24 a	35 $\pm$ 20 b
<u>Quercus prinus</u>	15 $\pm$ 8 a	3 $\pm$ 3 a
<u>Quercus rubra</u>	2 $\pm$ 2 a	12 $\pm$ 10 a
<u>Quercus velutina</u>	3 $\pm$ 3 a	7 $\pm$ 7 a
<u>Sassafras albidum</u>	54 $\pm$ 16 a	48 $\pm$ 29 a
Others	117 $\pm$ 29 a	110 $\pm$ 22 a
Total	1051 $\pm$ 151 a	755 $\pm$ 168 b

Table 4. Seedling densities in no. ha⁻¹ on control and charcoal hearth soils at Hopewell Furnace NHS. Means within a row ($\pm$ SE; n= 38) with the same letter are not significantly different at $p < .05$. Other species present among which there were no significant differences included Carpinus caroliniana, Carya glabra, Fagus grandifolia, Fraxinus americana, Fraxinus pennsylvanica, Prunus serotina, Prunus pennsylvanica, Prunus virginiana, Quercus coccinea and Tsuga canadensis.

Species	Control	Hearth
<u>Acer rubrum</u>	8316 $\pm$ 2179 a	11421 $\pm$ 2549 a
<u>Amelanchier arborea</u>	105 $\pm$ 73 a	514 $\pm$ 342 a
<u>Betula lenta</u>	500 $\pm$ 273 a	211 $\pm$ 101 a
<u>Cornus florida</u>	105 $\pm$ 105 a	895 $\pm$ 790 a
<u>Hamamelis virginiana</u>	158 $\pm$ 89 a	316 $\pm$ 267 a
<u>Liriodendron tulipifera</u>	3947 $\pm$ 1120 a	3421 $\pm$ 889 a
<u>Nyssa sylvatica</u>	3632 $\pm$ 1106 a	3184 $\pm$ 675 a
<u>Quercus alba</u>	947 $\pm$ 521 a	1000 $\pm$ 527 a
<u>Quercus prinus</u>	4053 $\pm$ 2350 a	526 $\pm$ 209 a
<u>Quercus rubra</u>	1526 $\pm$ 468 a	2882 $\pm$ 689 a
<u>Quercus velutina</u>	289 $\pm$ 136 a	1000 $\pm$ 352 b
<u>Sassafras albidum</u>	3842 $\pm$ 1170 a	4789 $\pm$ 1394 a
Others	1633 $\pm$ 1109 a	3473 $\pm$ 1783 a
Total	29053 $\pm$ 4065 a	33632 $\pm$ 4549 a

Of the 14 shrubs present, black huckleberry (Gaylussacia baccata (Wang.) K. Koch), azaleas (Rhododendron spp.), and blueberries (Vaccinium spp.) were significantly more abundant on control plots (Table 5). The herbaceous layer was dominated by mosses, grasses, and the hay-scented fern (Dennstaedtia punctilobula ((Michx.) Moore)) on both soils. Other important herbs present were bedstraws (Galium spp. (L.)), wood-sorrel (Oxalis spp. (L.)), violets (Viola spp. (L.)), hog-peanut (Amphicarpa bracteata (L.) Fern.), jack-in-the-pulpit (Arisaema triphyllum (L.) Schott.), cinquefoils (Potentilla spp (L.)), and wild sarsaparilla (Aralia nudicaulis (L.)). Greater herbaceous cover on charcoal hearths relative to control plots was due largely to an increase in mosses and grasses.

Age Structure of Charcoal Forests

Age and diameter distributions of hearth and control tree populations show differences in age, recruitment patterns, and composition (Figure 6). While the mean age ($\pm$ SE; $n=161$ for control, $n=100$ for hearth) of all control trees (82.1 ± 1.9 yrs.)was significantly higher than that of all hearth trees (72.4 ± 1.5 yrs.), the difference was lessened by relatively greater recent recruitment on control plots. The age difference arose mainly from the lack of an older generation of oaks on hearths predating the end of charcoal production. Both populations have roughly normal age distributions in which recruitment peaked in the decade from 1910 to 1920, although recruitment of control trees was interrupted from 1890 to 1900. The loss of oak dominance and the increase in the importance of tuliptree on hearths can be seen in Figure 6 B and C. Also, significant oak recruitment ended around 1930 with the cessation of cutting. At

Table 5. Percentage cover of common shrubs found on control and charcoal hearth soils at Hopewell Furnace NHS. Means ($\pm$ SE; n=38) within a row having the same letter are not significantly different at $p < .05$. Other species present included Kalmia latifolia, Celastrus orbiculatus, Rhus radicans, Rosa spp. and Smilax rotundifolia.

Species	Control	Hearth
<u>Gaylussacia baccata</u>	8.7 $\pm$ 3.4 a	0.5 $\pm$ 0.4 b
<u>Lindera benzoin</u>	2.7 $\pm$ 1.4 a	2.4 $\pm$ 1.4 a
<u>Parthenocissus cinquefolia</u>	2.5 $\pm$ 1.1 a	1.4 $\pm$ 0.7 a
<u>Rhododendron</u> spp.	4.9 $\pm$ 1.3 a	1.2 $\pm$ 0.7 b
<u>Rubus</u> spp.	4.1 $\pm$ 1.5 a	5.1 $\pm$ 1.7 a
<u>Vaccinium</u> spp.	12.8 $\pm$ 2.9 a	5.0 $\pm$ 3.0 b
<u>Viburnum acerifolium</u>	7.3 $\pm$ 2.4 a	7.5 $\pm$ 2.1 a
<u>Viburnum prunifolium</u>	2.4 $\pm$ 1.4 a	4.3 $\pm$ 2.4 a
<u>Vitis</u> spp.	2.3 $\pm$ 2.3 a	1.8 $\pm$ 1.6 a
Others	0.3 $\pm$ 0.1 a	0.5 $\pm$ 0.1 a
Total	48.0 $\pm$ 6.3 a	29.7 $\pm$ 5.0 b

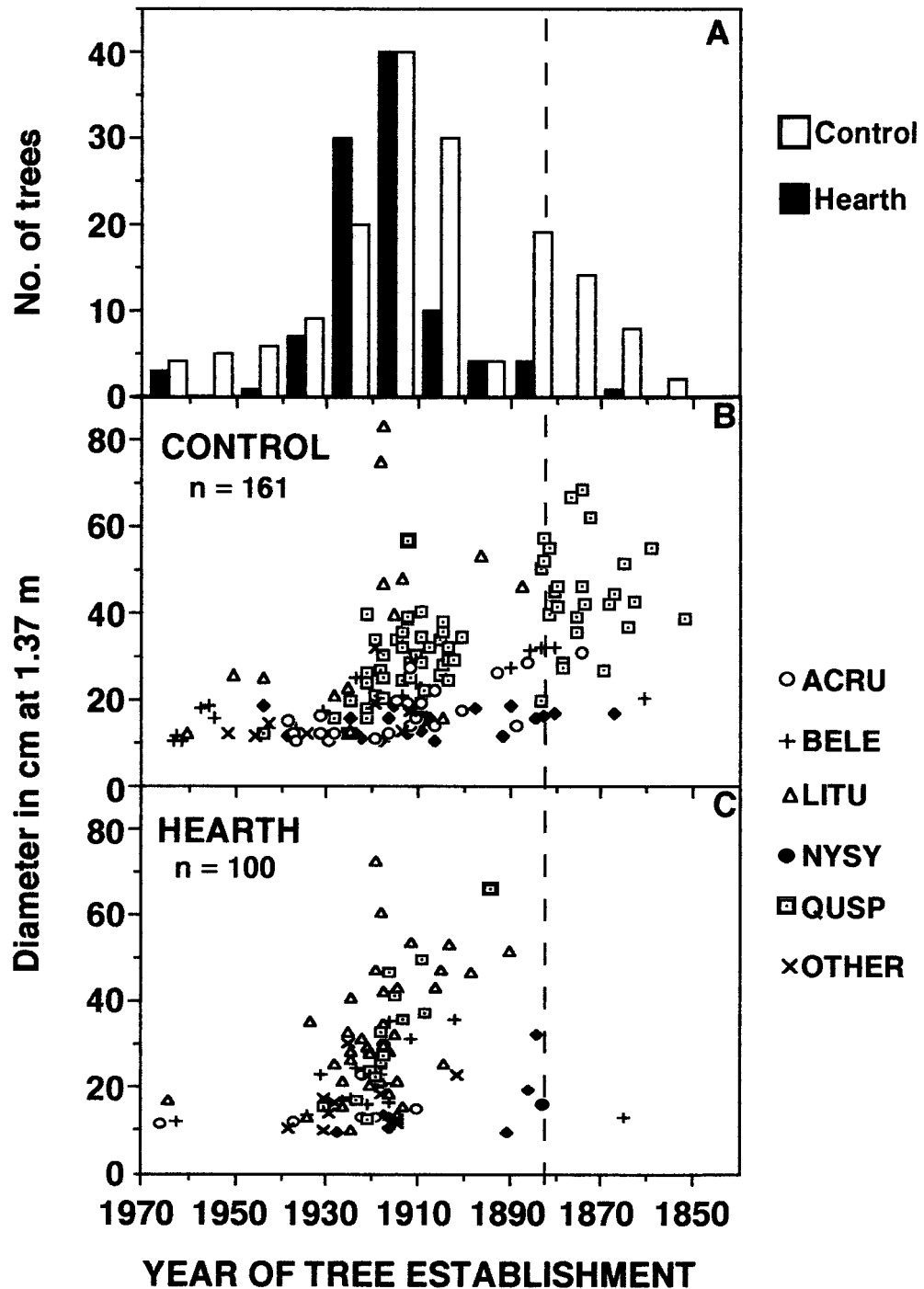


Figure 6. Age distributions and age-diameter relationships of all trees occurring in 38 paired control and charcoal hearth plots at Hopewell Furnace NHS. Species designations are as follows: ACRU: Acer rubrum, BELE: Betula lenta, LITU: Liriodendron tulipifera, NYSY: Nyssa sylvatica, QUSP: Quercus spp. **OTHER** included B. allegheniensis, Carya spp., Fraxinus pensylvanica and Populus grandidentata. The dashed line indicates the last year of major charcoal production, 1883.

this point, recruitment by black birch, tuliptree, and red maple occurred on control plots but was nearly absent from charcoal hearths.

Examination of tree age structure on a site basis gives results which are also consistent with our knowledge of cutting history in the forests at HOFU. A mosaic of coppice forests of different ages was apparently created by the last charcoal harvests of the industry (Table 6). The oldest trees in the park were found in cultural resource areas B and G, with average ages of 130 years and 127 years, respectively. The forests of area A, which were owned by a neighboring furnace and continued to support charcoal harvests until early years of this century, had a more variable, younger distribution of ages, with the oldest trees averaging 106 years. Area F forests were intermediate in age, with the oldest trees being very close in age to the area average of 113 years; it appears that the forest represented by these eight stands in area F was clear cut as a whole around 1880.

Soil Properties

Charcoal layers of the 38 hearths used in vegetation surveys extended an average 11.6 ± 1.9 cm below the organic layer. Physical properties on a smaller set of hearth soils differed from control soils to the extent of the depth of the charcoal layer, generally producing significant differences in the 0-10 cm and 10-20 cm samples ($n = 6$; Figure 7). Charcoal layers in all six cases appeared uniform to the eye; the original surface soil horizons have not yet been reestablished. One of the six hearths on which soil pits were dug, feature A-20, contained two distinct charcoal layers; a deeper charcoal layer 11 cm thick was separated from the surface charcoal layer by 8 cm of subsoil. Particle density was significantly reduced on hearth soils to a 10-cm depth, as

Table 6. Tree ages at 38 sites in Hopewell Furnace NHS. Nearby trees were located no farther than 30 m from hearth and control overstory plot perimeters.

Site	Number of Trees		Average Age		Oldest Nearby Tree
	Hearth	Control	Hearth	Control	
A-14	4	1	79	75	91
A-16	3	7	69	74	127
A-17	2	5	82	73	86
A-18	1	11	71	89	133
A-19	3	5	79	84	88
A-20	3	7	67	85	121
A-23	2	6	85	82	115
A-24	3	7	74	81	87
A-26	1	3	66	112	122
A-27	5	4	62	66	117
A-30	6	3	71	71	76
A-34	5	5	72	70	98
A-35	0	3	---	75	116
A-37	2	3	96	113	119
A-38	1	7	85	84	87
B-1	2	3	70	97	134
B-2	6	3	69	68	119
B-3	10	4	71	65	133
B-4	4	7	71	70	131
B-7	2	4	73	74	133

Table 6. (continued)

Site	Number of Trees		Average Age		Oldest Nearby Tree
	Hearth	Control	Hearth	Control	
F-41	3	3	90	67	112
F-42	1	7	93	77	113
F-43	1	5	73	83	113
F-44	5	5	80	79	113
F-45	3	4	74	99	111
F-52	3	3	87	78	110
F-51	3	3	65	96	114
F-56	1	5	57	87	115
G-60	3	6	66	88	126
G-67	1	4	74	87	136
G-78	2	2	26	53	131
G-91	3	3	76	73	131
G-96	5	7	86	77	123
G-98	3	5	67	87	130
G-99	0	4	---	112	140
G-124	2	4	79	90	130
G-129	4	8	65	78	111
G-132	0	4	---	109	116

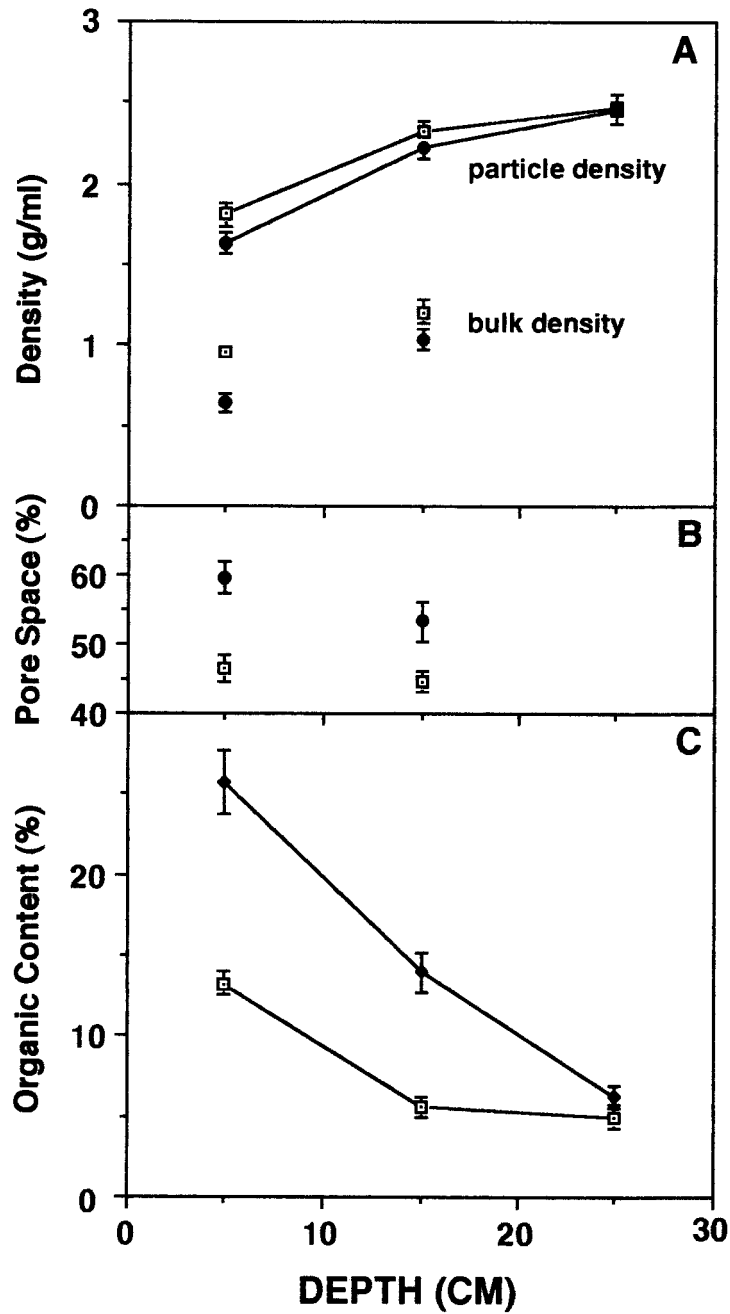


Figure 7. Soil physical properties on historic charcoal hearths (●) and controls (□) at Hopewell Furnace NHS. Mean values ($\pm$ SE; $n=6$) are plotted at the midpoints of 10 cm samples taken from 0 - 10 cm, 10 - 20 cm, and 20 - 30 cm.

was bulk density to a 20-cm depth. Pore space and organic content were significantly higher to 20 cm on hearth soil. Surface horizons (0 - 20cm) of both hearth and control soils exhibited a sandy loam texture, with 57 % sand, 34 % silt and 9 % clay.

Hearth soils were significantly higher in overall pH and this difference increased with depth to 40 cm (Figure 8A). Exchangeable acidity was generally lower on hearth soils, with a significant increase at the surface and significant decreases at deeper portions of the soil profile (Figure 8B). The sources of exchangeable acidity were similar in hearth and control soils; 86.4 ± 2.1 % (n=6) and 85.7 ± 2.0 % (n=6) of exchangeable acidity in hearth soils and control soils, respectively, was due to Al^{3+} ions. Sources of exchangeable acidity also did not vary with depth for either soil. Overall mean base saturation was significantly greater on hearth soils and increased dramatically with depth (Figure 8C). Cation exchange capacity was consistently greater for hearth soils although by only small margins at the intermediate depths (Figure 8D). Large overall increases in mean exchangeable base cations Ca and Mg and modest increases in mean K resulted on hearth soils (Figures 8E, F, and G). Control soils exhibited their largest pools of all three exchangeable cations at the surface but on hearth soils Ca and Mg levels increased greatly with depth (Figure 8). The distribution of K with depth, however, was similar for both soils (Figure 8). The soil incubation experiment revealed no significant differences in N availability between charcoal hearth and control soils during a three month period. Control soils mineralized 46.6 ± 11.1 kg N ha⁻¹ compared to 36.2 ± 5.9 kg N ha⁻¹ for hearth soils, the difference largely due to decreased net nitrification on hearths (n=12). Available P levels did not differ, with control and hearth soils having 25.2 ± 4.3 kg ha⁻¹ and 23.2 ± 3.2 kg ha⁻¹, respectively (n=6). Despite significant differences in exchangeable cation content, electrical conductivities of saturated soil pastes did not differ significantly

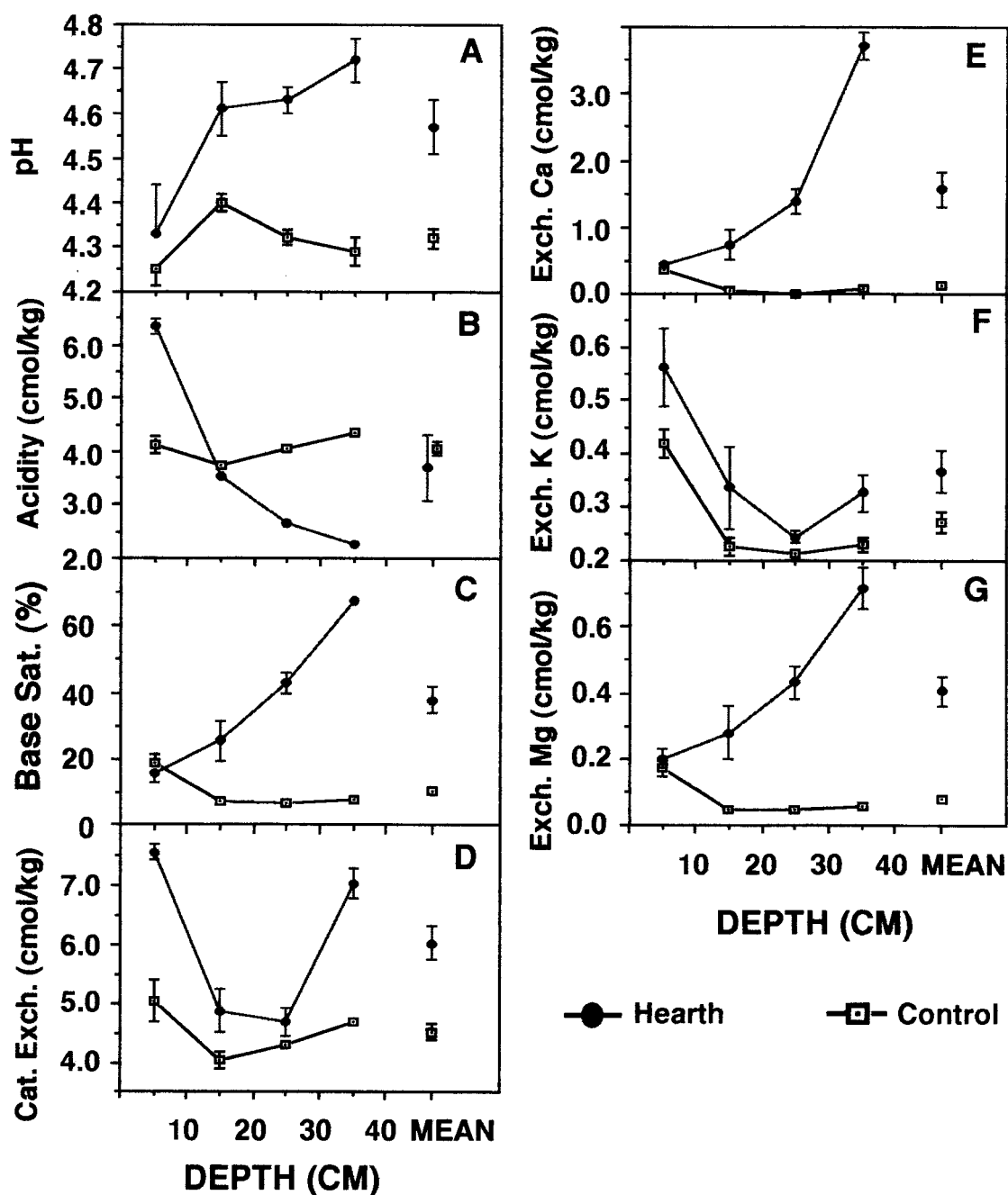


Figure 8. Soil chemical properties on historic charcoal hearth and control soils at Hopewell Furnace NHS. Mean values ($\pm$ SE; $n=6$) are plotted at the midpoints of four 10 cm samples taken from 0-40 cm. Overall MEANS ($\pm$ SE; $n=24$) are averages of values at all depths. Acidity, cation exchange capacity, and exchangeable Ca, K, and Mg are expressed in centimoles of + charge per kilogram of soil.

between hearth and control soils, averaging $0.20 (\pm 0.06) \text{ dS m}^{-1}$ and $0.26 (\pm 0.05) \text{ dS m}^{-1}$, respectively (n=6).

Chemical characteristics of fresh charcoal reflected its high ash content, with a greatly elevated pH of 7.8 (n=6). Fresh charcoal had $24.5 \text{ cmol kg}^{-1}$ of exchangeable Ca, a 60-fold increase over control surface soil (n=6). Mg and K levels of fresh charcoal were also elevated relative to control surface soils, with significant 14-fold and 2-fold increases, respectively (n=6). Fresh charcoal exhibited an electrical conductivity much higher than both charcoal hearth and control soils, as to be expected from the high soluble salt content, averaging $1.71 (\pm 0.34) \text{ dS m}^{-1}$ (n=6). See Bohn (1985) for a description of the standard soil chemistry units used here.

Presettlement Forest Composition

The 513 trees tallied from the records of colonial land surveyors' represented 18 species noted in the forests in and around Union Township, Berks County, Pennsylvania from 1733 to 1794, and are presented as they appeared on the original materials (Table 7). A third of all witness trees were black oaks (Quercus velutina Lam.). White oak (Quercus alba L.), American chestnut (Castanea dentata (Marsh.) Borkh.) , and hickories (Carya spp.) taken together accounted for nearly half of all witness trees. Chestnut oak and Spanish oak (probably pin oak, Quercus palustris Muenchh.) were important but mentioned in lower numbers. The remaining 12 trees were relatively uncommon and together accounted for less than 10 % of all witness trees. Although 18th century surveyors may have favored large, long-lived trees for boundary corners, it appears that presettlement forests of the Hopewell area were dominated by oaks, American chestnut, and hickories, and they probably contained

Table 7. Species percentages of 513 witness trees used by colonial land surveyors in and around Union Township, Berks County, Pennsylvania, from 1733 to 1794.

Species	% of Total
Black oak	33.1
White oak	16.6
Chestnut	15.4
Hickory	14.6
Chestnut oak	6.8
Spanish oak	4.3
Gum	1.8
Poplar	1.2
Scarlet oak	1.0
Ash	1.0
Birch	1.0
Maple	1.0
Walnut	0.8
Sugar tree	0.6
Buttonwood	0.2
Ironwood	0.2
Lightwood	0.2
Yew	0.2

little birch or maple. Frequent cutting of area forests during the charcoal iron era, alone or in concert with fire, maintained the dominance of oaks in the region (Day 1929, Russell 1980). Compositional shifts towards mesophytic species which began around the turn of the 20th century may be related to the adoption of fire suppression and the cessation of harvest, and are continuing under oak canopies of regional forests up to the present day (Russell and Schuyler 1988, Nowacki and Abrams 1991, Mikan et al. 1994).

Altered Successional Response

The unique vegetation and edaphic properties of charcoal hearths at HOFU are related to variations in disturbance frequency and severity and resultant successional processes in the century since the end of the charcoal iron era. Whereas control sites were clear cut every 25 or 30 years, amounting to four or five disturbances over the history of the furnace, charcoal hearths may have been disturbed 50 times, based on hearth size and density, and estimates of forest productivity (Heite 1988). Although soil disturbance undoubtedly accompanied harvest, and fire was likely a force that widely affected Pennsylvania charcoal forests (Pearse 1876, Birkinbine 1896, Nowacki and Abrams 1991), the production of charcoal in earthmound kilns represented a markedly more severe disturbance regime. As the process included the disturbance or removal of organic layers and mineral horizons, and soil compaction and heating, these recurrent disturbances had the potential to delay recovery of forest vegetation or alter its composition.

Fire has describable effects on the physical, chemical and biological properties of soil which can be applied to the analysis of disturbance and recovery of charcoal hearth vegetation. One factor delaying the initial revegetation of charcoal hearths may have been destruction of buried seed banks which serve important functions such as the conservation of diversity and the stabilization against erosion and nutrient loss following disturbance (Marks 1974, Fenner 1985, Hills and Morris 1992). Temperatures between 400 °C and 450 °C generated by the one- to two-week coaling process would have been sufficient to eliminate the soil seed bank (Beadle 1940, Sampson 1944). By eliminating soil seed banks and vegetative structures capable of regrowth after overstory removal, hearth plant communities could not unfold from elements existing prior to the disturbance.

Two other factors are likely to have inhibited hearth regeneration following abandonment. One is the widely observed post-fire elevation of maximum surface temperatures (Ahlgren and Ahlgren 1960). By removing shading vegetation, consuming insulating litter and organic matter of the forest floor, exposing dark mineral soils, or depositing charred residue, fire can create surfaces that are highly absorptive of insolation (Lutz 1956, Scotter 1963, Raison et al. 1986). Maximum midday temperatures have been observed to increase by 3 °C to as much as 17 °C for up to 20 years in response to fire (Ahlgren 1974). In temperate deciduous and other forests lacking thick organic layers, surface soils exposed by fire may be heated to temperatures lethal to tree seedlings (Isaac 1929, Isaac and Hopkins 1937, McCullogh 1944, Sims 1975). Lacking insulation and vegetative cover, it is likely that the blackened surfaces of charcoal hearths experienced temperature extremes in the period following abandonment until inputs of litter from surrounding vegetation reestablished the forest floor. Along with elevated surface temperatures, the release of

soluble salts probably acted to create a surface chemical environment hostile to regeneration. Soluble salts harm plants principally by lowering water availability. Measures of electrical conductivity in fresh charcoal were high enough to suggest that these soils would have been toxic to seedlings in the period following charcoal production.

Differences in age structure and composition support this interpretation of different initial successional responses of hearth and control sites. The last year of iron production at Hopewell, 1883, is used as a reference year representing the end of major charcoal production, although small areas within the current boundaries of the park were coaled by neighboring furnaces until the early 20th century, followed by widespread selective logging until the mid 1930s (Walker 1966). The multi-stemmed canopy dominant and codominant oaks predating 1883 were numerous on control plots, suggesting that they sprouted from stumps after the final charcoal clearcuts of the era (Figure 6B). The lack of oak recruitment from 1883 to 1900 probably reflects a period of decreased logging; land use was shifting from fuel harvests to the removal of timbers at a time when the supply of larger diameter stems in the recovering coppice forests would have been limited. A portable sawmill was employed in selective logging early in the 20th century at Hopewell (Heite 1989), and a period of heavy oak recruitment occurred from 1900 to 1930. Interestingly, it is only after intense harvesting for charcoal ended that non-oak species began to invade control and charcoal sites alike. During this period black gum, tuliptree, red maple, and black birch began to recruit in significant numbers on control plots.

In contrast to recruitment patterns on control plots, the absence of significant oak recruitment on charcoal hearths until around 1910 gives evidence that vegetative structures capable of sprouting had been eliminated by recurrent charcoal production (Figure 6C). The twofold difference in total tree recruitment during the period immediately after hearth abandonment and beyond (17 on controls vs 7 on hearths from 1883 to 1900) illustrates the delay of tree recolonization on hearth soils. The presence of numerous tuliptrees suggests that this species may have benefitted from an exposed seedbed, high light environment, and lack of competition from well rooted sprouts in becoming established on abandoned charcoal hearths. Characteristics of tuliptree that allow it to regenerate quickly after fire, colonize gaps, and persist through later successional stages have been noted by others (Little 1967, Shearin et al. 1972, Buckner and McCracken 1978, Skeen et al. 1980).

The present decreased sapling density on charcoal hearths suggests that hearth seedlings are still experiencing increased mortality relative to control seedlings, and are failing to recruit into the sapling size class in equal numbers; some unfavorable soil condition is still preventing the normal development of forest vegetation on charcoal hearths. A cumulative effect of this unfavorable condition is demonstrated by the fact that only half as many trees have recruited in the last 60 years on charcoal hearths as on control sites.

Results of this study did not indicate any unfavorable physical properties, such as compaction or poor drainage, and in general indicated a light soil with favorable air and water relations. If changes in soil texture were caused by the heat of coaling, these changes have been reversed in the intervening century, as hearth and control soil textures in the strict sense do not presently differ. Chemical properties, however, still show dramatic differences. It is likely that the increased pH and availability of base

cations is affecting the productivity of hearth soils by creating subtle changes in soil nutrient availability, uptake, and balance within plants. For example, the ericaceous shrubs showing markedly decreased abundance on hearth soils are known to grow poorly in areas where Ca availability is high. Also, large changes in P availability such as that demonstrated in fresh charcoal are known to cause problems in the uptake and metabolism of several micronutrients (Adams 1980).

Most studies of post-fire soil chemistry have shown that the pH of surface soils returns to pre-fire levels in a few years (Wells et al. 1979). That hearth soils at HOFU are still significantly less acidic (albeit only slightly) and have retained a higher base cation content than control soils after a century probably reflects both the large volumes of ash deposited and the delay in reestablishing forces that acidify forest soils, such as the decomposition of organic material and leaching of base cations.

The negative correlation between herbaceous cover and seedling density observed on charcoal hearths suggests that increased herbaceous vegetation may presently be inhibiting woody regeneration. If this were the case, however, the relationship with herbaceous cover would be expected to hold for sapling density and shrub cover on hearths as well. As grasses and mosses tends to dominate hearths where they occur, these plants may be inhibiting successional replacement (cf. Connell and Slatyer 1977) or may simply be preadapted to the unique soil chemistry and physical properties of abandoned hearth soils.

Preservation

The severity of the disturbances which created charcoal hearths and their unique edaphic properties have acted together to preserve them in relatively good condition; most hearths are easily identified even through the dense vegetation of the summer season. At the present, those hearths which are poorly defined are nearly all the result of human disturbance. Several hearths located near Route 345 were disturbed during road building and have since stabilized. Others are located along or are bisected by major trails and have been continuously disturbed by decades of pedestrian, animal, and bicycle traffic. These hearths are few in number and have probably already lost much of their value as cultural resources. The long-term threat to the majority of hearths, however, is the main natural force which disturbs forest soils in our area - the uprooting of large trees by wind. Soil mixing by uprooting is a slow process; the passage of several hundred years and several generations of trees will probably occur before most hearths are significantly damaged or unrecognizable due to windthrow. On a few hearths, however, the mixing of surface and subsoil caused by uprooting has already begun to obscure the margins and the distinct charcoal layer. As the current generation of hearth trees (mainly tuliptrees) begins to decay, windthrow will undoubtedly damage numerous hearths at HOFU. Hearth preservation may thus require the removal of large trees which are growing on or within several meters of the hearths, before they are uprooted. If this strategy were adopted, periodic inspections at 3-5 year intervals and removal of tree regeneration would be necessary for long-term preservation. Trees should be felled away from the hearth surfaces, and large amounts of wood and litter should be removed to prevent the buildup of organic matter and the development of a normal forest floor. Care should be taken to minimize

soil disturbance by falling trees, human and vehicular traffic, and by dragging logs. Complete vegetation removal is not recommended. Many hearths are only sparsely covered with herbs and shrubs; these plants help to stabilize the soil against erosion.

Conclusion

The repeated use of earthmound kilns for over 100 years has had both immediate and long-lasting effects on the vegetation and edaphic properties of charcoal hearths at HOFU. The cumulative effects of as many as 50 separate disturbances are presently reflected in the altered composition, age structure, and decreased abundance of woody vegetation on charcoal hearths. High temperatures achieved during the coaling process sterilized hearth soils and killed the soil seed bank and vegetative structures that were important historically in the rapid revegetation of area forests. At the same time, the release of large quantities of soluble salts in ash and the exposure of blackened soil surfaces created a hostile soil environment; salt stress and elevated surface temperatures further delayed the recolonization of hearth soils in the post-abandonment period. The unique soil chemistry of charcoal hearths appears to have had long-term negative effects on the survival and recruitment of trees into sapling and tree classes. The altered forest succession on hearth soils may thus be analogous to serpentine communities, in which compositional changes and stunted growth forms are believed to be the result of elemental deficiencies and toxicities.

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Appendix A
Abundance and Diversity Measures

Species importance values (IV) and measures of woody plant diversity were calculated for each plot as follows:

$$\text{Relative IV} = \frac{\text{relative density} + \text{relative dominance}}{2}, \text{ where}$$

$$\text{Relative density} = \frac{\text{\# individuals of a particular species}}{\text{sum of individuals of all species}}, \text{ and}$$

$$\text{Relative dominance} = \frac{\text{basal area of a particular species}}{\text{sum of basal areas of all species}}.$$

These abundance measures are usually reported after multiplying by 100 %.

Richness (S) is the total number of species occurring in a given plot.

The Heterogeneity Index (H') is calculated by summing the products of relative importance (in the case of trees) or relative density (for saplings, seedlings, and shrubs) and the base 2 logarithm of the same abundance measure.

$H' = - \sum p_i (\log_2(p_i))$: The - sign creates a positive value. The higher H', the more diverse the community. By taking the logarithm of the abundance measure, this type of diversity index will be higher not only when more species are present (higher richness) but also when abundance is shared more equally between species.

Evenness (J') is a measure of the degree to which abundance is shared among co-occurring species, and is calculated by dividing H' by its maximum value possible given the number of species on a plot. For example, a plot with four species would have a maximum heterogeneity of 2 if each species had a relative density of 0.25. A plot in which one species' relative density is 0.70 and each of the other three has relative densities of 0.10 yields $H' = 1.36$, somewhat less than the maximum possible. Evenness, then, is $1.36 / 2$, or 0.67.

Appendix B

Summary of Features

Summary of charcoal hearths and colliers' huts at Hopewell Furnace National Historic Site¹.

Area	No.	Feature	Aspect	Width (meters)		Condition
				Parallel	Perpendicular	
A	10	hearth ²	flat	6.1	6.1	
A	11	hearth ²	flat	9.1	9.1	
A	12	hearth ²	flat	9.1	9.1	
A	13	hearth ²	flat	10.1	6.7	
A	14	hearth	270	11.0	6.7	2.0
A	15	hearth	270	13.4	14.3	0.5
A	16	hearth	270	11.3	11.3	2.5
A	17	hearth	315	9.8	11.9	2.0
A	18	hearth	flat	12.8	12.8	2.0
A	19	hearth	180	12.5	13.1	1.5
A	20	hearth	flat	14.9	12.2	1.5
A	22	hearth	flat	12.8	11.0	0.5
A	23	hearth	225	14.0	14.0	2.0
A	24	hearth	315	11.3	11.3	2.5
A	26	hearth	flat	10.7	8.5	0.5
A	27	hearth	90	13.1	13.1	3.0
A	28	hearth ²	135	13.4	13.4	
A	29	hearth	135	12.2	12.2	2.0
A	30	hearth	135	11.6	13.4	2.5

Area	No.	Feature	Aspect	Width (meters)		Condition
				Parallel	Perpendicular	
A	31	hearth ²	flat	12.8	12.2	
A	33	hearth ²	flat	10.1	10.1	
A	34	hearth	180	10.1	10.7	1.0
A	35	hearth	225	9.8	10.1	2.0
A	37	hearth	flat	14.3	14.3	0.0
A	38	hearth	0	10.1	10.1	2.0
B	1	hearth	270	9.5	11.6	1.0
B	2	hearth	225	11.0	12.5	1.0
B	3	hearth	45	13.1	14.3	2.0
B	4	hearth	225	12.2	14.3	3.0
B	7	hearth	flat	13.4	11.0	2.0
B	8	hearth	225	9.1	11.3	2.0
C	152	hearth	10	12.0	12.0	2.0
C	153	hearth	340	14.0	15.0	1.0
C	154	hearth	5	12.5	13.0	2.0
C	155	hearth	0	14.5	15.0	2.0
C	156	hearth	20	11.0	13.0	1.0
C	157	hearth	225	12.0	12.5	2.0
C	158	hearth	55	14.0	14.5	2.0
C	160	hearth	70	13.0	14.5	1.5
C	161	hearth	110	14.5	16.0	2.5
C	162	hearth	85	13.5	13.5	2.0

Area	No.	Feature	Aspect	Width (meters)		Condition
				Parallel	Perpendicular	
C	163	hearth	75	16.0	16.0	2.5
C	164	hearth	90	14.0	14.0	1.5
C	165	hearth	80	10.5	14.0	0.5
C	166	hearth	70	13.5	16.0	2.0
C	167	hearth	65	12.0	16.0	1.0
C	168	hearth	60	14.5	18.5	2.5
C	169	hearth	50	11.0	12.5	1.5
C	170	hearth	85	11.0	15.0	1.0
C	171	hearth	85	12.0	13.0	2.5
C	172	hearth	90	11.0	14.0	2.0
C	173	hearth	140	damaged	damaged	0.0
E	133	hearth	190	12.5	15.0	1.0
E	134	hearth	180	10.0	12.0	1.0
E	136	hearth	220	13.5	15.0	1.0
E	137	hearth	210	13.5	14.0	1.5
E	138	hearth	215	13.5	13.5	1.5
E	139	hearth	300	14.0	14.0	1.5
E	140	hearth	215	15.0	14.0	1.0
E	141	hearth	225	14.0	14.0	1.0
E	143	hearth	310	9.5	14.0	1.0
E	144	hearth	280	13.5	16.0	0.5
E	145	hearth	295	15.5	15.5	1.5

Area	No.	Feature	Aspect	Width (meters)		Condition
				Parallel	Perpendicular	
E	148	hearth	290	10.5	12.0	1.0
E	149	hearth	flat	16.0	18.5	1.5
E	150	hearth	flat	damaged	damaged	0.0
E	151	hearth	320	damaged	damaged	0.0
F	40	hearth	0	11.0	11.0	0.5
F	41	hearth	0	13.1	11.9	1.5
F	42	hearth	0	11.9	13.6	1.0
F	43	hearth	45	12.2	11.9	2.0
F	44	hearth	45	11.0	12.5	2.0
F	45	hearth	315	12.2	14.0	0.5
F	46	hearth	flat	9.5	11.3	1.5
F	47	hearth ²	flat	11.0	11.0	
F	49	hearth ³	flat	damaged	damaged	1.0
F	50	hearth	315	damaged	damaged	0.0
F	51	hearth	315	13.4	13.7	2.0
F	52	hearth	45	11.6	10.7	1.5
F	54	hearth	0	11.6	11.3	1.0
F	55	hearth ²	0	9.5	11.6	
F	56	hearth	80	14.5	16.5	2.0
F	57	hearth	320	15.0	16.5	1.0
G	58	hearth	265	damaged	damaged	0.0
G	60	hearth	220	13.0	14.0	1.5

Area	No.	Feature	Aspect	Width (meters)		Condition
				Parallel	Perpendicular	
G	61	hearth	270	damaged	damaged	0.5
G	62	hearth	190	16.5	15.5	1.0
G	63	hearth	205	13.5	16.0	1.0
G	64	hearth	200	12.5	15.0	1.5
G	65	hearth	200	15.0	15.5	1.5
G	67	hearth	150	14.5	15.0	2.0
G	68	hearth	180	14.0	15.0	0.5
G	69	hearth	200	14.0	15.0	2.0
G	70	hearth	180	14.0	12.5	1.0
G	71	hearth	170	16.0	16.0	3.0
G	72	hearth	190	14.0	14.0	0.5
G	73	hearth	210	13.0	15.5	2.0
G	74	hearth	160	11.5	11.5	0.5
G	75	hearth	260	17.0	20.0	1.0
G	76	hearth	180	14.0	14.5	1.5
G	77	hearth	200	15.0	15.0	2.0
G	78	hearth	190	15.5	16.5	2.0
G	79	hearth	220	13.0	14.5	2.0
G	80	hearth	170	15.0	15.0	1.5
G	82	hearth	150	15.0	14.5	3.0
G	83	hearth	220	13.5	14.5	2.0
G	84	hearth	210	11.0	14.0	1.5

Area	No.	Feature	Aspect	Width (meters)		Condition
				Parallel	Perpendicular	
G	81	hearth	230	13.0	16.0	0.5
G	86	hearth	180	15.0	16.5	2.5
G	87	hearth	220	13.0	14.5	2.0
G	88	hearth	140	14.0	14.0	1.5
G	91	hearth	210	13.0	12.0	2.0
G	92	hearth	180	15.0	16.0	2.0
G	93	hearth	205	16.0	16.0	2.0
G	94	hearth	230	15.0	17.0	2.0
G	96	hearth	200	14.5	15.5	3.0
G	97	hearth	175	13.5	15.0	2.5
G	98	hearth	195	15.0	17.5	2.0
G	99	hearth	210	14.0	15.0	1.5
G	100	hearth	170	14.0	16.0	2.0
G	101	hearth	230	16.0	17.0	2.5
G	102	hearth	180	15.0	16.0	1.0
G	103	hearth	220	15.5	15.5	1.0
G	104	hearth	175	15.0	15.5	2.5
G	105	hearth	160	16.0	16.0	2.5
G	106	hearth	165	14.5	16.5	2.0
G	107	hearth	170	15.5	16.0	1.0
G	108	hearth	205	15.5	15.5	3.0
G	109	hearth	170	12.5	14.0	2.0

Area	No.	Feature	Aspect	Width (meters)		Condition
				Parallel	Perpendicular	
G	111	hearth	170	13.5	15.0	1.5
G	112	hearth	220	14.0	14.0	1.0
G	113	hearth	200	14.0	14.0	2.0
G	114	hearth	160	14.5	15.5	2.0
G	115	hearth	200	13.5	14.5	2.0
G	116	hearth	185	13.5	15.0	1.5
G	117	hearth	145	11.5	12.5	2.5
G	119	hearth	215	14.0	15.0	1.0
G	120	hearth	185	12.5	13.0	1.5
G	121	hearth	220	13.5	16.0	1.0
G	122	hearth	135	15.5	15.5	2.0
G	123	hearth	165	15.0	16.0	1.0
G	124	hearth	180	13.0	13.5	1.5
G	125	hearth	150	14.0	15.0	1.5
G	126	hearth	165	15.0	16.0	1.5
G	127	hearth	160	12.0	15.0	0.5
G	128	hearth	205	damaged	damaged	0.0
G	129	hearth	190	14.5	15.5	1.5
G	130	hearth	170	14.5	14.5	1.0
G	131	hearth	175	damaged	damaged	0.5
G	132	hearth	185	14.0	14.0	1.5

Area	No.	Feature	Aspect	Width (meters)	
				Parallel	Perpendicular
A	21	hut	flat	7.0	7.0
A	25	hut	flat	4.6	4.6
A	32	hut ²	flat	5.3	5.3
A	36	hut	225	6.7	7.9
B	5	hut	flat	5.0	5.0
B	6	hut	flat	5.2	5.2
B	9	hut	flat	5.2	5.2
C	159	hut	255	4.5	4.5
E	135	hut	10	6.8	6.8
E	142	hut	310	7.3	7.3
E	146	hut	280	7.5	7.5
E	147	hut	300	5.6	5.6
F	39	hut ²	0	5.2	5.6
F	48	hut ²	flat	5.2	5.2
F	53	hut	0	4.0	4.0
G	59	hut	260	7.3	7.3
G	66	hut	175	4.0	4.0
G	85	hut	195	7.2	7.2
G	89	hut	180	7.9	7.9
G	90	hut	220	7.5	7.5
G	95	hut	180	7.8	7.8
G	110	hut	175	5.5	5.5

Area	No.	Feature	Aspect	Width (meters)	
				Parallel	Perpendicular
G	118	hut	215	7.2	7.2

1 Measurements of features from areas A, B, and F are taken from Heite (1988, 1989) except for F-56 and F-57, which, along with features in areas C, E, and G, were located by this study.

2 Features not detected by this study.

3 Feature F-49 is located differently by this study. See Figure 4.

