Habitat Modeling and Protection of American Ginseng

(*Panax quinquefolius L.*)

in Great Smoky Mountains National Park

National Park Service
107 Park Headquarters Road, Gatlinburg, Tennessee 37738
December, 1999

Habitat Modeling and Protection of American Ginseng (*Panax quinquefolius* L.) in Great Smoky Mountains National Park

Janet Rock, J. Hope Hornbeck, Jennifer Tietjen, and Erica Choberka

U.S. National Park Service
Great Smoky Mountains National Park
107 Park Headquarters Road
Gatlinburg, Tennessee 37738

December 1999

CONFIDENTIALITY OF INFORMATION

"Information concerning the nature and specific location of a National Park System resource which is endangered, threatened, rare, or commercially valuable … may be withheld from the public in response to a request under section 552 of Title 5 United States Code …." Sec. 207. Confidentiality of Information. National Parks Omnibus Management Act of 1998.

- This report printed on 100% recycled paper.

ACKNOWLEDGMENTS

This project could not have been accomplished without the expertise, and technical assistance of John Boetsch and Dr. Frank van Manen. Stephanie Wilds, Jim Corbin, Dr. Peter White, and Dr. Daniel Gagnon also contributed to the study's success in model development. Thank you to the field technicians and volunteers who put in long hours of hard work in the summers of 1997 and 1998: Jillian Archer, Beth Buchanan, Chandra Vostral, Eric Nielsen, Jennifer Dean, Mark Whited, Jeff Merrick, Daniel Noon, Luke Bruner, Mike Keyes, Brian Yahn and Thomas Moore. Additional assistance was provided by Will Blozan, Bob Dellinger, Keith Langdon, and the following Great Smoky Mountains National Park rangers: Walt West, Richard Jenkins, John Garrison, Lamon Brown, Paul Williams, Al Voner, Ken Davis, Lora Peppers, Steve Spanyer, and Mike Farley. And special thanks to Meryl Rose and Don DeFoe for excellent editorial comments. Finally, Steve Kemp, Great Smoky Mountains Natural History Association, generously designed and produced our report cover.

ABSTRACT

A two-year study was initiated to determine the status of American ginseng (*Panax quinquefolius*), in Great Smoky Mountains National Park (GSMNP). The objectives of this study were to:

(1) create a ginseng habitat model,
(2) estimate the abundance of ginseng in the Park,
(3) describe ginseng habitat(s) and evaluate species associations,
(4) locate and mark existing ginseng populations as a poaching deterrent, and
(5) assess any other pressures on the species.

A predictive distribution model was developed using a multivariate modeling technique, Mahalanobis distance, to identify ginseng habitat in GSMNP. Ninety-eight plots were visited during the 1998 field season to refine the model's predictive ability.

Data suggest that ginseng occupies a wider variety of habitats than previously believed. Our hypothesis that ginseng most frequently occurs in rich cove forests was supported by the predictive model. However, because this habitat type is targeted for illegal harvest, ginseng can often be found in greater abundance in atypical habitats that are less likely to be detected by poachers.

Ordination analyses of environmental and vegetation data were consistent with previous habitat studies. Soil analyses revealed significant relationships between pH, zinc, calcium to magnesium ratio, and ginseng distributions. Parallel analyses of ginseng and its associated plant species suggest that the model accurately predicts ginseng habitat irrespective of the confounding factors of illegal harvest.

To allow identification of illegally harvested ginseng roots from the Park, Park staff located and marked roots of wild ginseng plants throughout GSMNP. Further conservation efforts are recommended.

The study was conducted and reported as two separate projects:

Part I: Habitat Modeling
Part II: Ginseng Protection

Table of Contents

List of Tables and Figures

Part I: HABITAT MODELING

INTRODUCTION

Background

American ginseng (*Panax quinquefolius*) has been illegally collected in Great Smoky Mountains National Park (GSMNP) since the Park's establishment (1934). In 1991, Park law enforcement rangers began counting the number of roots seized from poachers annually. To date, Park law enforcement rangers have intercepted over 10,000 roots. However, this number is believed to be only a small percentage of what is actually poached from the Park. Over 9,000 roots have been weighed and aged by Park biologists to track the general health of ginseng populations throughout the Park, and over 6,500 roots have been replanted for monitoring. Biologists do not have an adequate understanding of how many populations of ginseng occur in GSMNP, its preferred habitat, or the extent of the poaching problem.

American ginseng (hereafter "ginseng") is now considered rare or threatened throughout its North American range (Nault 1997). Due to the long history of ginseng harvest in North America, the population demography of the species is poorly understood. Examination of the impact of stochastic environmental events (e.g., forest fire, severe weather episodes such as drought) and harvesting on Canadian ginseng populations yielded a minimum viable population size of 172 plants (Nantel et al. 1996). This conservative estimate assumes that less than 5% of mature plants are harvested annually, seeds are allowed to ripen, and random environmental catastrophes will not occur. Additional research in Ontario showed 26% of known ginseng populations there became extinct within a 10-year period (1987-1997), of which only seven populations qualified as viable (Nault et al. 1998).

Evidence exists that harvesting pressure on natural populations is increasing. Further, the U. S. Forest Service (USFS) reports that collecting of wild roots may be escalating; specifically, numbers of legal collecting permits for harvesting wild roots has increased up to 300% over previous levels in only a three-year period. GSMNP is flanked by three national forests where such activity occurs.

Throughout the species' range, American ginseng populations most frequently are associated with nutrient-rich soils (particularly calcium) with a pH higher than 5.5, and usually occur with certain herbaceous species (Nault et al. 1998). Ginseng specialists have consistently observed the presence of bloodroot (*Sanguinaria canadensis*), black cohosh (*Cimicifuga* spp.), maidenhair fern (*Adiantum pedatum*), and yellow lady's slipper (*Cypripedium pubescens*) associated with ginseng (J. Corbin, NCDA, pers. comm. and J. Rock, NPS, pers. obs.). Ginseng in the southern Appalachians occurs in rich cove forests characterized by high plant diversity, and occupies sheltered mesic sites with circumneutral, well-drained, rocky, and deep soils (Whittaker 1956, Schafale and Weakley 1990).

The distribution of rich cove forest in GSMNP has been examined in numerous studies (Cain 1931, Whittaker 1956, Golden 1981, Parker and Parker 1986, Callaway et al. 1987). These studies identified large-scale topographic gradients as the primary determinants of forest type. Herbaceous species diversity and richness within cove forests has been regularly studied in GSMNP (Bratton 1976, Hicks 1980, Newman and Reddell 1988). These studies identified within-stand microtopography, soil gradients, and canopy species associations as the primary influences on species distributions. The influence of Eastern hemlock (*Tsuga canadensis*) has also been identified as an important influence on within-stand microtopography and soil characteristics (Hicks 1980, Beatty 1984). The distribution of herbaceous species is still poorly understood across the mosaic of topographic gradients and within-stand variability of the cove forests of GSMNP.

The remote, rugged terrain of many parts of GSMNP, in combination with the cultural tradition and economic incentive for ginseng harvesting in the southern Appalachian region, has resulted in serious resource management problems. This two-year study was initiated to evaluate the status of ginseng in GSMNP by researching the following questions:

(1) can a Geographic Information System (GIS)-based predictive habitat model for ginseng be created,
(2) can this model be used to estimate the abundance of ginseng in the Park,
(3) are other plant species consistently associated with ginseng or ginseng habitat, and
(4) do topographic or soil characteristics play a role in ginseng distribution?

The Species

American ginseng (*Panax quinquefolius*) is a long-lived forest herb native from southern Quebec through the lake states to central Minnesota and south into several Gulf states (Figure 1).

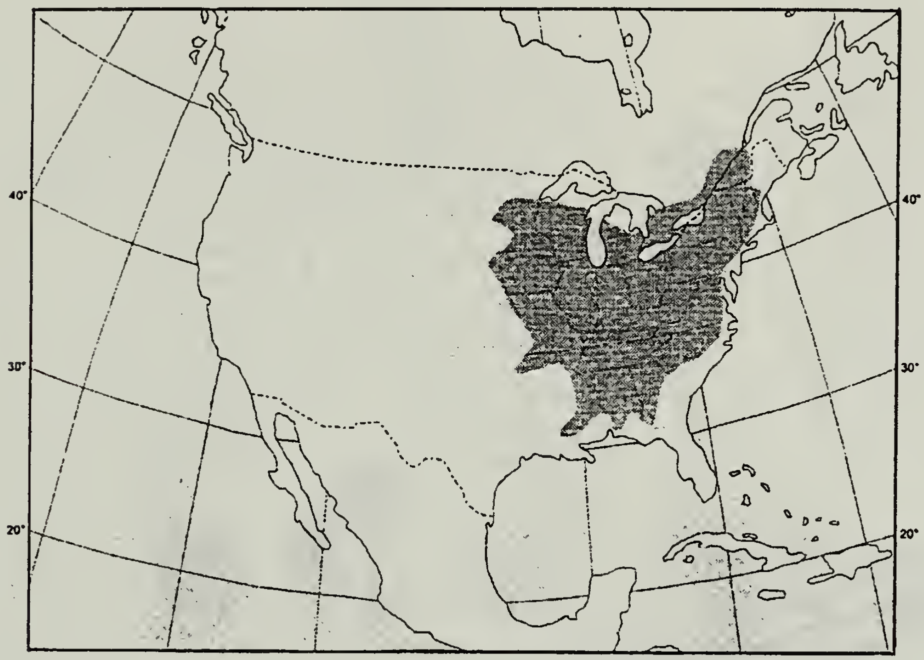

Figure 1. Distribution of American ginseng in North America (Argus and White 1989).

The mature plant has a single, rhizome-borne stem topped with a whorl of three or four leaves, or "prongs", each of which is comprised of three to five leaflets (Figure 2). Plant height ranges from just six centimeters to nearly one meter tall. Height and leaf number appears to be more a factor of nutrient availability and other habitat qualities than of plant age (Lewis and Zenger 1982). Plants may grow very large in just a few years under optimal environmental conditions, or may persist for decades in marginal habitat with very little increase in the size of their roots or aboveground stems. The plant produces a single inflorescence bearing tiny white flowers from the center of its whorl of leaves. The flowers mature into bright red fruits. Each fruit contains one or two seeds, occasionally three in larger plants. Ginseng typically reproduces by seed, rarely propagating vegetatively by producing more than one rhizome. Plants must be at least several years old in order to flower and produce viable fruit, and ginseng seeds require a two-

winter stratification period before germination can occur. The combination of these factors results in slow rates of population growth (Lewis and Zenger 1982).

Figure 2. Morphology and habit of American ginseng (*Panax quinquefolius*) (illustrated by Hornbeck 1998).

Like Asian ginseng (*Panax ginseng*), the roots of American ginseng are highly valued as a medicine and tonic. Although American ginseng is cultivated in the U.S., particularly in the north-central states, the wild roots are considerably more valuable in both the North American and Asian markets (Robbins 1998). The presumed increased chemical potency and gnarled appearance of wild ginseng roots, compared to cultivated roots, are the result of stressful growing conditions and slower growth often associated with natural populations. The unique shapes of wild roots also are considered a factor in the species' medicinal and mystical value in traditional Chinese medicine (Hu 1976).

METHODS and MATERIALS

Study Area

GSMNP covers over 200,000 hectares (800 square miles) along the Tennessee and North Carolina border with a perimeter of about 290 kilometers (182 miles). This area contains a wide variety of habitats distributed across elevations ranging from 268 to 1,982 meters (880 to 6,684 feet). Approximately 72% of the Park is made up of hardwood forests, and approximately 45% (or roughly 70,000 hectares) of these are rich cove forests (Mackenzie 1991) believed to be the forest type most often associated with ginseng occurrence (Lewis and Zenger 1982). GSMNP provides the largest protected area for wild American ginseng in the eastern U.S. The southern Appalachians, including the Park, are believed to provide the highest quality habitat at the southern limit of this species' range.

Habitat Model Development

During the 1997 field season, data collection protocols were determined for the 1998 field season and ginseng reference points were provided for habitat model development. The Park's East District was selected for data collection based on habitat diversity (Mackenzie 1991), a range of elevations, and verified populations of ginseng. A field survey of ginseng habitat was conducted within the USGS Cove Creek Gap and Luftee Knob quadrangles in the Cataloochee area. The predictive model was developed in spring 1998 by John Boetsch (Boetsch and Rock 1999) based upon high-quality observations from 1997 data and additional ginseng locations throughout the Park (n = 56 positions). The model was applied and tested during the 1998 field season (May – August).

The modeling technique used in this study, Mahalanobis distance, is a unitless, multivariate statistic that describes the deviation from an optimal set of conditions (Rao 1952). This mathematical function (denoted by D^2) was calculated from a set of 13 GIS variables (12 topographic and a single vegetation type) for each 30 x 30-meter pixel (Appendix 1).

D^2 was used to describe each pixel's dissimilarity or "distance" from ideal habitat conditions based upon the 56 positions. The resulting model is the distribution of the D^2 values across each pixel in the Park. We hypothesized that ginseng locations would be correlated with lower D^2

values, as the model function predicts that the probability of ginseng occurrence decreases with increasing dissimilarity from ideal habitat. Thus, the lower a pixel's D^2 value, the greater probability ginseng would be encountered.

Field Validation

Model output was stratified into six validation classes. Classes were related to habitat quality and guided the validation effort. Class I represented pixels hypothesized to be most preferred habitat and class VI represented the least preferred. Classes were designed so that the area within class II was twice that of class I, and so on. One hundred-twenty random positions, 20 in each of the six classes, were selected to field-test the model. Stratified sampling was used due to the wide range of habitats in GSMNP. Sampling evenly across the entire range of D^2 values would have resulted in an inordinate number of plots where ginseng is unlikely to be found. Therefore, validation efforts were concentrated toward the smaller values of D^2, which were hypothesized to possess optimal ginseng habitat characteristics. In addition, data were collected in less-favorable habitats to determine if the model omitted potential habitat and if our assumptions were correct.

Field Methods

Plot Location

One hundred twenty random validation points were mapped using Universal Transverse Mercator (UTM) coordinates on standard USGS quadrangle maps (7.5 minute, 1:24,000 scale). Coordinates were entered into a global positioning system unit (GPS; PLGR +96, Rockwell International, Cedar Rapids, Iowa) for field navigation. Points were located in the field using, topographic characteristics, compass bearings, altimeter readings, and an unassisted, military Y-code GPS signal from the Department of Defense. The locations were confirmed either by GPS (accuracy within 15 meters), or by a combination of elevation, aspect, and other topographic attributes.

Plot Design

Level 1validation plots were 31.6 x 31.6 meters (1000 m^2), which approximated pixel size (900 m^2) in the GIS database. In the field, plots were centered on random points. Two 31.6 meter

transects defined a plot by orienting one along the contour of the dominant slope and the other perpendicular to it, criss-crossing at the plot center. Transects divided the level 1 plot into four level 2 quadrats (250 m^2 each). One of these quadrats was randomly selected for division into level 3 and 4 nested sub-plots. Orienting from plot center facing out, the nested sub-plots were always placed to the end, and to the right, of the transect in each random quadrat (Figure 3).

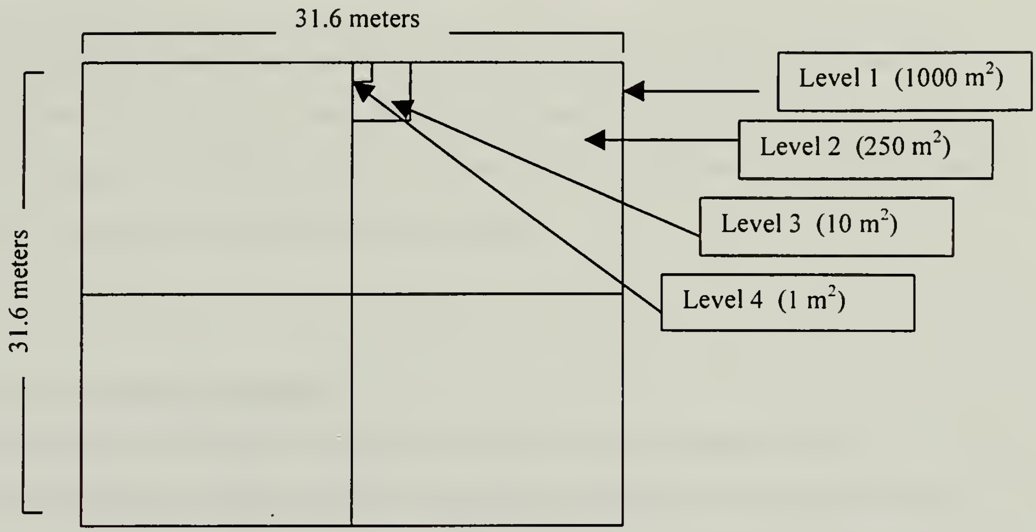

Figure 3. Plot design showing transects, quadrats, and nested sub-plots.

<u>Data Collection</u>

Topographic data (quantitative) and vegetation data (qualitative) were collected throughout the 1000 m^2 plot (see Data Sheet, Appendix 2). All vascular plant species were listed as well. The five dominant species in the canopy (level 1), sub-canopy (level 2), and herbaceous layers (levels 3 and 4) were recorded in order of importance, and cover percentages were estimated for each layer to the nearest 10% (100% total coverage). Cover for the sub-canopy layer was estimated at level 2 (250 m^2) and the herbaceous layer was estimated at level 4 (1 m^2) to simplify cover estimates for these layers. The presence of four ginseng-associates, bloodroot *(Sanguinaria canadensis)*, black cohosh (*Cimicifuga* spp.), maidenhair fern (*Adiantum pedatum*), and yellow lady's slipper (*Cypripedium pubescens*), was recorded. The 1000 m^2 plot, including the three sub-plots, was searched for ginseng plants and the smallest sub-plot containing ginseng was recorded.

Soil samples were taken from several locations within each 1000 m^2 plot for analysis. The North Carolina Department of Agriculture Agronomic Division (NCDAAD) performed the following soil analyses: percent humic matter, acidity, weight per volume of soil, pH, percent basic solvency, percent calcium, percent magnesium, ammonium and nitrate content, and potassium, manganese, phosphorus, zinc, copper, and sulfur indices.

Additional data were collected when ginseng was present in the plot including: size class and reproductive status of each ginseng plant, any observable damage to the plant, general health of the population, and any signs of poaching activity. Concentrations of ginseng encountered while traveling to and from the plots were mapped for future study.

Data Analysis

<u>Chi-square and Pearson Correlation Analyses</u>

Variability within and between validation classes was tested with chi-square analyses. Relationships between Mahalanobis distance (D^2) and ginseng occurrence and abundance, and the occurrence of associated plant species and soil components, were identified using Pearson correlation coefficients. Ginseng occurrence and abundance data were regressed against independent variables (D^2 and quantitative habitat characteristics) using logistic and linear regression analyses, respectively.

<u>Detrended Correspondence Analysis (DCA)</u>

A comprehensive species-occurrence matrix and environmental variables (elevation, aspect, slope, microtopography, slope position, dominant stratum height, canopy gaps, and soil components) were ordinated using DCA (Hill and Gauch 1980). DCA generated a two-dimensional scatterplot depicting the relative position of the validation plots based upon the degree of similarity or difference in plant species composition. General ecological patterns were determined from field-validated plot positions by examining individual plot characteristics and community associations. Plant species that occurred in less than 5% of the validation plots were not included in the analysis. Ordination analysis was conducted using PC-ORD (McCune and Medford 1995).

Canonical Correspondence Analysis (CCA)

The relationships between five dominant canopy species in each validation plot and 11 environmental variables were examined using CCA (PC-ORD, McCune and Medford 1995). These environmental variables are: elevation, aspect, slope, pH, acidity, percent basic solvency, cation exchange capacity, phosphorus and zinc indices, percent calcium, and percent magnesium. Like DCA, CCA produces a two-dimensional scatterplot depicting the spatial relationship between plots based upon the degree of similarity or difference in species composition. Unlike DCA, CCA performs a multiple regression of the environmental variables against plot relationships.

Mahalanobis Distance Cutoff

To refine the model's ability to predict ginseng occurrence, a D^2 cutoff value was identified. The percentage of correctly classified ginseng occurrences (X-axis) and correctly classified ginseng absences (X-axis) were plotted against the D^2 values (Y-axis). D^2 values at, and below, the point at which the two prediction curves intersect, provide a range of ginseng habitats and corresponding model values.

Abundance Estimate

Ginseng abundance in the Park was estimated from the validation data and the model cutoff. The ginseng abundance estimate is the "product" of the number of pixels with a D^2 equal to or less than the D^2 cutoff, the saturation rate, and average ginseng abundance. The ginseng habitat saturation value was calculated by dividing the number of plots with ginseng by the total number of plots visited below the D^2 cutoff. The average ginseng abundance value was determined by dividing total ginseng abundance by total number of plots visited for that range. A refined abundance estimate also was produced for a broader range of habitats above the D^2 cutoff.

RESULTS

Habitat Model Validation

Ginseng was present in 15 of the 98 plots sampled (15.3%), and 184 ginseng plants were counted. The ranges of D^2 values, total D^2 area, pixels per class, number of plots visited for each validation class, ginseng abundance, ginseng occurrence, and the occurrence of one or more associated plant species are given in Table 1.

Table 1. Ginseng occurrence and abundance in validation plots (n = 98).

Class	Min. D^2	Max. D^2	Area (ha)	Pixels (area/.09)	Plots visited	Ginseng abund.	Ginseng occur.	Associate occur.
I	4.170	6.262	3,238	35,982	16	7	2	13
II	6.816	7.976	6,476	71,965	18	21	5	11
III	8.055	10.010	12,954	143,929	18	88	4	9
IV	10.378	12.716	25,907	287,860	12	8	2	9
V	13.845	17.917	51,815	575,718	15	60	2	1
VI	18.384	62.809	103,628	1,151,437	19	0	0	1
Totals			**204,018**	**2,266,891**	**98**	**184**	**15.3%**	**45%**

The relationships between ginseng occurrence and abundance and Mahalanobis distance (D^2) are illustrated in Figures 4 and 5. Ginseng occurs most often in class II (Figure 4), and ginseng abundance is greatest in classes II, III, and V (Figure 5).

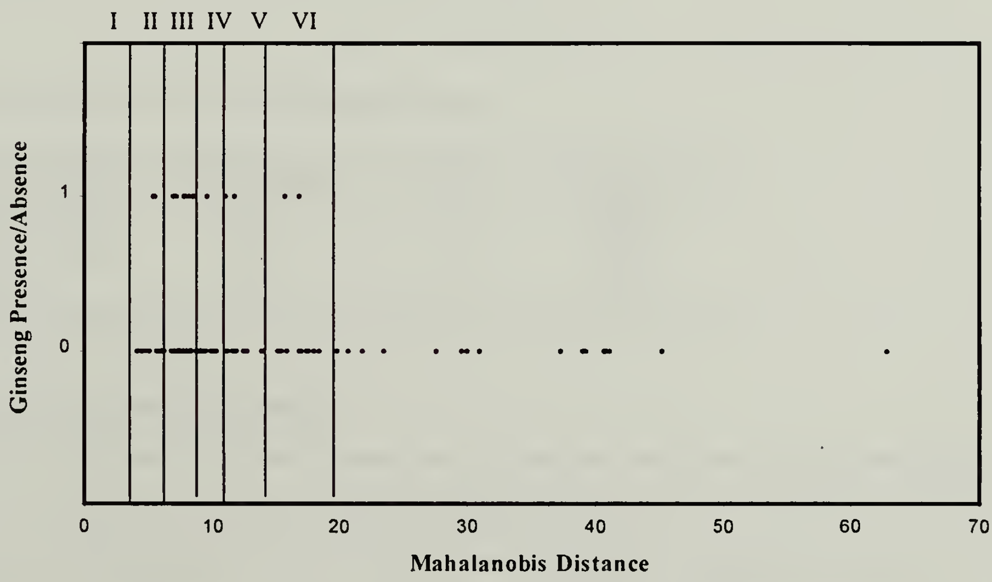

Figure 4. Relationship of ginseng occurrence with D^2 and class.

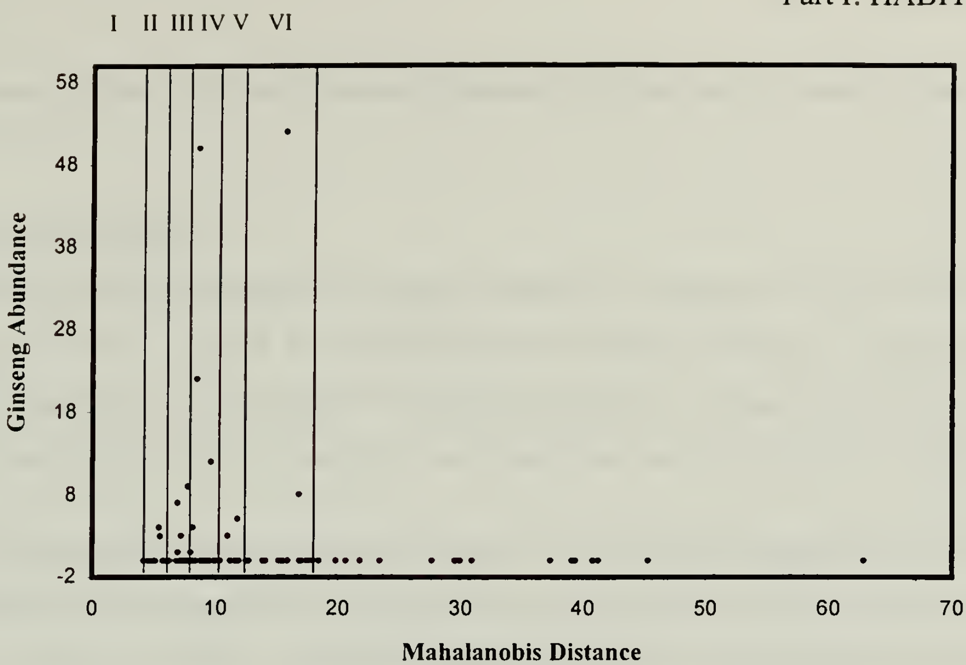

Figure 5. Relationship of ginseng abundance with D^2 and class.

Chi-square Analysis

A chi-square test was performed for ginseng occurrence variability across the validation classes. The data were analyzed for each class and by grouping classes. The results were not significant; however, the *P*-value was marginally significant for group I-III compared with group IV-VI, (Table 2).

Table 2. Chi-square analysis of ginseng presence.

Validation Classes	Chi-square	Df	*P*-value
I, II, III, IV, V, VI	6.2	5	0.287
I-II, III-IV, V-VI	2.8	2	0.246
I-III, IV-VI	3.3	1	0.070

Pearson Product Moment Correlation

Pearson Product Moment Correlation was used to examine relationships between ginseng occurrence and ginseng abundance with Mahalanobis distance (D^2). The occurrence of ginseng was negatively correlated with D^2 (r = -0.194, $P < 0.05$); that is, ginseng occurrence decreased with increasing D^2 values. In contrast, ginseng abundance was not correlated with D^2 (r = -0.059, $P > 0.05$). The same analyses for validation plots (n = 15) containing ginseng revealed a

positive correlation between increasing ginseng abundance and increasing D^2 values ($r = 0.551$, $P < 0.05$).

Regression Analyses

Logistic regression suggests that ginseng occurrence is negatively correlated with lower D^2 values (n = 98, $r = -0.101$, $P = 0.078$) but only marginally significant. Logistic regression shows a significant relationship between D^2 and *Cimicifuga* spp. occurrence (n = 98, $r = -0.110$, $P = 0.047$) and occurrence of one or more associated plant species (n = 98, $r = -0.108$, $P = 0.029$).

Linear regression of ginseng occurrence and D^2 was marginally significant (n = 98, $r = -0.006$, $P = 0.056$), but linear regression of ginseng abundance and D^2, however, was not significant (n = 98, $r = -0.052$, $P = 0.464$). Regression analyses (logistic and linear) of ginseng occurrence and soil variables were not significant. However, linear regression of ginseng abundance and pH was significant (n = 78, $r = 0.341$, $P = 0.003$).

Mahalanobis Distance (D^2) Cutoff

The model's ability to predict ginseng occurrence was determined by plotting the percentage of correctly classified presence and absence against possible D^2 cutoffs (Figure 6). The curve for

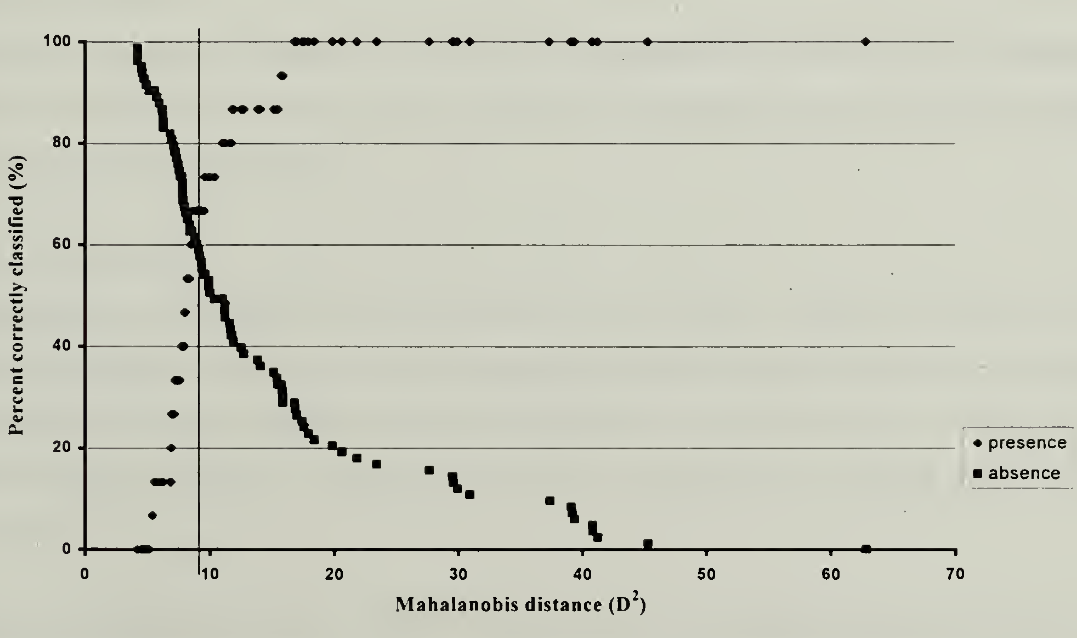

Figure 6. Classification of validation results (n = 98).

correctly classified presence increased with D^2, and the curve for correctly classified absence decreased with increasing D^2. Figure 6 shows that 60% of both presence and absence predictions are correct for the 8.5 cutoff.

Ginseng Habitat Description

Elevations in plots where ginseng occurred (n = 15) ranged from 655 to 1,098 meters (2,160 to 3,620 feet) with a mean of 900 meters (2,968 feet). Aspect within these plots varied. Slopes ranged from 8-36% with a mean of 24.2%. Eight plots had a mid-slope position, four plots were situated low on the slope, two plots were high-slope, and one plot occurred at the crest of a ridge. Canopy cover ranged from 20-70% with a mean of 61.3%.

Plant Species Associations

Canopy layer

Dominant canopy species occurring with ginseng included tuliptree (*Liriodendron tulipifera*), red maple (*Acer rubrum*), and white basswood (*Tilia americana* var. *heterophylla*). Additional species were yellow buckeye (*Aesculus flava*), black locust (*Robinia pseudoacacia*) and silverbell (*Halesia tetraptera* var. *monticola*).

Sub-canopy layer

Dominant sub-canopy species were silverbell, sugar maple (*Acer saccharum*), red maple and striped maple (*Acer pensylvanicum*). Additional sub-canopy species were yellow buckeye, tuliptree, and white basswood.

Herbaceous layer

Herbaceous cover ranged from 10-100% with a mean of 52%. Nine of the 15 plots had a cover of 50% or greater. One or more of the ginseng-associated species (*Sanguinaria*, *Cimicifuga*, *Adiantum*, and *Cypripedium*) occurred with ginseng in 13 of the 15 plots. *Cimicifuga* occurred with ginseng in nine plots, *Adiantum* in eight plots, *Sanguinaria* in six plots, and *Cypripedium* in two plots.

Pearson correlation analyses revealed a significant, positive relationship between the occurrence of ginseng and *Cimicifuga* ($P < 0.0001$), *Adiantum* ($P < 0.0001$), *Sanguinaria* ($P < 0.0001$), and

Cypripedium (P = 0.049). In contrast, ginseng abundance was marginally correlated with *Cimicifuga* (P = 0.06) and *Sanguinaria* (P = 0.13), and not correlated with *Adiantum* (P = 0.22) or *Cypripedium* (P = 0.91). Analyses suggest that ginseng occurred in habitats where the associated plant species occurred, but was more abundant in habitats where the associated plant species were less likely to occur (Table 3).

Table 3. Pearson correlation coefficients for ginseng occurrence, abundance, and associated plant species (n = 98).

	Ginseng Occurrence	Ginseng Abundance	*Cimicifuga*	*Sanguinaria*	*Cypripedium*
Cimicifuga	0.457***	0.190			
Sanguinaria	0.454***	0.154	0.579***		
Cypripedium	0.199*	0.010	0.302**	0.292**	
Adiantum	0.567***	0.125	0.499***	0.447***	0.580

P-values * < 0.05 ** < 0.01 *** < 0.001

Soil Analysis

Pearson correlation analyses of soil composition, and ginseng occurrence and abundance, indicated strong positive relationships among ginseng occurrence and percent basic solvency (BS%), manganese (Mn-I) and sulfur (S-I) indices, and soil pH. Correlation with soil components varied between ginseng occurrence and abundance (Table 4). Results of the NCAAD tests were incomplete for ammonium and nitrate and, therefore, not included in any analyses.

Table 4. Pearson correlation coefficients for soil components (n = 78).

	Ca:Mg	BS%	P-I	K-I	Mn-I	Zn-I	Cu-I	S-I	pH
Occur.	0.193	0.512	0.15	0.304	0.416	0.231	0.307	-0.365	0.372
***P*-value**	NS	***	NS	**	***	*	**	***	***
Abund.	0.288	0.536	0.173	0.208	0.538	0.594	0.348	-0.262	0.125
***P*-value**	*	***	NS	NS	***	***	**	*	NS

P-value * < 0.05 ** < 0.01 *** < 0.001

Detrended Correspondence Analysis (DCA)

Figure 7 displays the results of DCA analyses (n = 96). Figure 8 shows only the validation plots in which ginseng was present (n = 15); habitat groupings are outlined to facilitate interpretation.

The X-axis appears to represent the interaction of moisture and topographic gradients. The Y-axis appears to follow a substrate gradient (e.g., soil composition, parent geology, and/or topographic interactions). Plots cluster into three habitat groups: group A represents plots on dry ridge tops, group B represents plots in moist, rich coves, and group C represents plots at higher elevations. Comprehensive plant species lists for the three habitat groups are given in Appendix 3.

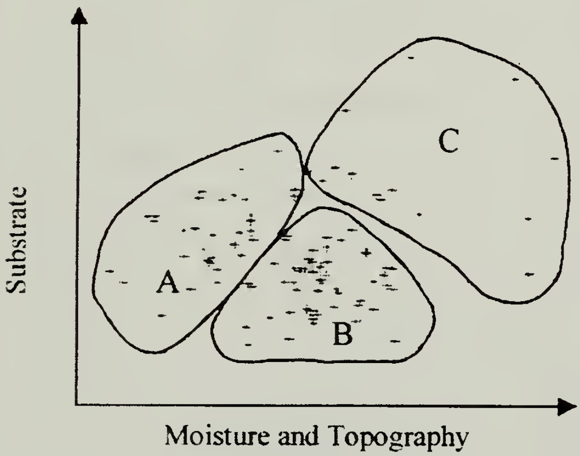

Figure 7. DCA of validation plots (n = 96).

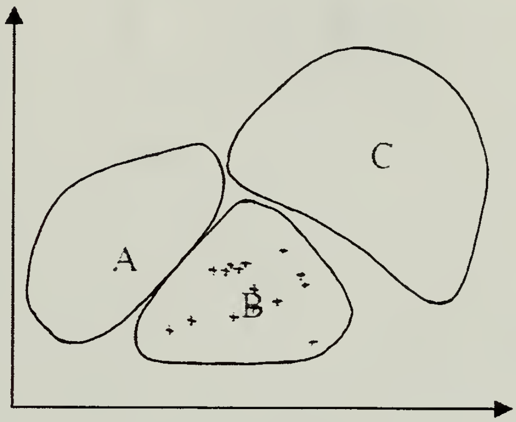

Figure 8. DCA of validation plots with ginseng (n = 15).

<u>Legend for Figures 7 and 8</u>
A: Dry, ridge-top plots: mid-elevations, low moisture, convex topography and high slope position (similar to xeric oak and pine-oak vegetation classifications described by Mackenzie 1993).
B: Cove hardwood plots: low to middle elevations, high moisture, well-drained, concave topography, low-middle slope positions (similar to cove hardwoods and mixed mesic hardwoods classifications described by Mackenzie 1993).
C: High elevation plots: high elevation, high moisture, boggy or seepy, level to convex topography, and high slope position (similar to spruce-fir and northern hardwoods classifications described by Mackenzie 1993).

Figure 9a shows the abundance of ginseng within each plot. The percentage of Ca, Mg, and BS of each plot is shown in Figures 9 b-d. Figures 9e-f give the values of P-I and Mn-I. Analyses of the soil data suggest that five of the soil components cluster similarly as the habitat groups. Plots located near the bottom of the Y-axis and the center of the X-axis had high percentages of Mg, Ca, BS, and high values for Mn-I, and P-I. Plots with ginseng were also found in this position.

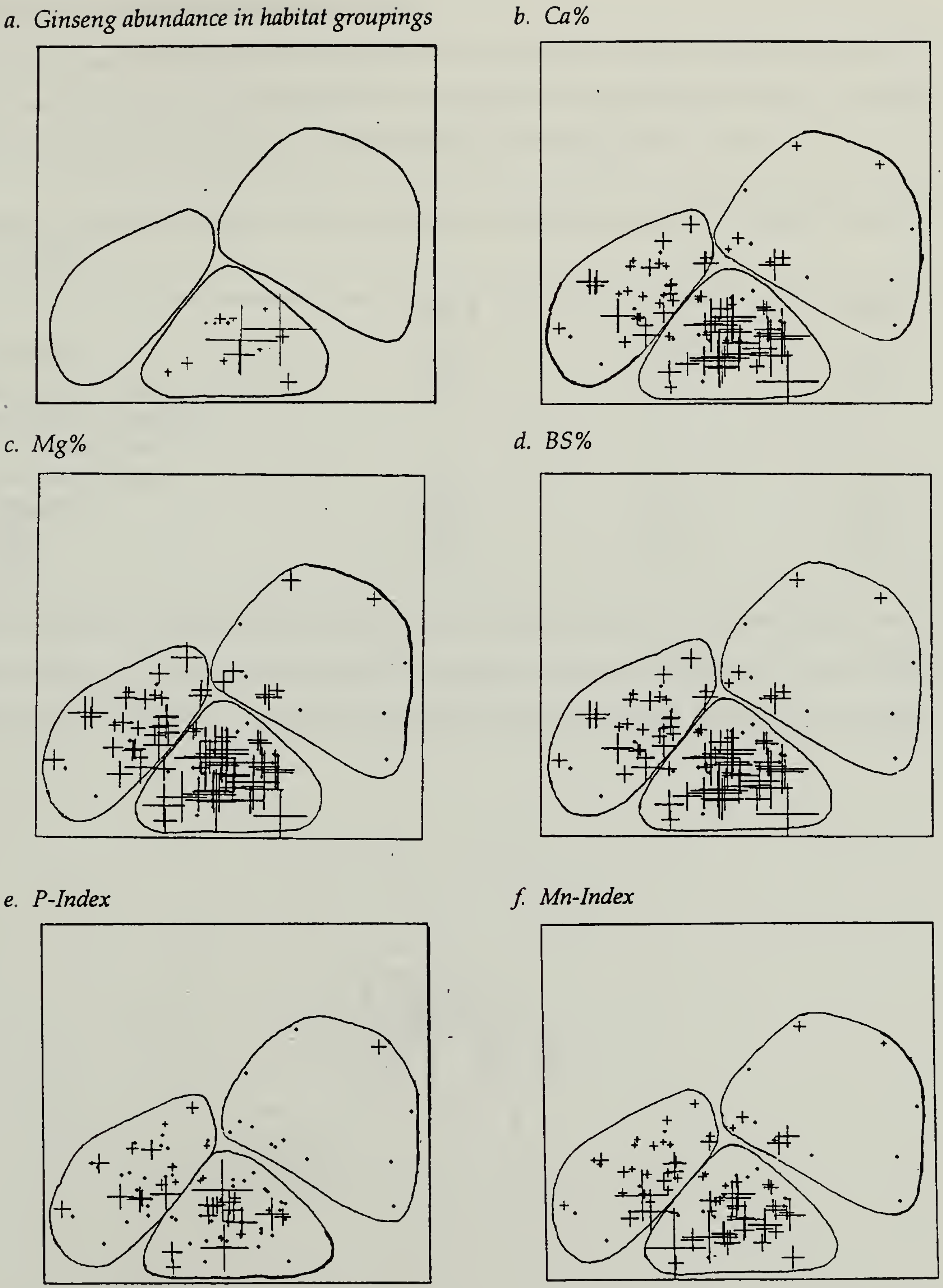

Figure 9. DCA of ginseng abundance and soil components. Crosses (+) indicate plot locations and cross size is proportional to ginseng abundance (a) or percentages of soil components (b-f).

Canonical Correspondence Analysis (CCA)

CCA of the canopy layer dominants against 11 environmental variables identified elevation, slope, and pH as having the most influence on plant species composition (Table 5). All three axes were significant according to a Monte Carlo permutation test ($P < 0.05$).

Table 5. Ordination results for CCA of canopy layer dominants and environmental variables (ter Braak 1997).

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.293	0.240	0.157
Species environment correlations	0.787	0.745	0.683
Cumulative % variance of species data	3.2	5.8	7.5
Intraset correlations			
Elevation	-0.765	0.577	-0.007
Slope	0.649	0.397	0.501
pH	-0.423	-0.490	0.742

The ordination of validation plots shows the relative importance of pH, elevation, and percent slope (Figure 10). Plots in which ginseng was present typically had higher pH, lower elevation, and lower percent slope. In contrast, many outlier plots (e.g., in high elevations, or on steep

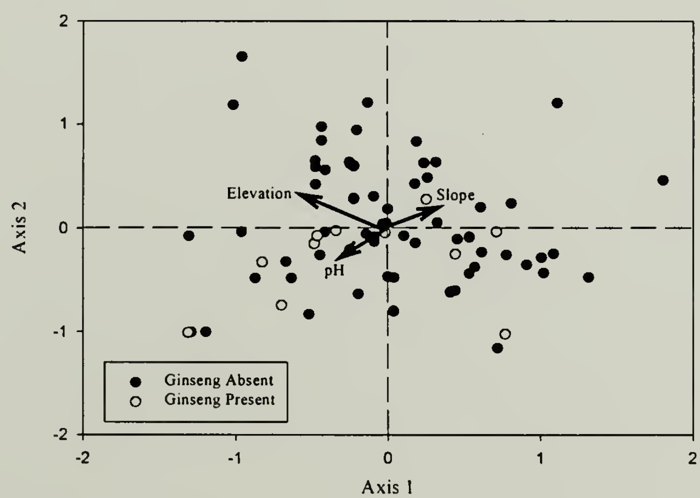

Figure 10. CCA plot ordination of dominant canopy species. Each circle represents a validation plot (n = 73).

slopes) did not contain ginseng.

Distribution Map

A distribution map of currently known ginseng occurrence in GSMNP was produced using the 52 positions and ginseng protection and validation data. The map identifies highly suitable, moderately suitable, and unsuitable ginseng habitat in the Park. Due to data sensitivity, the map is not included in this report.

Abundance Estimate

The model estimate for ginseng was produced from average habitat saturation and density for a refined portion of the study area (below the D^2 cutoff of 8.5 comprised of 136,519 pixels). The abundance estimate for the 8.5 cutoff was 51,195 plants. Because ginseng occurred beyond this cutoff in greater densities, but less frequently, an abundance estimate was also calculated for an extended portion of the study area (D^2 cutoff = 12.7). The higher cutoff yielded a total estimate of 212,559 ginseng plants. This cutoff was selected based upon the range of habitats in which ginseng and its associated plant species were predicted with reasonable accuracy. The predictive ability of the model was consistent for ginseng and the four associated species for all D^2 cutoff values tested.

DISCUSSION

The modeling effort increased our understanding of ginseng habitat in GSMNP. Results indicate that ginseng occurs most often in rich cove forests (smaller D^2 values). However, ginseng occurred in a wider range of habitats than previously believed, and a greater abundance of ginseng was encountered in habitats with higher D^2 values. During model development, we focused on rich cove forests, but, because poachers target these areas, we expanded the range of potential habitats. Two ginseng populations (approximately 160 plants each) were encountered en-route to random plot locations. These populations were not included in the model validation, however similar habitat was described in plots where ginseng occurred. These habitats generally were small-scale, with a limited composition of cove forest species and D^2 values greater than the model cutoff 8.5. All ginseng occurrences had a D^2 less than 16.8. We describe this habitat range, 8.5 to 16.8, as moderately suitable in the distribution map and remainder of this discussion.

Ginseng Habitat Description

Associated Plant Species

As expected, there was a positive correlation between the four associated plant species and ginseng occurrence. *Sanguinaria, Cimicifuga, Adiantum,* and *Cypripedium* spp. consistently were found in similar habitats as ginseng. In contrast, there was weak negative correlation between ginseng abundance and *Sanguinaria* and *Cimicifuga*, and no correlation with *Cypripedium* and *Adiantum*. This suggests that poachers may also use these species to locate ginseng, or, ginseng is currently concentrated in moderately suitable habitats with limited composition of associated species. Parallel analyses were performed for ginseng and the associated plant species in order to detect habitat characteristics and distribution patterns confounded by the effects of poaching. All data analyses for ginseng and its associated plant species, and tests to determine the model cutoff, suggest *Sanguinaria*, *Cimicifuga*, *Adiantum*, and *Cypripedium* are effective surrogates for predicting ginseng and its habitat.

Large-scale Patterns

DCA grouped validation plots into three broad habitat types: high elevation forest, cove forest, and dry, ridge-top forest communities. This pattern has been reported in previous GSMNP

vegetation studies (Hicks 1980, Muller 1982, Parker and Parker 1986, Callaway et al. 1987) and demonstrates that the data set we used represents habitat types in the Park. However, the cove forest community type appears to include a range of habitats, and ginseng can occur in any of them. Within the cove forest group (Figures 7, 8, and 9), ginseng, its associated plant species, and high percentages of calcium, magnesium, and basic solvency, generally occurred together.

CCA of dominant canopy species was consistent with earlier vegetation distribution studies in GSMNP, where elevation, slope, and pH were identified as determining factors of canopy composition (Cain 1931, Whittaker 1956, Hicks 1980).

Plots where ginseng occurred generally possessed a dense, broadleaf sub-canopy and infrequent occurrence of evergreen species. In contrast, dense, species-poor stands of rosebay rhododendron (*Rhododendron maximum*) and/or Eastern hemlock (*Tsuga canadensis*), with a species-poor understory, were regularly encountered in the validation plots.

<u>Small-scale Patterns</u>

Larger populations of ginseng located during this study occurred in pockets of habitat that were too small (less than 900 m^2, or one pixel) to be detected by conventional GIS techniques. This limited our ability to incorporate these moderately suitable, small-scale habitats into the predictive habitat model. Ginseng's consistent occurrence in moderately suitable habitats in association with yellow buckeye (*Aesculus flava*), white basswood (*Tilia americana* var. *heterophylla*), and black locust (*Robinia pseudoacacia*) suggests strong plant species associations. The co-occurrence of herbaceous species, such as ginseng, with specific canopy species may be due to soil-enhancing mycorrhizal fungi-tree associations or other site-enhancing qualities (Newman and Reddell 1988). Earlier research in GSMNP has demonstrated that small-scale gradients, such as within-stand microtopography and soil gradients, determine herbaceous species distributions (microhabitats), but the overall distribution of habitats is determined by canopy associations and large-scale environmental gradients (Bratton 1976, Hicks 1980, Newman and Reddell 1988).

Microtopography and Soil Factors

The results of all analyses of species occurrence and soil factors were consistent with earlier research (Bratton 1976, Hicks 1980) and suggest that soil composition influences ginseng distribution (Nault et al. 1998). Bratton (1976) identified a close correlation between herbaceous species' distributions and intra-stand soil heterogeneity. Patterns of pH and ginseng distribution suggest that moderately suitable habitats with high densities of evergreen sub-canopy species possess higher pH usually not reflected by the occurrence of these acid-tolerant species (requiring low pH). This suggests a moderating influence that creates a suitable microhabitat in otherwise unsuitable habitat. This requires further study due to the potential role microhabitats serve in maintaining and re-establishing ginseng populations.

Abundance Estimate

The estimate of ginseng abundance using the 8.5 D^2 cutoff is 51,195 plants. An additional estimate of 212,559 plants is calculated using the D^2 cutoff 12.7, which includes moderately suitable habitats occupied by ginseng and its associated plant species.

SUMMARY

There are several possible explanations for ginseng distribution in GSMNP including: local extirpation due to illegal harvest, land-use history, limited population re-establishment due to dispersal or physiological limitations, and/or opportunistic occupation of canopy gaps in otherwise unsuitable habitats. Contrary to our hypothesis, ginseng was sparse in optimal rich cove forests, and was found in greater numbers in moderately suitable habitats – habitats not targeted by poachers. This unexpected distribution pattern strongly suggests that poaching is a serious problem in GSMNP.

The results of this study will assist in future habitat assessment and plant conservation efforts by:

(1) identifying potentially suitable ginseng habitat to focus search efforts, especially when working across large landscapes,

(2) locating additional populations to refine the habitat model and to better understand the ecology of ginseng, and

(3) re-evaluating appropriate and sustainable levels of ginseng harvest, if any.

RECOMMENDATIONS

During this two-year study, Park staff found only two populations of more than 160 plants. Further searches for viable populations are needed. Examination of aerial and infrared photos to locate marginal habitats and "pockets" should be used to direct on-the-ground searches.

Associated plant species should be used to model ginseng habitat to circumvent the confounding effects of poaching. Roads, trails, and boundaries should be assessed for their role as poaching corridors.

Demographic studies to compare GSMNP ginseng populations with populations in other areas of the eastern U.S. and Canada, may help us understand similarities and differences among populations. Such studies could provide crucial data needed to help conserve ginseng throughout its range.

There are a number of other biotic factors that could affect ginseng distribution and, therefore, merit further study, including:

(1) forest structure and structural/functional diversity in ginseng habitats,
(2) exclusion of ginseng or its associated plant species by competitors or pathogens,
(3) genetic variability within and between ginseng populations, and
(4) seed dispersal mechanisms.

Part II: PROTECTION

INTRODUCTION

Illegal Harvest from GSMNP

Park biologists and law enforcement rangers began keeping records of the amount of ginseng (number of roots and weight) illegally harvested from GSMNP in 1991. In only the past nine years, GSMNP rangers have seized 10,515 ginseng roots from illegal harvesters (Table 6). In addition, rangers state they detect only a small percentage – only 1 to 3% – of people poaching ginseng within the Park, and actually apprehend fewer still. Rangers' duties at GSMNP are varied and only a fraction of their time can be spent in the backcountry focused on resource protection.

Table 6. Summary of amount of illegally harvested ginseng (number of roots and undried weight) seized in Great Smoky Mountains National Park, 1991 – 1999.

Year	No. of roots seized	Undried weight (g)
1991	846	2,347.97
1992	399	1,447.83
1993	3,301	11,394.78
1994	1,723	7,052.73
1995	1,846	5,953.36
1996	1,797	7,691.79
1997	52	154.59
1998	365	1,843.85
1999	186	680.57
Total	10,515 roots (35.38 dry lbs. @ 298 roots/lb.)	38,567.47 (85.04 lbs. fresh)

Despite this fact, from 1991 through 1999 rangers seized 85.04 pounds of fresh roots, equivalent to 35.28 dry pounds (Tables 6 and 7) (an average of 298 roots per dry pound from data collected from North Carolina dealers, by North Carolina Department of Agriculture, over the past nine years) (J. Corbin, NCDA; pers. comm.).

The current value of ginseng, based on 1999 figures, ranges from $475.00 per dry pound (value to digger) to $1,900.00 per dry pound (market value overseas, a four-fold increase over digger price) (Table 7) (M. Boyer, NCDA; J. Corbin, NCDA; and C. Robbins, TRAFFIC; pers. comm.).

If a conservative 1% apprehension rate is applied, and the amount of ginseng apprehended is multiplied by 100, then approximately $1,330,056.00 (value to digger) to $5,320,224.00 (market value overseas) worth of ginseng roots have been illegally harvested from GSMNP in just the past 9 years. This figure is calculated from the average price per dry pound ($377) over the last nine years (Table 7).

Table 7. Average number of roots per dry pound, and average price per dry pound paid to diggers, 1991 – 1999.[1]

Year	Average number of roots/dry pound	Average price /dry pound
1991	295	$310.00
1992	295	310.00
1993	299	575.00
1994	288	300.00
1995	285	350.00
1996	314	350.00
1997	291	385.00
1998	315	325.00
1999	296	490.00
Average	298 roots	$377.00

[1]data gathered from North Carolina ginseng dealers (J. Corbin, NCDA; pers. comm.)

Further, harvesting techniques are directly destructive to ginseng populations because the root is removed from the soil in its entirety leaving nothing behind to produce a new plant. Destruction to the habitat, and trampling and disturbance of neighboring plants occurs as well. Such substrate destruction, in itself, further impedes the recovery, if any, of any plants left behind. Poaching has become more sophisticated through the years. Often, several days are spent digging in remote off-trail areas. Poachers arrange drop-offs and pick-ups to avoid detection. They also cache roots for later pick-up. Recently it was observed that poachers were covering the holes created from plant removal to avoid post-harvesting detection. Tragically, in many

seized bags there are roots as young as one year up to 48 years of age. Although poachers appear to be most active in late summer, some are harvesting roots while the fruit/seeds of the ginseng plant are still green and on the plant, thus removing all reproductive potential from the population. Seizures by rangers have been made in early July – weeks before ginseng fruit/seeds ripen. If any plants were left in a poached population, they typically are not able to regenerate, or recover, before being poached again. In most cases, only a minimal seed reservoir remains in the soil.

Ginseng in GSMNP

Due to the biology of the ginseng plant and the nature of harvesting techniques, plants are unable to recover from harvest (natural history information on American ginseng is provided in Part I: Introduction). To reiterate, ginseng reproduces mainly by seed and rarely propagates by producing more than one rhizome. Plants must be older than five years to produce viable fruit, and the seeds require two winters of stratification before germinating. When combined, these factors result in slow rates of population growth (Lewis and Zenger 1982).

Genetic analysis using Randomly Amplified Polymorphic DNA (RAPD) markers showed GSMNP ginseng to possess unique genetic integrity and may represent a distinct center of genetic diversity when compared to wild ginseng populations in Pennsylvania and Wisconsin (C. Boehm, University of Wisconsin, pers. comm.). To lose, or even reduce, populations of ginseng on a local scale will represent a significant loss for the species as a whole.

METHODS and MATERIALS

Protection Techniques

GSMNP rangers and a plant specialist from North Carolina Department of Agriculture (NCDA) developed two marking techniques to deter poaching. The first technique involves applying a semi-permanent, powdered dye to the root of ginseng plants (by partially excavating a portion of the root surface for application then recovering with soil). The dye serves as an immediate deterrent and can be detected when the poacher sells collected roots to a dealer. The dye application method was used on roots of small, two- or three-pronged plants, or in combination with the following technique: the insertion of a stainless steel ribbon into the top portion of larger roots (usually three- and four-pronged plants). Once the ribbon is inserted under the surface of the root body, it can be detected with the use of a strong magnet or by x-ray. Roots were marked with a gauge of ribbon specific to one of the five ranger districts. This allows law enforcement officials to determine the source of seized roots within the Park and aids Park biologists in replanting the roots (if the roots are still viable) in or near the same general area. Any evidence of human activity at ginseng locations, such as digging, construction or maintenance of unofficial trails, and illegal camping were reported to district rangers.

Data collection

Areas to search in the field were identified through:

(1) aerial photographs and USGS quadrangle maps (7.5 minute, 1:24,000 scale),
(2) locations of extant GSMNP ginseng populations gathered from Park staff observations,
(3) Park natural history records,
(4) Park law enforcement observations on poaching activity, and
(5) vegetation type (e.g., cove forest, northern hardwood forest) and topographic attributes such as slope, aspect, and elevation.

These areas were located in the field using topographic features, compass bearings, and altimeter readings. A thorough search for ginseng was made when bloodroot *(Sanguinaria canadensis*), black cohosh (*Cimicifuga* spp.), maidenhair fern (*Adiantum pedatum*), and yellow lady's slipper (*Cypripedium pubescens*) or suitable habitat was present.

At each site, ginseng plants were flagged, aged (by counting the annual bud scars on excavated rhizomes), and marked with one of the two techniques described above. Ginseng plants encountered within, or during navigation to, the validation plots (see Part I) were also marked. When a population was discovered, its location was pinpointed on a topographic map and, whenever possible, a digital position reading obtained using a GPS unit (PLGR + 96).

Data collected at each ginseng location included dominant aspect, slope, and elevation (Data sheet, Appendix 6). Percent cover was estimated for canopy and the five dominant species were ranked. Information on reproductive status, age, and marking technique were recorded for each plant. The presence of one or all of the associated plant species was noted as well.

Size Class and Age Distribution

According to ginseng researchers (Lewis and Zenger 1982, Charron and Gagnon 1991), the structure of a ginseng population should contain mostly three-pronged plants. Four-pronged plants (typically the best reproducing individuals) are the least abundant. In order to determine the structure of each ginseng population, the number of prongs per plant was recorded. The ages of all three- and four-pronged plants were determined during the marking procedure. All roots excavated for marking were carefully aged without damage to the root or rhizome. Ages were recorded and graphed to show an overall age distribution for all plants found.

RESULTS

Habitat Data

The most common dominant canopy species associated with the protection sites were tuliptree (*Liriodendron tulipifera*), white basswood (*Tilia americana* var. *heterophylla*), and sugar maple (*Acer saccharum*). Also present were silverbell (*Halesia tetraptera* var. *monticola*), white ash (*Fraxinus americana*), yellow buckeye (*Aesculus flava*), and black locust (*Robinia pseudoacacia*). Aspects were to the north ranging from 354 °– 10°. Elevation range was 610 meters (2,000 feet) up to 1,024 meters (3,360 feet). All sites had a canopy cover greater than 75%.

Associated Plant Species Occurrence

Habitat modeling data showed positive correlations among the presence of ginseng and the four associated plant species (*Sanguinaria*, *Cimicifuga*, *Adiantum*, and *Cypripedium*) (Table 3, Part I). However, there were sites in which one or all four associated species were found, but ginseng plants were absent.

Size Class Distribution

A total of 501 plants was found in 46 locations during the 1998 protection effort. Eighty-two plants (16.4%) were marked by one of the two techniques and 97.5%. Forty-five percent of all plants were three-pronged and only 8.6% were four-pronged (Figure 11).

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

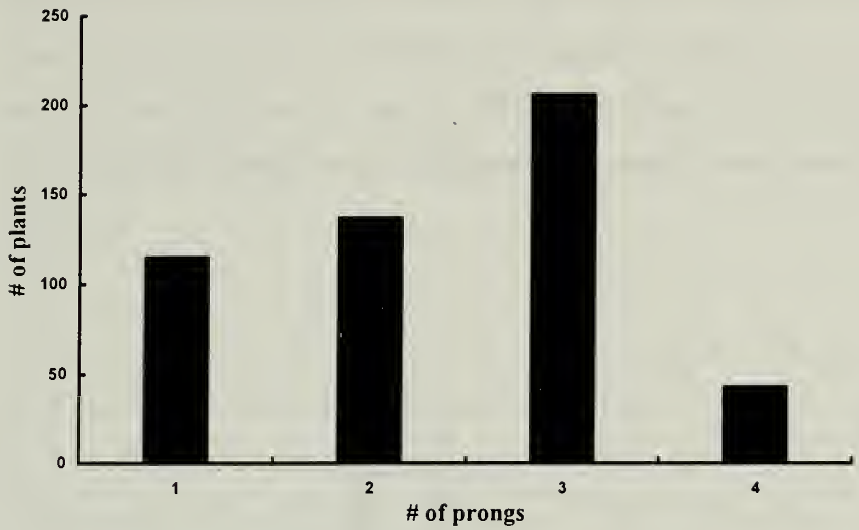

Figure 11. Size class distribution of ginseng plants encountered in 1998 (n = 501).

Age Distribution

Eighty marked plants were aged. The results were consistent with Lewis and Zenger (1982). The ages of all ginseng plants encountered during the 1998 protection effort ranged from three to 20 years, with an average age of seven years (Figure 12).

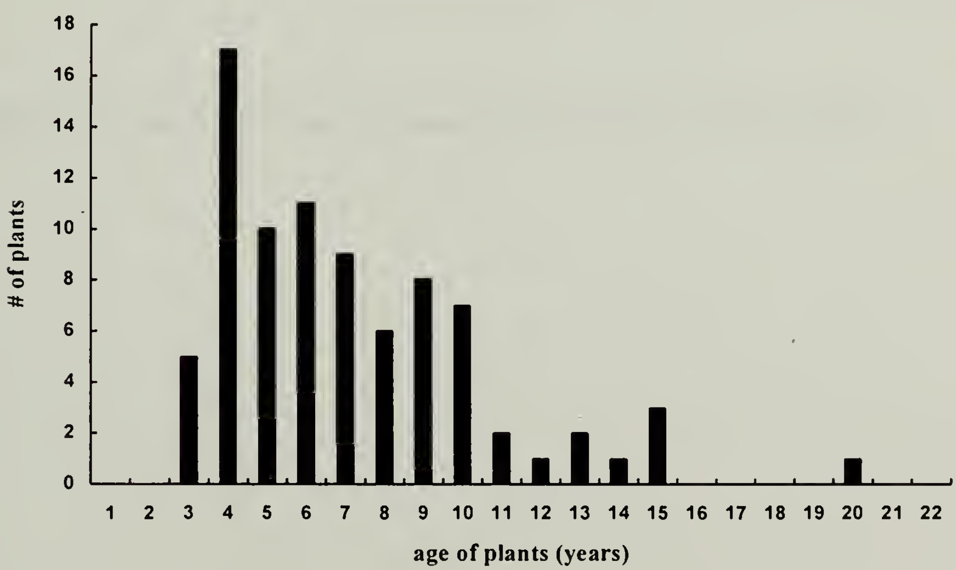

Figure 12. Age distribution of naturally occurring ginseng plants encountered during the 1998 field season efforts.

Seized Roots and Poaching Evidence

During this two-year project, GSMNP rangers seized a total of 354 ginseng roots from poachers. These roots were aged by Park biologists and then replanted. Ages of seized roots ranged from one to 47 years, with an average age of 15 years (Figure 13). Evidence of poaching, including obvious signs of digging and other human disturbance, were noted at one third of the 46 ginseng locations.

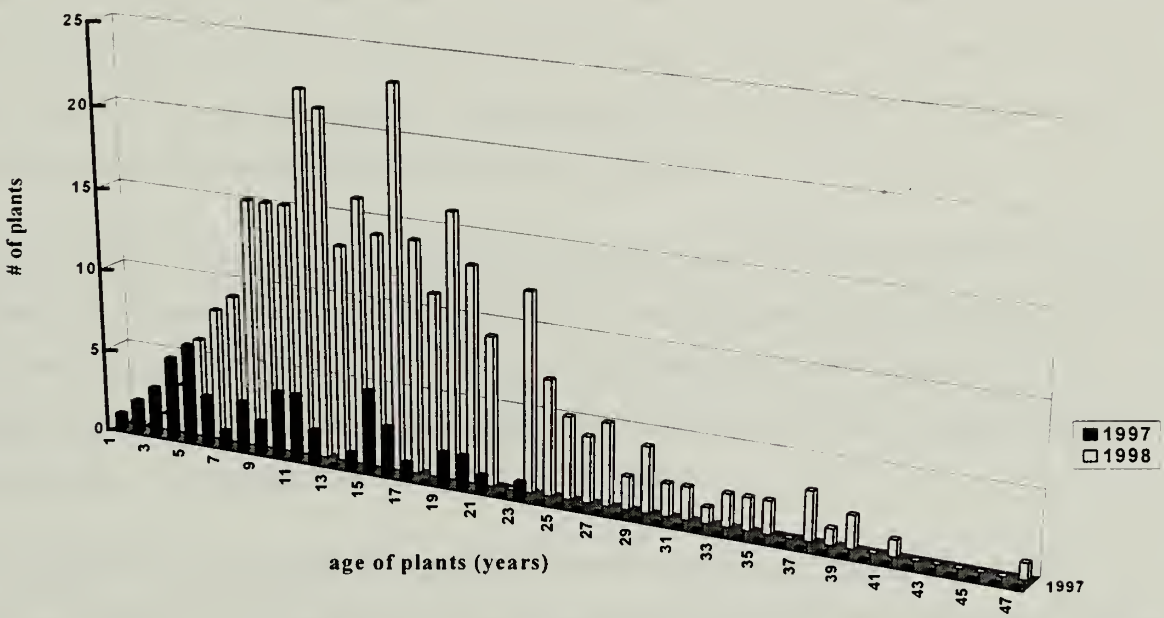

Figure 13. Age distribution of ginseng plants seized in 1997 and 1998.

DISCUSSION

Much effort and staff resources were directed towards accomplishing all aspects of the study. In particular, the protection effort (marking plants in the field) employed six full-time biological science technicians, including more field technicians working off-trail on this and other natural resource projects. Despite the scope of the project and the involvement of seasoned technicians, fewer than 1,000 ginseng plants were encountered and no additional viable populations (172 plants or more) (Nantel et al. 1996) were discovered. Many areas that were reported to have ginseng as recently as 1996 were found to have very few, if any, plants remaining in 1998. Over 600 plants within one drainage, discovered by Park rangers in August 1997, were poached less than a year later. In another instance, a ginseng population was discovered by field technicians on one day, and was poached before noon the very next day.

We were disheartened by the advanced ages of the roots seized in 1998 – the trend seems to be shifting to older plants. The oldest root was 47 years, and the mean age of all seized roots was 16.1 years (SD = 7.7). Compared with data from past years, this is the highest mean age (although not statistically significant). In 1991, the mean age was 13.2 years, higher than the mean ages for 1992 through 1996 (range 8.6 to 11.1 years).

It is evident from our study that an increase in protection efforts in GSMNP is critically important. Marking of ginseng roots by Park rangers and biologists will continue over the next several years, or until a reduction in poaching activity is seen.

LITERATURE CITED

Argus, G. W. and J. White. 1989. Panax quinquefolium L. *in*: G.W. Argus and C.J. Keddy (Eds.). Atlas of the rare vascular plants of Ontario. Part 3. Museum of Natural Sciences, National Museum of Canada, Ottawa.

Beatty, S. W. 1984. Influence of microtopography and canopy species on spatial patterns of forest understory plants. Ecology, 65: 406 - 1419.

Beers, T.W., P.E. Dress, and L.C. Wensel. 1966. Aspect transformation in site productivity research. Journal of Forestry 64: 691-692.

Beven, K. J., and M. J. Kirby. 1979. A physically based, variable contributing area model of basin hydrology. Hydrol. Science Bull. 24: 43-69.

Boetsch, J. R. and J. Rock. 1999 unpublished. Habitat modeling and conservation status of four vascular plants endemic to the southern Appalachian Mountains: National Park Service, Great Smoky Mountains National Park. 52 p.

Bratton, S. P. 1976. Resource division in an understory herb community: responses to temporal and microtopographic gradients. The American Naturalist, 110 (974): 679-693.

Cain, S. A. 1931. Ecological studies of the vegetation of the Great Smoky Mountains of North Carolina and Tennessee. I. Soil reaction and plant distribution. Botanical Gazette, 91: 22-41.

Callaway, R. M., E. C. Clebsch and P. S. White. 1987. A multivariate analysis of forest communities in the western Great Smoky Mountains National Park. The American Midland Naturalist, 118: 107–120.

Charron, D. and D. Gagnon. 1991. The Demography of Northern Populations of Panax quinquefolium (American Ginseng). Journal of Ecology, 79: 431-445.

Golden, M. S. 1981. An integrated multivariate analysis of forest communities of the central Great Smoky Mountains. American Midland Naturalist, 106: 37–53.

Halpin, P. N. 1995. A cross-scale analysis of environmental gradients and forest patterns in the Giant Sequoia - Mixed Conifer forest of the Sierra Nevada. Ph.D. dissertation, University of Virginia, Charlottesville.

Hicks, D. J. 1980. Intrastand distribution patterns of southern Appalachian cove forest herbaceous species. American Midland Naturalist, 104 (2): 209-223.

Hill, M. O. and H. G. Gauch. 1980. Detrended correspondence analysis, an improved ordination technique. Vegetatio, 42: 47-58.

Hu, S. Y. 1976. The Genus Panax (Ginseng) in Chinese Medicine. Economic Botany, 30: 11-28.

Lewis, W. H. and V. E. Zenger. 1982. Population Dynamics of theAmerican Ginseng *Panax quinquefolium* (Araliaceae). American Journal of Botany, 69(9): 1483-1490.

MacKenzie, M. D. 1993. The vegetation of Great Smoky Mountains National Park: past, present and future. Ph.D. Dissertation, University of Tennessee, Knoxville, TN.

McCune, B., and M. J. Medford. 1995. PC-ORD. Multivariate Analysis of Ecological Data, Version 2.0. MjM Software Design, Gleneden Beach, Oregon, USA. 126 p.

McNab, W. H. 1993. A topographic index to quantify the effect of mesoscale landform on site productivity. Canadian Journal of Forest Research 23: 1100-1107.

Miller, R. 1986. Predicting rare plant distribution patterns in the southern Appalachians of the southeastern U.SA. Journal of Biogeography 13: 293-311.

Muller, R. N. 1982. Vegetation patterns in the mixed mesophytic forest of eastern Kentucky. Ecology, 63(6): 1901-1917.

Nantel, P., D. Gagnon and A. Nault. 1996. Population viability analysis of American ginseng and Wild leek harvested in stochastic environments. Conservation Biology, 10: 608-620.

Nault, A. 1997. Le situation du ginseng a cinq folioles (Panax quinquefolius L.) au Quebec. Gouvernment due Quebec, Ministere de l'Environement et de la faune, Direction de la conservation et du patrimoine ecologique, Quebec, 43 p.

Nault, A., D. Gagnon, D. White, and G. Argus. 1998 unpublished. Conservation of Ginseng in Ontario. Ministry of Natural Resources, Science and Technology Report 1997/1998. 19 p.

Newman, E. I. and P. Reddell. 1988. Relationship between mycorrhizal infection and diversity in vegetation: evidence from the Great Smoky Mountains. Functional Ecology, 2: 259-262.

Parker, A. J. 1982. The topographic relative moisture index: an approach to soil-moisture assessment in mountain terrain. Phys. Geogr. 3(2): 160-168.

Parker, A. J. and K. C. Parker. 1986. A comparison of ordination techniques for interpreting forest composition in the Southern Appalachians. Southeastern Geographer, 26(1): 12-24.

Rao, C. R. 1952. Statistical methods in biometric research. J. Wiley and Sons, New York, N.Y. 390 p.

Robbins, C. S. 1998. American Ginseng: the Root of North America's Medicinal Trade. Report by TRAFFIC North America, Washington, D. C. 94 p.

Schafale, M. P., and A. S. Weakley. 1990. Classification of the natural communities of North Carolina: third approximation. North Carolina Heritage Program. 325 p.

ter Braak, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67:1167-1179.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecological Monographs, 26: 1-80.

Wilds, S. P. 1996. Gradient analysis of the distribution of flowering dogwood (*Cornus florida* L.) and dogwood anthracnose (*Discula destructiva* Redlin.) in western Great Smoky Mountains National Park. M.S. Thesis, Univ. of North Carolina, Chapel Hill. 151p.

Wolock, D. M. 1993. Simulating the variable-source-area concept of streamflow generation with the watershed model TOPMODEL. U.S. Geol. Surv. Water Resour. Invest. Rep. 93-4124.

Wolock, D. M. and G. J. McCabe, Jr. 1995. Comparison of single and multiple flow direction algorithms for computing topographic parameters in TOPMODEL. Water Resources Research 31(5): 1315-1324

APPENDICES

Appendix 1. GIS variables used to calculate Mahalanobis distance values (D^2) in GSMNP.

Name	**Description**[a]	**Value Range**[b]	**Source**
Aspect	Aspect transformed using: Beers = 1 + cos (45-aspect)	0 to 2.0	Beers et al. 1966
Elevation	Elevation (meters)	914-2,027	USGS digital elevation model (DEM)
Landform Index	Index of meso-scale topographic protection	-4.026 to 93.587	McNab 1993
Planiform	Slope curvature in horizontal - plane	8.802 to 8.838	calculated from elevation with the curvature command (grid)
Profile Curvature	Slope curvature in vertical plane	-10.906 to 8.639	calculated from elevation with the curvature command (grid)
Relative Slope Position	Relative slope position (percent)	0 to 100	Wilds 1996
Slope	Slope steepness (degrees)	0.0 to 64.467	calculated from elevation with the curvature command (grid)
Solar Insolation	Index of exposure to sunlight; approximated for the solar equinox; considers both nearby and distant shadowing factors	1 to 227	calculated from elevation with the hillshade command (grid)
Shannon-Weiner Index	Shannon-Weiner index of topographic complexity	17 to 35	Miller 1986
Topographic Convergence Index	Simulates the flow accumulation of water; TCI = ln(A/ tan B), where A is drained surface area and B is drained surface slope	17 to 182	Beven and Kirkby, 1979; Wolock 1993; Wolock and McCabe 1995; Halpin 1995
Topographic Relative Moisture Index	Index of moisture considering the effects of slope position, aspect and elevation	0 to 85	Parker 1982
Terrain Shape Index	Index of micro-scale topographic sheltering	-169 to 71	McNab 1989

Appendix 1 continued

Vegetation	Vegetation type (9 forest types, heath bald, grassy bald; grape thicket, or treeless)	categorical (1 to 13)	McKenzie 1993

[a] All variables were continuous and had base resolution of 30 m except for vegetation, which was a nominal variable. Vegetation had a base resolution of 90 m
[b] Range values were for the study area, defined as GSMNP above 914 m.

Appendix 2. Ginseng model validation data sheet.

Date: ____________ **Surveyors:** JRB JHR HH EC JT KC BY TM **Ginseng Model Validation, 3d**
Plot ID #: ________________ **Location:** ____
Coordinates: ____________e _____________n +/-______m WP# _____GPS? Y N **Quad:** ____
Elevation (ft): ___________**Aspect:** _____**Var:** high mod low **Slope** (deg): _______**Var:** high mod low
Terrain shape index (15 m): aspect____ +45 ____ +90 ____ +135 ____ +180 ____ +225 ____ +270 ____ +315 ____
Microtopography: exaggerated well-developed modest non-existent **Horizontal curvature** (30 m): concave straight convex
Slope position: toe low mid high crest **Vertical curvature** (30m): concave straight convex
Surface water: inside plot <50m >50m **Hydrology:** permanent drainage intermittent drainage seep boulderfield upland
Dominant stratum height: 30+m 20 - 30 10 - 20 5 - 10 0.5 - 5 <0.5m **Gaps:** numerous, influential few, nominal none
Dominant stratum cover (%): >60 >25 >10 <10 **Composition:** evergreen (>75% of cover) deciduous (>75% of cover) mixed

	Cover (nearest 10%)	Dominant species, in order (! principal, = equivalent dominance, ~ negligible)					
Canopy	0 20 40 60 80 100	______	______	______	______	______	**Leaf litter** : ____
Sub-canopy	0 20 40 60 80 100	______	______	______	______	______	**Evergreen** : ______
Herb	0 20 40 60 80 100	______	______	______	______	______	**Nonvasc**: ______

Y N *Sanguinaria* Y N *Cimicifuga* spp. Y N *Adiantum* Y N *Cypripedium pubescens*

Rock cover: _____ **Type:** bedrock boulders talus cobbles gravel **Old-growth?** Y N **?Soil sample collected?** Y N
Disturbance: none BWA beech scale rooting exotics homesite _______**Degree:** Slight Mod Severe

Standnotes: ____

	Panax	***Panax*** **poached?** Y N
Present in plot (31.6m²)?	Y N	
Abundance class for plot (below):	Inf: 4P_____ 3P_____2P______ 1P________	
Fertility class for plot (below):	Fert: 4P_____ 3P_____2P______ 1P________	
Are plants generally healthy? Y N	***Panax*** **health:** Anthracnose Mildew Alternaria	

Notes:____
____

Abundance: 1: < 10 2: 10 - 24 3: 25 - 49 4: 50 - 99 5: 100 - 199 6: 200 - 499 7: 500 - 999 8: 1000 - 10,000 9: 10,000 +
Fertility: 0 1: < 10% 2: 10 - 40% 3: 40 - 60% 4: 60 - 90% 5: >90% **Subplot:** 5: $(.316m)^2$ 4: $(1m)^2$ 3: $(3.16m)^2$ 2: $(15.8m)^2$ 1: plot

Canopy Species	**Coll.**	**Sub-canopy Species**	**Coll.**	**Herb Species**	**Coll.**

Appendix 3. Plant Species List For DCA Plots

A. Dry Ridgetop Plots

Acer rubrum
Carya alba
Castanea dentata
Chimaphila maculata
Cornus florida
Dryopteris intermedia
Galax aphylla
Gaylussacia ursina
Huperzia sp.
Kalmia latifolia
Leucothoe editorum
Liriodendron tulipifera
Medeola virginiana
Oxydendron arboreum
Pinus echinata
Pinus rigida
Pinus strobus
Pyrularia pubera
Quercus coccinea
Quercus montana
Quercus velutina
Rhododendron maximum
Thelypteris noveboracensis
Tsuga canadensis
Uvularia pudica
Viburnum acerifolium

B. Cove Hardwood Plots

Acer rubrum
Adiantum pedatum
Arisaema triphyllum
Betula lenta
Carya alba
Castanea dentata
Cimicifuga racemosa
Clintonia umbellulata
Cornus florida
Dryopteris intermedia
Halesia tetraptera var. *monticola*
Huperzia lucidula
Impatiens sp.
Laportea canadensis
Leucothoe fontanesiana
Liriodendron tulipifera
Lysimachia quadrifolia
Medeola virginiana
Monarda didyma
Panax quinquefolius
Parthenocissus quinquefolius
Pinus strobus
Pyrularia pubera
Quercus velutina
Rhododendron maximum
Rudbeckia lacinata
Sanguinaria canadensis
Sanicula sp.
Thelypteris noveboracensis
Tiarella cordifolia
Tilia americana var. *heterophylla*
Tsuga canadensis
Uvularia pudica
Viburnum acerifolium
Viola hastata

C. High Elevation Plots

Abies fraseri
Acer rubrum
Acer spicatum
Athyrium felix-femina spp. *asplenioides*
Betula alleghaniensis
Clintonia borealis
Dryopteris intermedia
Huperzia lucidula
Ilex montana
Impatiens sp
Laportea canadensis
Oxalis montana
Picea rubens
Prunus pensylvanica
Rhododendron catawbiense
Rubus canadensis
Sambucus canadensis
Sambucus pubens
Tiarella cordifolia
Viburnum lantanoides

Appendix 4. Ginseng protection data sheet.

Date: ______________ **Surveyors:** JRB JHR HH EC JT BY TM ______________.
Location:____

____

Ranger District: Cades Cove Little River East Oconaluftee Lake
Coordinates: ____________e ______________n +/- _____m GPS? Y N **WP#** _______
Quad: _________________**Elevation (ft):** _________ **Aspect:** ________ **Slope (deg):** _________
Slope position: toe slope low slope mid slope high slope crest **Soil sample collected?** Y N
Canopy Composition: evergreen (>75% of cover) deciduous (>75% of cover) mixed

Cover (nearest 10%) Dominant species, in order (!principal species, =equivalent dominance, ~negligible)
Canopy 0 20 40 60 80 100 _________ _________ _________ _________
Sub-canopy 0 20 40 60 80 100 _________ _________ _________ _________
Herb 0 20 40 60 80 100 _________ _________ _________ _________

Disturbance: none poaching beech scale hog rooting exotic spp homesite

___ *Sanguinaria canadensis*
___ *Cimicifuga* spp.
___ *Adiantum pedatum*
___ *Cypripedium pubescens*

Notes: ____

____

	1 pr	**2 pr**	**3 pr**	**4 pr**
# fertile				
# infertile				
Total				

	1 pr	**2 pr**	**3 pr**	**4 pr**
# marked with dye				
# marked with steel ribbons				
ages of marked plants				