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American ginseng (*Panax quinquefolius* L.) floristic associations in Pennsylvania: guidance for identifying calcium-rich forest farming sites

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Abstract In the eastern United States, there is interest among forest landowners in American ginseng husbandry, and particularly in cultivating this plant on forestlands using a wild-simulated forest farming approach. This study documented the flora and soil conditions associated with wild and wild-simulated ginseng populations throughout Pennsylvania (PA) to develop floristic "indicators" that can be used to identify supportive growing sites on forestlands. A total of 243 plant species were documented associates of ginseng across PA: 32 over-story trees, 37 shrubs and understory trees, 15 vines, 143 herbs, and 16 ferns. Statistical analysis revealed a largely shared floristic assemblage throughout the state although some associates did differ according to region and physiographic province. Previous studies have suggested that a soil calcium content, especially soils having at least 3,360 kg ha^{-1} (3,000 lbs ac), appear to be particularly conducive to wild and wild-simulated ginseng occurrence and/or vigor, and indicator species analysis in this study revealed that three of the top plant associates that can be used for determining sites that meet this calcium threshold in PA are white ash, Jack-in-the-pulpit, and rattlesnake fern. These results suggest that successful adoption of wild-simulated ginseng forest farming is likely to be improved in forested areas where these species are found collectively as a dominant component of local plant assemblages.

Keywords American ginseng · Forest farming · Medicinal plant cultivation · Plant husbandry · Wild-simulated ginseng

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Introduction

American ginseng (*Panax quinquefolius* L.), hereafter referred to as ginseng, is an herbaceous perennial forest plant that has been collected throughout eastern North America as a valued export commodity for nearly 300 years (Carlson 1986; Evans 1985). The historic native range of this species includes a broad geographic area in North America spanning from southern Canada to Georgia, and west to states along the Mississippi River (Gleason and Cronquist 1991). Currently, 19 states within this range export wild ginseng roots to supply a niche market centered in East Asia where ginseng is valued as a tonic and adaptogen (Court 2000; Hu 1976). Between 1990 and 2011, wild ginseng root exports from the United States totaled between ~20,000 and ~72,000 kg (dry weight) annually (FWS 2012). During the past 100 years, ginseng has also become a specialty field crop in certain parts of its natural North American range (e.g., Wisconsin, Ontario) and elsewhere in the world (e.g., China, Korea). These operations involve intensive cultivation methods incorporating artificial shade and mechanization, and rely heavily on pesticides to produce most of the ginseng found in commerce (OMAFRA 2005).

Significant price disparities exist between wild appearing ginseng roots originating from forestlands and cultivated product from artificially-shaded farming operations. These prices can differ as much as 100 fold with an average of $20–70 (US$ dry kg) paid for root that appears "cultivated" versus $550–2,200 (US$ dry kg) for roots with "wild" attributes (Burkhart and Jacobson 2009; Persons and Davis 2005). Such price differences are an expression of Asian cultural predilections and tradition rather than a reflection of any differences in medicinal chemistry between "wild" and "cultivated" product per se (Lim et al. 2005; OMAFRA 2005). In recent years, American ginseng has been recommended as an agroforestry crop candidate since the species appears well suited to the practice of forest farming and in particular the so-called "wild-simulated" approach to forest farming that seeks to capitalize on the premium paid for wild-appearing roots (Hill and Buck 2000; Nadeau et al. 2003; USDA NAC 2012). Using this approach, ginseng is established in the forest understory, with little site preparation or manipulation, and the resulting roots are then sold as wild in the marketplace (Beyfuss 1999; Persons and Davis 2005; Pritts 2010). This is in contrast to the 'woods-cultivated' or 'woods-grown' approach which involves greater investment of time, labor, and equipment in site modifications intended to hasten and improve yields as well as facilitate convenient management. Such investments may include forest understory manipulation (e.g., thinning), soil tillage and amendments (e.g., fertilizer, limestone), preparing and maintaining beds, and pest management (ibid).

Financial models suggest the production of "wild appearing" ginseng roots on forestlands through the use of wild-simulated forest farming methods is financially lucrative under a variety of husbandry scenarios and historic price levels (Burkhart and Jacobson 2009). As such, the production of wild-simulated ginseng on forestlands is an economic opportunity for forest landowners for generating short-term (relative to timber harvest) income. Adoption of wild-simulated ginseng husbandry could also contribute to ginseng conservation efforts by substituting intentionally grown and stewarded roots for wild-collected, spontaneously-occurring ones (Burkhart 2011; Burkhart et al. 2012). If broadly adopted, ginseng forest farming might also contribute to price stabilization and help to curb undesirable collector behaviors resulting from short-term price spikes (e.g., over-exploitation when prices peak).

For wild-simulated ginseng forest farming to be successfully practiced, landowners must be able to identify favorable planting sites. This is important because the most successful and profitable strategy for producing roots with wild traits relies upon a "hands-off" approach with little or no site manipulation (Beyfuss 1999; Persons and Davis 2005; Pritts 2010). In this regard, one of the most practical, and least expensive, means for forest landowners to identify suitable growing sites is to provide them with so-called "plant indicators" or ginseng floristic associates that can serve to identify the most promising locations (ibid).

Because forest vegetation is at least in part a reflection of underlying soil conditions (Gilliam and Roberts 2003), the use of floristic "indicators" can be of even greater value to landowners if these can be used to identify forest farming sites with desirable soil nutrient levels. Previous research suggests soil calcium content, in particular, may be important for wild and wild-simulated ginseng growth, survival and chemistry. In wild ginseng habitat studies, for example, soil calcium content of 3,360 kg ha^{-1} and greater has been associated with healthy or vigorous populations (Beyfuss 2000; Persons and Davis 2005). In wild-simulated research trials, survival and growth were improved following lime additions (Nadeau et al. 1999, 2003; Slak 2004). Konsler and Shelton (1990) found that dolomitic lime increased final root weight under cultivation while Stoltz (1982) demonstrated that calcium deficiency symptoms were the first to be expressed in hydroponic nutrient deficiency studies. Additions of lime were found by Konsler et al. (1990) to significantly alter the content of certain ginsenosides in vegetative and root tissue, as well as increase total ginsenoside levels. Ginsenosides are the secondary metabolites in *Panax* believed to be responsible for many of the purported beneficial health effects associated with consuming ginseng and ginseng products (Court 2000).

The objective of this study was to answer the following questions regarding the use of floristic associations to identify suitable forest farming sites in Pennsylvania (PA) and the surrounding region: (1) What over-, mid- and under-story species are associated with viable, reproducing wild and wild-simulated ginseng populations? (2) What soil conditions are associated with these populations? (3) Do floristic associates differ according to region, physiographic province, and/or soil conditions? (4) Of the top ginseng associates encountered in PA, are any useful for indicating desirable soil calcium levels of at least 3,360 kg ha^{-1}?

Methods and materials

Solicitation of research sites and inclusion criteria

Between 2002 and 2011, wild and wild-simulated ginseng study sites were solicited from botanists, ginseng collectors and planters, and forest landowners in PA. More than 100 sites were volunteered by individuals but only 54 were eventually included in this study because others did not meet the population criteria described below. Because of a long history of human interaction with ginseng in PA, and since the main objective of this study was to develop floristic information that could guide adoption of wild-simulated ginseng forest farming, successful wild-simulated farming sites were included in this study. Of the 54 growing sites studied, four were known wild-simulated populations established at least 10 years prior to study.

Each site was required to have at least 25 genets of various demographic stages from seedling to adult, and had to occur in reproductive clusters in at least five separate areas of the study site so that sampling plots did not overlap. The number of genets at each study location accordingly ranged from a minimum of 25 genets to more than 1,000. Most populations in this study contained between 51 and 100 genets and were scattered in reproductive clusters over an area of two or more acres (Fig. 1a, b).

A total of 54 sites and 270 understory plots were included in this study. These sites were located throughout the state within 34 of PA's 67 counties (Fig. 2). Most study locations (33 sites, 165 plots) were located in the Appalachian Plateau Province, followed by the Ridge and Valley (14 sites, 70 plots), Piedmont (5 sites, 25 plots), and New England Provinces (2 sites, 10 plots). Because only two sites were in the New England Province, these were included with the geographically adjacent Piedmont Province data for analysis.

Vegetation sampling methods

Plots and plot centers were established at each site using a stratified but non-random approach in which the goal was to document only the vegetation in close proximity to "clusters" or "patches" of ginseng while still attempting to capture any and all floristic and/or site features. The intent was to ensure that only the nearest neighbors to ginseng at each location were recorded; no attempt was made to inventory the entire flora at each site or account for any vegetation differences associated with areas of each site where ginseng did not occur. Similar approaches have been used in Arkansas (Fountain 1986), Illinois (Anderson et al. 1984, 1993), Kentucky (Jones and Wolf 2001), Missouri (Farrington 2006), Quebec (Nadeau and Olivier 2003) and Wisconsin (Anderson 1996; Carpenter 1980) (Fig. 3).

Forest over-story and under-story vegetation associated with ginseng were documented using a combination of plot and plot-less sampling methods. At each site, five circular plots, each with an area of 29.2 m^2 ($d = 6.1$ m, $r = 3.1$ m), were used for sampling the herbaceous layer. The size of this plot was based on the premise that only the nearest neighbors to ginseng were to be recorded. Each plot was then divided into four quarters to document mid- and over-story trees following a point-centered quarter-method approach (Causton 1987; Kent and Coker 1992). Using this method, only the nearest dominant or co-dominant canopy tree (stems $\geq$7.6 cm diameter at breast-height (DBH) (1.4 m) and height $\geq$1.4 m) within each quarter was recorded, yielding one tree per quarter and four trees per plot. DBH was recorded for each tree species to calculate importance values (Curtis and McIntosh 1951; McCune and Grace 2002).

Each study site was visited for sampling purposes at least three times between 2002 and 2011. Multiple visits were made to ensure thorough documentation of seasonal transitions in vegetation and to ensure accuracy of any questionable plant species identifications. Visits were timed to document the spring and early summer flora at each site (April–May) and then mid- to late summer flora (July–August). Most sites

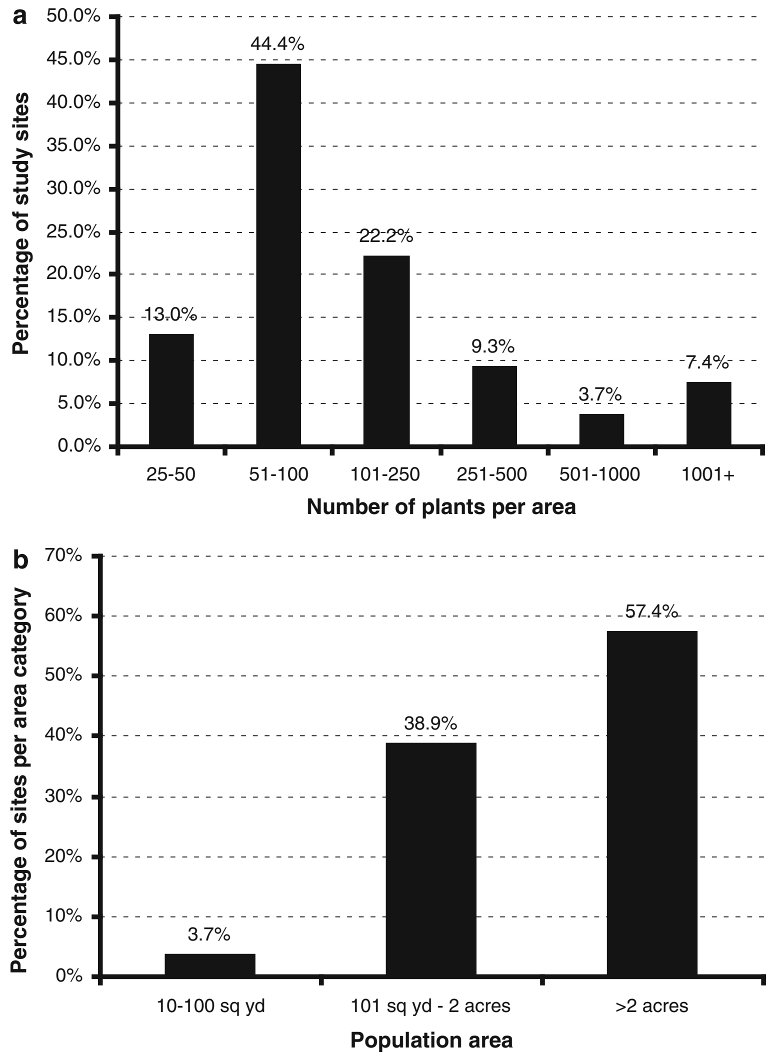


Fig. 1 **a** (*top*) American ginseng population sizes n = 7, 24, 12, 5, 2, 4 (*left to right*) and **b** (*bottom*) the total area per population for field study sites in Pennsylvania n = 2, 21, 31 (*left to right*)

were visited more than three times to achieve comprehensive documentation.

Global Positioning System (GPS) coordinates for all study sites are on file with PA Department of Conservation and Natural Resources (DCNR). Voucher specimens for ginseng were collected at all study sites and were deposited in 2011 in herbaria at the Carnegie Museum of Natural History (Pittsburgh, PA) and The Morris Arboretum of the University of Pennsylvania (Philadelphia, PA).

Soil sampling methods and analysis

A soil auger was used to collect five soil samples (A-horizon, generally 0–20 cm depth) at each site, one from each plot. When collecting these samples, any coarse leaf litter (O-horizon) was first removed. Because plots were located throughout each site, these samples represented a variety of microsite differences resulting from slope position and/or location, but were always proximal (i.e., within 15 cm) of the stem and immediately adjacent to the root) to a selected vigorous individual ginseng plant within each plot. Due to cost, only a single sample was collected for texture analysis (i.e., particle size analysis) at each site, at random from one of the five plots.

All soil samples were delivered to the Pennsylvania State Agricultural Analytical Services Laboratory, University Park, PA for analysis. At the laboratory, samples were dried and then analyzed using the

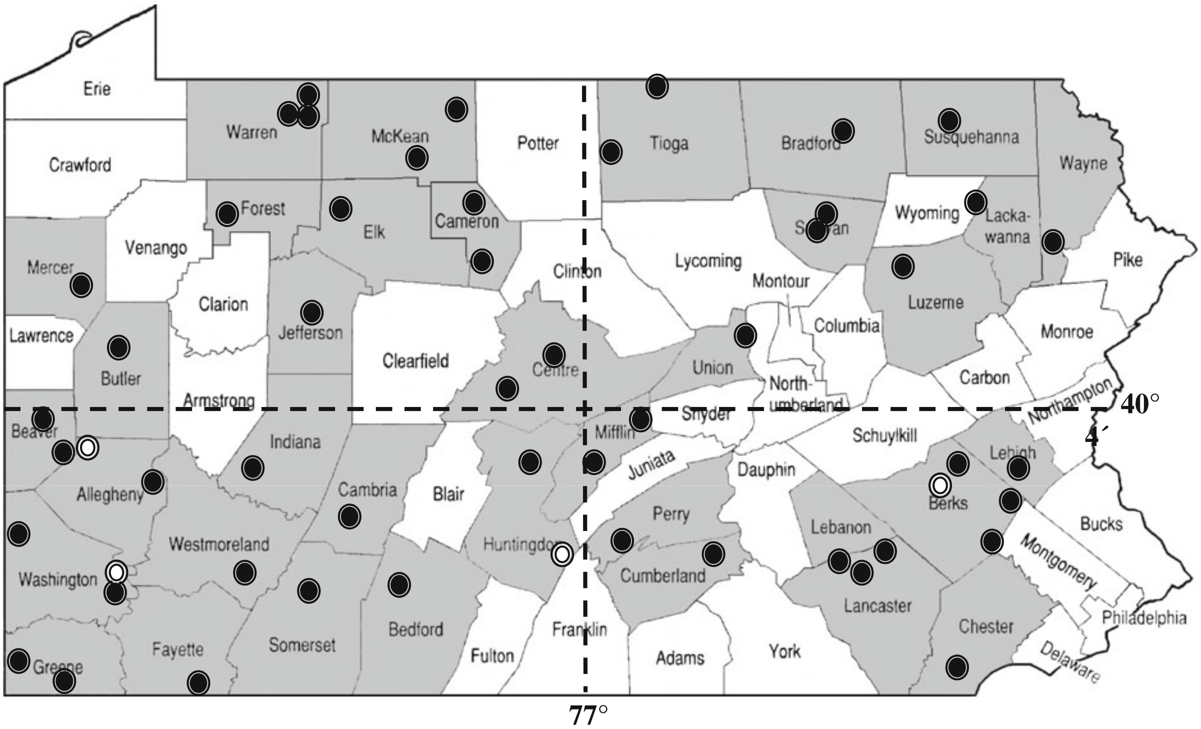
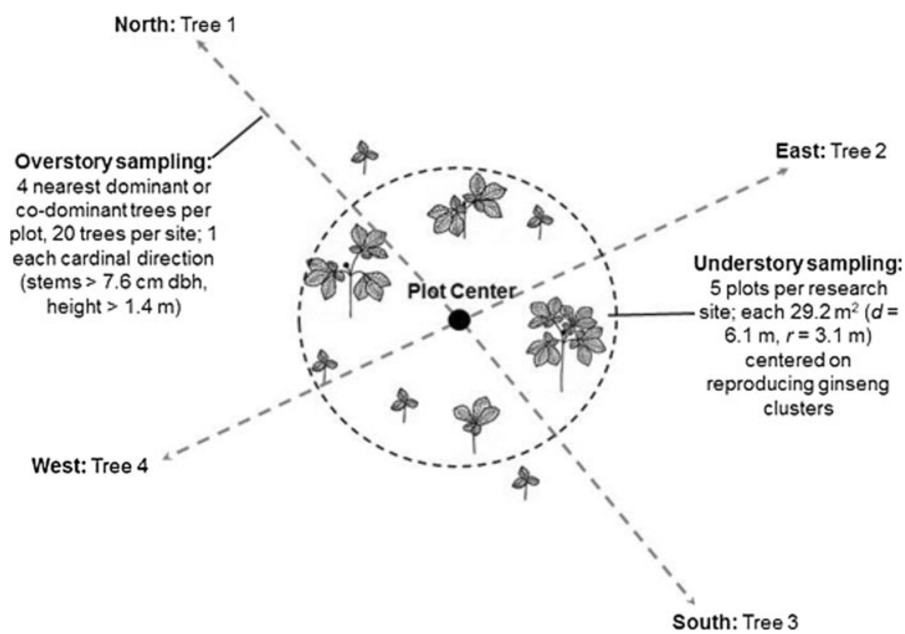


Fig. 2 Counties where ginseng floristic associations were studied in Pennsylvania (*shaded*). *Open circles* (*white*) represent "wild simulated" ginseng study sites while *closed circles* (*black*) were presumed wild study populations. For analyses by region, the latitude of 40°45′ was used to divide Pennsylvania into northern and southern halves, while the longitude 77°45′ was used to divide the state into eastern and western halves

Fig. 3 Vegetation documentation schematic for American ginseng field study sites in Pennsylvania



following protocol: soil pH was determined using the Water method (Eckert and Sims 1995); macro-nutrient content (available P, K, Ca, Mg) of samples was determined using the Melich 3 (ICP) method (Wolf and Beegle 1995); organic matter content was determined via the Loss on Ignition method (Schulte 1995); and texture analysis was conducted using the Hydrometer method (Gee and Bauder 1986).

Data analysis

The data set consisted of: 270 herbaceous layer sample plots; 1,180 over-story trees; 270 soil chemistry samples; and 54 texture samples. In addition to generating descriptive statistics for all floristic and soil data collected, indicator species analysis (ISA) was conducted and two parameters of interest were calculated: (1) An index of floristic similarity between sites (Sørenson coefficient (S_s) = 1 − 2C/A + B where *A* and *B* are the species numbers in samples A and B and C is the number of species shared by the two samples) (McCune and Grace 2002); and (2) Importance values for top over-story species. Importance values (IV) for each dominant or co-dominant over-story tree species were calculated using relative density, relative dominance, and relative frequency data (Curtis and McIntosh 1951; Kent and Coker 1992).

To examine soil characteristics between study sites, a two- or three-way parametric analysis of variance (ANOVA, $P \leq 0.05$) was used to compare soil traits (e.g., pH, nutrient levels, physical properties) using region (df = 1) and physiographic province as main effects (df = 2). For site variables having three categories (e.g., physiographic province), post hoc mean separation between main effects was by Fisher's Least Significant Difference test (LSD) with the significance level set at $P \leq 0.05$. The Levene Test for Homogeneity of Variances was used to examine data normality prior to conducting parametric ANOVA.

ISA was used to determine if floristic associates differed according to geographic location and/or soil calcium content. ISA was also used to examine the presence of indicator flora that might be expected under soil conditions supportive to ginseng growth/survival. This method uses relative frequency and abundance data, and the product of the two, to derive an "indicator value" (IndVal = $A_{ij} \times B_{ij} \times 100$, where A_{ij} = $\text{Nindividuals}_{ij}/\text{Nindividuals}_{i}$ and $B_{ij} = \text{Nsites}_{ij}/\text{Nsites}_{j}$). A Monte Carlo randomization procedure is then used to determine significance (Dufrêne and Legendre 1997; McCune and Grace 2002).

Geographic factors of interest in this study were: region (north, south, east, and west) and physiographic province (Appalachian Plateaus, Ridge and Valley, and Piedmont). For ISA and ANOVA using region as a variable of interest, PA was dissected according to latitudes and longitudes which roughly divide the state into quarters. The latitude of 40°45′ to divided PA into northern and southern halves, while the longitude 77°45′ divided the state into eastern and western halves (Fig. 2).

For ISA, a soil calcium content of ≥3,360 kg ha^{-1} was chosen as the break point since this threshold has been suggested as important to ginseng survival and vigor by previous researchers and authors (c.f., Beyfuss 2000; Persons and Davis 2005).

ISA and similarity indices were calculated using PC-ORD (Multivariate Analysis of Ecological Data, v. 6.0, MJM software design, Gleneden Beach, Oregon). A total of 4,999 randomizations were used for Monte Carlo tests, with the significance level set at $P \leq 0.10$ (herbaceous flowering plants and ferns) and $P \leq 0.15$ (over-story and mid-story trees, shrubs, and vines) for analyses according to region and province. A significance level of $P \leq 0.10$ was used for examining floristic associations according to soil calcium levels. ANOVA analysis of soil data was conducted using the Statistical Package for the Social Sciences (v. 15, SPSS Inc. 2007). All plant nomenclature follows Rhoads and Block (2007).

Results and discussion

Overall similarity in flora

A total of 243 plant species were documented associates of ginseng across the study sites: 32 over-story trees (i.e., dominant or co-dominant canopy position), 52 mid- and under-story trees, shrubs, and vines, 143 herbs and 16 ferns. Although a large number of species were associated with ginseng across PA, Sørenson coefficients revealed considerable similarity between sites with an average of one-third (35 %) to nearly half (45 %) shared floristic similarity between sites (Table 1). The highest average Sørenson coefficients were associated with ferns. The range in Sørenson coefficients was 0 (i.e., no shared species) to

100 % (i.e., identical species composition) for both plots and sites. Given the diverse geographical and ecological context of PA, this suggests that a shared floristic indicator assemblage may provide useful guidance throughout the state for site selection. This shared assemblage is discussed further in the following sections; a complete list of floristic associates is available in Burkhart (2011).

Table 1 Floristic similarity index results for American ginseng study sites in Pennsylvania

	Sørenson coefficient (S_s)			
	Mean (%)	SD (%)	Min (%)	Max (%)
Between sites (*n* = 54)				
Trees, shrubs, vines	36	14	0	79
Herbaceous flowering plants	36	12	4	72
Ferns and allies	45	23	0	100
Overall	37	10	5	63
Between plots (*n* = 270)				
Trees, shrubs, vines	23	18	0	100
Herbaceous flowering plants	24	13	7	100
Ferns and allies	33	29	0	100
Overall	25	12	15	100

Over-story associates (i.e., dominant and co-dominant canopy trees)

Thirty-two canopy tree species were associated with ginseng in PA. The most common associate was sugar maple (*Acer saccharum* Marshall), which occurred on 69 % of sites and 56 % of plots (Table 2). There was little difference in ranking when importance values for the 10 most common trees were calculated, except tulip-poplar which increased from fourth to second rank based on site dominance values (Table 3). Of 32 species, 21 occurred on less than 20 % of sites and fewer than 5 % of plots. ISA indicated that the occurrence of the more common over-story trees (occurring on 20 % or more of sites) differed according to region (i.e., latitude, longitude) and/or physiographic province. Of these, region was the most common determinant of co-occurrence with 9 of 11 top associated species differing according to latitude or longitude.

A comparison of the top ranked over-story tree associates from this study with results from other states and regions reveals many similarities. Of particular interest is the fact that sugar maple was the most common (70 %) over-story tree associated with ginseng in PA. ISA indicated that sugar maple is most commonly associated with ginseng in the

Table 2 Over-story trees associated with American ginseng in PA along with indicator species analysis (ISA) results for geographic region, physiographic province and soil characteristics

Scientific name	Common name	Percentage of sites and (*n*)	Percentage of plots and (*n*)	ISA variables (refer to footnotes)			
				Lat	Long	Prov	Ca
Acer saccharum Marshall	Sugar maple	70 (38)	56 (151)	N***	W*	AP***	
Fraxinus americana L.	White ash	61 (33)	31 (83)	N***	E**		>3,360**
Tilia americana L.	American basswood	59 (32)	31 (84)	N**			
Liriodendron tulipifera L.	Tulip-poplar	48 (26)	27 (74)	S***	E*	P***	
Prunus serotina L.	Black cherry	46 (25)	20 (53)		W***	AP***	<3,360***
A. rubrum L.	Red maple	44 (24)	19 (51)	N***	E***		
Quercus rubra L.	Northern red oak	44 (24)	18 (49)	S***			
Fagus grandifolia Ehrhart	American beech	43 (23)	14 (38)				
Q. alba L.	White oak	25 (14)	9 (24)	S***			<3,360*
Betula lenta L.	Black birch	22 (12)	9 (23)	S*	E***	P***	
Tsuga canadensis (L.) Carrière	Eastern hemlock	22 (12)	6 (16)				

Only associates occurring on 20 % or more of research sites are given (*n* = 54 sites/270 plots)

Lat latitude: *N* north, *S* south relative to 40°45′; *Long* longitude: *W* west, *E* east relative to 77°45′; *Prov* physiographic province: *AP* Appalachian Plateau, *RV* Ridge and Valley, *P* Piedmont; *Ca* soil calcium content (kg ha^{-1})

Monte Carlo test of significance *P*-values: * $P \leq 0.10$, ** $P \leq 0.05$, *** $P \leq 0.01$

Table 3 Relative abundances and importance values (IV) for the top ten ranked overstory tree species (stems greater than 3 in. dbh) associated with wild and "wild simulated" populations of ginseng in Pennsylvania (all study plots combined)

Species	Relative Abundance			IV	IV %
	Frequency	Density	Dominance		
Acer saccharum	55.9	25.1	47.4	128.4	42.8
Liriodendron tulipifera	27.4	13.0	21.0	61.4	20.5
Fraxinus americana	30.7	9.9	10.4	51.1	17.0
Tilia americana	31.1	9.4	7.8	48.3	16.1
Prunus serotina	19.6	6.6	3.5	29.7	9.9
A. rubrum	18.9	6.9	3.1	28.9	9.6
Quercus rubra	18.1	4.9	3.5	26.5	8.8
Fagus grandifolia	14.1	4.1	1.2	19.4	6.5
Q. alba	8.9	2.2	0.5	11.6	3.9
Betula lenta	8.5	2.3	0.3	11.1	3.7

northern and western regions, which largely overlap and correspond with the Appalachian Plateau Province (also indicated by ISA). This may be expected since the northern third of PA is dominated by the "northern hardwood" forest type of the Appalachian Plateau and sugar maple figures prominently across these sectors (Rhoads and Block 2005).

Sugar maple has similarly been reported as the most common over-story associate in Illinois (Anderson et al. 1984, 1993), Missouri (Farrington 2006), New York (Beyfuss 2000) and Quebec (Nadeau and Olivier 2003), and one of the top ranked associates in Wisconsin (Anderson 1996) and Arkansas (Fountain 1986). Although sugar maple can tolerate a wide range of pH conditions, it has most commonly been linked to "rich" sites having soils with a pH above 5.5 (Godman et al. 1990) and high levels of exchangeable calcium (Long et al. 2009; Sharpe and Drohan 1999). Unexpectedly in this study, however, ISA revealed that there was no statistically significant correlation observed between sugar maple and soil calcium levels. Beyfuss (2000) has similarly noted this apparent contradiction in New York and suggested it may be due to the often significant foliar calcium contributions provided by decaying sugar maple leaves (Godman et al. 1990), but which may not be reflected in soil analysis results unless the O-horizon (i.e., organic litter or "duff" layer) is included in analysis samples. In this study, soil core samples were taken after removing the O-horizon to expose the mineral soil and so calcium may have inadvertently been excluded.

Of the remaining top ranked over-story trees in PA, the following have been reported as frequent associates elsewhere in the natural range of ginseng: American beech (*Fagus grandifolia* Ehrhart), white ash (*Fraxinus americana* L.), tulip-poplar (*Liriodendron tulipifera* L.), white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), and basswood (*Tilia americana* L.) (Anderson et al. 1993; Anderson 1996; Farrington 2006; Fountain 1986; Nadeau and Olivier 2003). ISA indicated that many of these tree species were more or less common as associates on a regional basis in PA. For example, ISA revealed that tulip-poplar was a more frequent associate in the southern and eastern portions of the state, including the Piedmont Province. This correlates well with distribution maps for the species (c.f., Beck 1990; Rhoads and Block 2005), which indicate a more southerly distribution. Similarly, both of the top associated oak species, white oak and northern red oak, were more commonly associated with ginseng in the southern half of PA, a distribution that corresponds with the "Appalachian oak" forest type found in the southern two-thirds of the state (Rhoads and Block 2005).

The fact that red maple (*Acer rubrum* L.) and black cherry (*Prunus serotina* L.) were among the top ranked over-story associates in PA (both in terms of frequency and importance value) is notable since these species are less commonly reported as top associated species elsewhere in the range. Exceptions are Rock et al. (1999) and Farrington (2006) who noted red maple as a canopy species in eastern Tennessee–North Carolina and Missouri, respectively, and Nadeau and Olivier (2003) who noted black cherry as an associated over-story element on 38 % of research sites in Quebec. Overall both of these species appear to figure more prominently as ginseng associates in PA than in other states (based on existing published research). It is worth noting that red maple is the most abundant tree in PA according to the most recent forest inventory analysis data while black cherry ranks closely behind at third (McWilliams et al. 2007). Thus, the more common association of these species in PA may be a consequence of historical land-use and/or forest management practices.

Of the tree species associated with ginseng, white ash may be the most useful and/or reliable indicator for moderate to high calcium sites. This species is commonly associated with high calcium soils, and research has shown calcium is second (after nitrogen) in importance among white ash macronutrient requirements (Schlesinger 1990). In this study, white ash was found on nearly two-thirds (61 %) of sites and ISA revealed it was associated with ginseng most commonly on sites with soil calcium content greater than 3,360 kg ha^{-1}. This species was a more commonly associated with ginseng in the northern and eastern halves of PA.

Mid- and under-story woody associates (i.e., shrubs, understory trees and vines)

Fifty-two species of shrubs, trees, and vines were mid- or under-story floristic associates of ginseng in PA (Table 4). The most common associate was Virginia-creeper (*Parthenocissus quinquefolia* (L.) Planch.), occurring on 76 % of sites and 51 % of plots. Forty-one species occurred on less than 20 % of sites and fewer than 8 % of plots. ISA indicated that the occurrence of some of the more common associates (occurring on 20 % or more of sites) differed according to region (i.e., latitude, longitude) and/or physiographic province. Region was the most common determinant of co-occurrence with 10 of 11 top associated species differing according to latitude.

Virginia-creeper was the most frequent vine associate of ginseng in this study, found on more than three-quarters (76 %) of sites and over half (51 %) of plots. This species has been documented as a frequent ginseng associate in other parts of its range (c.f., Anderson 1996, Anderson et al. 1993, Farrington 2006, Jones and Wolf 2001). However, Virginia-creeper can persist under a variety of habitat conditions, many of which are not especially conducive to ginseng (e.g., forest edges, field margins, and roadside areas). Rather than attributing this association to both of these species having a similar ecological niche, the frequent association of these two species may be better explained by similarities in morphology: both have a palmate-compound leaf. This vegetative similarity makes distinguishing between the two difficult to the untrained eye during many life stages and seasons.

Table 4 Mid- and under-story trees, shrubs and vines associated with American ginseng in PA along with indicator species analysis (ISA) results for geographic region, physiographic province and soil characteristics

Scientific name	Common name	Percentage of sites and (*n*)	Percentage of plots and (*n*)	ISA variables (refer to footnotes)			
				Lat	Long	Prov	Ca
Parthenocissus quinquefolia (L.) Planch.	Virginia-creeper	76 (41)	51 (138)	S***		P***	
Lindera benzoin (L.) Blume	Spicebush	56 (30)	41 (111)	S***		P***	
Viburnum acerifolium L.	Maple-leaved viburnum	52 (28)	23 (62)	S***		P***	
Hamamelis virginiana L.	Witch-hazel	52 (28)	22 (60)	S**		RV*	
Toxicodendron radicans (L.) Kuntze	Poison-ivy	46 (25)	23 (61)	S***		P***	
Ostrya virginiana (Mill.) K. Koch	Hop-hornbeam	44 (24)	16 (43)	N**			
Ribes cynosbati L.	Prickly gooseberry	35 (19)	12 (32)	N***		AP***	
Vitis spp.	Wild grape	35 (19)	11 (30)	S**			
Acer pensylvanicum L.	Striped maple	25 (14)	19 (50)	N*		RV**	>3,360*
Sambucus racemosa L.	Red-berried elder	30 (16)	11 (29)	N***			
Rubus spp.	Blackberry	30 (16)	9 (25)				

Only associates occurring on 20 % or more of research sites are given ($n = 54$ sites/270 plots)

Lat latitude: *N* north, *S* south relative to 40°45′; *Long* longitude: *W* west, *E* east relative to 77°45′; *Prov* physiographic province: *AP* Appalachian Plateau, *RV* Ridge and Valley, *P* Piedmont; *Ca* soil calcium content (kg ha^{-1})

Monte Carlo test of significance *P*-values: * $P \leq 0.10$, ** $P \leq 0.05$, *** $P \leq 0.01$

This association could therefore be a result of "plant mimicry" whereby collectors inadvertently pass over ginseng due to the presence of Virginia-creeper. On sites where Virginia-creeper is not present, or occurs in low numbers, ginseng would be more readily apparent to collectors and thus is perhaps more likely to be collected.

Nearly all of the remaining top ranked mid- and under-story shrub/tree/vine ginseng associates in PA have been reported as associates elsewhere (e.g., Anderson et al. 1984; Anderson 1996; Farrington 2006; Nadeau and Olivier 2003) and most are "weedy." This is true also of striped maple (*A. pensylvanicum* L.) which ISA associated with ginseng on sites having at least 3,360 kg ha^{-1} of calcium. Exceptions are maple-leaved viburnum (*V. acerfolium* L.), which was found on more than half (52 %) of study sites, and prickly gooseberry (*Ribes cynosbati* L.) which co-occurred on about a third (35 %) of sites. Other researchers (e.g., Anderson 1996, Farrington 2006) have noted gooseberries (*Ribes* spp.) as ginseng associates in other states, especially *R. missouriense* Nutt. Ex Torr. and A. Gray (also found in PA but not on any sites in this study), but none have reported prickly gooseberry.

Maple-leaved viburnum occurs statewide in PA (Rhoads and Klein 1993) but was most commonly associated with ginseng in the southern portion of the state, and especially within the Piedmont Province. By contrast, ISA results indicated that prickly gooseberry was more commonly associated with ginseng in northern PA, and within the Appalachian Plateau Province in particular. The latter finding agrees with the known distribution for this species in the state which is largely restricted to the Appalachian Plateau Province (Rhoads and Klein 1993; Rhoads and Block 2007). Both findings suggest delimited indicator values for each of these species with maple-leaved viburnum being more useful or reliable in southern PA while prickly gooseberry may be a more useful/reliable in the northern part of the state. Neither species was associated with soil calcium levels of 3,360 kg ha^{-1} or greater.

Under-story herbaceous layer associates (i.e., flowering plants and ferns)

A total of 143 species of herbaceous flowering plants were associated with ginseng in PA, along with 16 ferns. The most commonly associated flowering herb was Jack-in-the-pulpit (*Arisaema triphyllum* (L.) Schott), which occurred on 93 % of sites and 80 % of plots, while the most common fern was Christmas fern (*Polystichum acrostichoides* (Michx.) Schott), which occurred on 74 % of sites and 54 % of plots (Table 5). One-hundred and twelve species of flowering herbs occurred on less than 30 % of sites and fewer than 20 % of plots. Eleven ferns occurred on less than 30 % of sites and fewer than 15 % of plots. ISA indicated that the occurrence of the more common of these herbs (occurring on 30 % or more of sites) differed according to region (i.e., latitude, longitude), physiographic province and/or soil conditions. A complete listing of all ginseng herbaceous layer associates is included in Burkhart (2011).

Based upon fieldwork in Great Smoky Mountains National Park in eastern Tennessee and North Carolina, Rock et al. (1999) suggested that bloodroot (*Sanguinaria canadensis* L.), black cohosh (*Actaea racemosa* L.), maidenhair fern (*Adiantum pedatum* L.), and yellow lady-slipper (*Cypripedium parviflorum* Salisb.) could be useful for predicting ginseng habitat. Of these four species, black cohosh and maidenhair fern were the most common associates in PA, and were present on 42 and 27 % of sites, respectively. Bloodroot and yellow lady-slipper, comparatively, were only present on 18 and 4 % of sites in PA, respectively.

Jack-in-the-pulpit was the most common flowering herb ginseng associate in PA, occurring on 93 % of sites and 80 % of plots. This species has also been found to be a top or top-ranked associate in Illinois (Anderson et al. 1984), Kentucky (Jones and Wolf 2001), Missouri (Farrington 2006), Quebec (Nadeau and Olivier 2003) and Wisconsin (Anderson 1996). Thatcher et al. (2006) found this species was one of the top ginseng indicators on sites located in eastern Kentucky and southern West Virginia. Rhoads and Block (2007) describe the habitat for this species as "moist woods, swamps, and bogs" and note it is found throughout PA. ISA results indicate Jack-in-the-pulpit was most commonly associated with ginseng in the eastern half of the state, and on soils with calcium levels greater than 3,360 kg ha^{-1}. These findings, and considering the broad habitat niche associated with this species, suggest it is most useful as an "indicator" when encountered on forestlands.

With regard to ferns, the most common ginseng associates in PA were Christmas fern, rattlesnake fern

Table 5 Under-story herbaceous layer (flowering plants and ferns) associates of American ginseng in PA along with indicator species analysis (ISA) results for geographic region, physiographic province and soil characteristics

Scientific name	Common name	Percentage of sites and (*n*)	Percentage of plots and (*n*)	ISA variables (refer to footnotes)			
				Lat	Long	Prov	Ca
Arisaema triphyllum (L.) Schott	Jack-in-the-pulpit	93 (50)	80 (216)		E**		>3,360*
Polygonatum pubescens (Willd.) Pursh	Solomon's-seal	80 (43)	39 (104)			P*	
Circaea canadensis (L.) Hill	Enchanter's-nightshade	74 (40)	59 (158)	S***		P*	
Polystichum acrostichoides (Michx.) Schott	Christmas fern	74 (40)	54 (146)	N**			
Galium triflorum Michx.	Sweet-scented bedstraw	69 (37)	41 (110)	N***			
Botrychium virginianum (L.) Sw.	Rattlesnake fern	69 (37)	38 (102)		E**	P***	>3,360**
Podophyllum peltatum L.	Mayapple	65 (35)	37 (101)	S***		P**	
Maianthemum racemosum Link.	False Solomon's-seal	63 (34)	33 (90)	S**		P***	
Ageratina altissima (L.) R.M. King and H. Robinson	White-snakeroot	59 (32)	35 (95)				
Eurybia divaricata (L.) Nesom	White wood aster	57 (31)	33 (88)	N*			
Dryopteris marginalis (L.) A. Gray	Marginal wood fern	54 (29)	34 (92)	N***			
Persicaria virginiana (L.) Gaertner	Jumpseed	52 (28)	31 (83)		W***		
Viola pubescens Aiton	Downy yellow violet	52 (28)	26 (71)				
D. carthusiana (Vill.) H.P.	Spinulose wood fern	50 (27)	36 (96)	N*	W**	AP*	
Osmorhiza claytonii (Michx.) C.B. Clarke	Sweet-cicely	48 (26)	26 (69)				
Actaea pachypoda Elliot	Doll's-eyes	44 (24)	29 (78)	N***			
A. racemosa L.	Black cohosh	43 (23)	30 (80)	S***		P*	
D. intermedia (Muhl.) A. Gray	Evergreen wood fern	43 (23)	25 (68)	N***		RV*	
G. circaezans Michx.	Wild-licorice	43 (23)	24 (66)		E*	P***	
Trillium erectum L.	Purple trillium	43 (23)	19 (50)	N***		AP**	
Pilea pumila (L.) A. Gray	Clearweed	41 (22)	24 (64)		W*		
Collinsonia canadensis L.	Horse-balm	41 (22)	21 (56)	S***		P***	
Uvularia perfoliata L.	Bellwort	39 (21)	19 (50)				
Geum canadense Jacq.	White avens	39 (21)	14 (38)				
Ranunculus abortivus L.	Small-flowered crowfoot	37 (20)	11 (31)				
V. hirsutula Brainerd	Southern wood violet	35 (19)	20 (53)	S***			
Caulophyllum thalictroides (L.) Michx.	Blue cohosh	35 (19)	19 (51)	N**		AP**	
Geranium maculatum L.	Wood geranium	35 (19)	16 (42)	S***		P**	
V. canadensis L.	Canada violet	33 (18)	24 (65)				
Dioscorea villosa L.	Wild yam	31 (17)	15 (41)	S***		P**	

Only associates occurring on 30 % or more of research sites are given ($n = 54$ sites/270 plots)

Lat latitude: *N* north, *S* south relative to 40°45′; *Long* longitude: *W* west, *E* east relative to 77°45′; *Prov* physiographic province: *AP* Appalachian Plateau, *RV* Ridge and Valley, *P* Piedmont; *Ca* soil calcium content (kg ha^{-1})

Monte Carlo test of significance *P*-values: * $P \leq 0.10$, ** $P \leq 0.05$, *** $P \leq 0.01$

(*Botrychium virginianum* (L.) Sw.), and wood fern (*Dryopteris* spp.). All have similarly been reported as top associates elsewhere within the natural range (Anderson et al. 1984; Farrington 2006; Nadeau and Olivier 2003). Of particular interest is rattlesnake fern, which was present on more than two-thirds (69 %) of sites in this study and most commonly on eastern sites with soil calcium levels above 3,360 kg ha^{-1}. Rhoads and Block (2007) have noted the habitat for this species in PA is "rich loamy woods and moist wooded slopes" and is distributed throughout the state. This fern was associated with ginseng on 69 % of sites in Illinois (Anderson et al. 1984), 59 % of research sites in Kentucky (Jones and Wolf 2001), 53 % of sites in

Missouri (Farrington 2006) and 45 % of sites in Quebec (Nadeau and Olivier 2003), suggesting an important indicator role for this species across a broad range of eastern North America. In addition to rattlesnake fern, other common names for this fern include "seng/sang pointer," "seng/sang sign," and "seng/sang fern" (Bergen 1894, Waters 1903). All of these latter common names allude to this species usefulness as a "folk indicator" to locate ginseng throughout Appalachia, a belief that goes back at least 100 years (Bergen 1894; Waters 1903). It should be noted that this species is the most widespread *Botrychium* in North America (Wagner and Wagner 1993).

Soil results

Soil characteristics associated with wild and wild-simulated ginseng varied considerably in PA both within and between sites (Table 6). The minimum soil pH associated with ginseng across all study sites was 4.2 and the maximum was 7.8, with an average pH across all sites of 5.3. Macro-nutrient levels also varied considerably. Varying soil conditions have been reported in ginseng studies from Arkansas (Fountain 1982), Illinois (Anderson et al. 1984, 1993), Kentucky (Jones and Wolf 2001), Missouri (Farrington 2006), New York (Beyfuss 2000), and Wisconsin (Anderson 1996). Ginseng is mycorrhizal (McGonigle et al. 1999; Whitbread et al. 1996) and this may account for the ability to tolerate the wide variety of soil chemical conditions.

ANOVA results indicated a number of soil parameters differed according to physiographic province. In general, average pH and nutrient levels were greatest in the Piedmont Province (eastern PA) but declined incrementally in the central (Ridge and Valley) and western (Appalachian Plateaus) provinces. The exception to this trend was for P, which increased in the central and western provinces.

Fertility was generally low for all major nutrients, except calcium which averaged greater than 3,500 kg ha^{-1} in all physiographic provinces and regions. This finding is in agreement with Beyfuss (2000) and Persons and Davis (2005), for example, who have suggested a threshold of at least 3,360 kg ha^{-1} (3,000 lbs ac) in wild-simulated ginseng site selection. As noted earlier in this paper, soil calcium appears to be particularly important for ginseng growth, survival and chemistry.

Soil texture was the most consistent soil trait in PA with all soils being loams (e.g., sandy clay loam, loamy sand, sandy loam, clay loam). Furthermore, loams were the most common textural class in all provinces except the Piedmont where sandy loams were most common. Soils were generally high in organic matter, even with the removal of the O-horizon prior to sampling.

Table 6 Soil pH, fertility and physical characteristics associated with wild and wild-simulated ginseng in Pennsylvania in relation to physiographic province

	Appalachian Plateaus ($n = 33$)		Ridge and Valley ($n = 14$)		Piedmont ($n = 7$)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
pH*	5.1 (0.6)	4.2–7.1	5.5 (0.7)	4.5–7.8	6.1 (0.6)	5.0–7.1
P (kg ha^{-1})*	175 (222)	11–1,443	151 (19)	26–744	124 (140)	16–549
K (kg ha^{-1})*	268 (107)	79–605	271 (107)	119–571	372 (164)	89–799
Ca (kg ha^{-1})*	3,577 (3,100)	315–18,171	5,462 (6,982)	664–46,746	4,448 (2,681)	677–11,666
Mg (kg ha^{-1})*	388 (258)	63–1,515	432 (234)	164–1,328	827 (547)	183–2,974
Sand %**	41 (10)	24–60	51 (16)	20–84	52 (9)	42–66
Silt %**	38 (8)	23–53	30 (11)	9–53	33 (7)	23–40
Clay %**	22 (5)	10–29	19 (6)	7–31	15 (3)	11–18
OM %*	10 (7)	3–53	11 (7)	3–40	10 (7)	3–22

* Number of soil samples analyzed: Appalachian Plateaus: $n = 165$; Ridge and Valley: $n = 70$; Piedmont: $n = 35$

** Number of soil samples analyzed: Appalachian Plateaus: $n = 33$; Ridge and Valley: $n = 14$; Piedmont: $n = 7$

Conclusions

The principal objective of this study was to document the vegetation and soils associated with wild and wild-simulated ginseng in Pennsylvania for purposes of helping guide land-owner adoption of wild-simulated forest farming in the state and region. Accordingly, this study followed a targeted, stratified-random but "subjective" sampling approach that did not include sites where ginseng did not occur. Similar approaches have been used in Arkansas (Fountain 1986), Illinois (Anderson et al. 1984; Anderson et al. 1993), Kentucky (Jones and Wolf 2001), Missouri (Farrington 2006), Quebec (Nadeau and Olivier 2003) and Wisconsin (Anderson 1996; Carpenter 1980). As noted by McGraw et al. (2003), this type of data collection approach is prone to bias if the results are used to establish a "preferred" habitat for the species since the approach does not account for sites where ginseng is not found. In addition, a long history (nearly 300 years) of ginseng collection in PA complicates recognition of ginseng habitat since many suitable sites can lack or contain very few plants due to previous collection. Collection pressure may also continue to influence specific plant associates commonly encountered. Thus, the results obtained in this study should be cautiously used when providing guidance to forestland owners and/or managers.

Further limits to this approach stem from the fact that some of the more common ginseng associates documented in this study can be encountered under a broad range of habitat conditions (i.e., they are "weedy"). Consequently, in developing any list of possible plant "indicators," one must consider the reproductive and ecological predilections of each species (c.f., Bierzychudek 1982a) with emphasis given to those that have biological and ecological requirements similar to ginseng (i.e., slow-growing perennial, shade-obligate species). The utility and reliability of floristic associates for identifying favorable ginseng habitat for forest farming is also likely to be improved by concomitant attention to all species occurring in all forest strata (i.e., over-story, mid-story, under-story), rather than any particular stratum or species per se. In this regard, a triangulated approach should be employed where one looks for species associations using all strata (i.e., over-story, mid-story, and under-story).

In this study, 243 plant species were associated with wild and wild-simulated ginseng populations in PA. Despite this diversity, Sørenson coefficients indicated many similarities between sites and suggest a shared assemblage of over- and under-story species (i.e., a "ginseng association") (refer to Tables 2, 3, 4, 5). Comparison of these results with findings from other published North American ginseng habitat studies reveals that this assemblage is shared in many regions outside of PA, and therefore the results obtained in this study undoubtedly have broader applicability.

In previous studies (c.f., Nadeau et al. 2003), soil calcium content has been shown to benefit ginseng growth and survival and calcium is also important in the production of the medicinally-active ginsenosides (c.f., Konsler et al. 1990). Average soil calcium levels associated with ginseng in all PA physiographic provinces was $\sim$3,500 kg ha^{-1}, although there was a range of values observed including some soils that were much lower (e.g., 315 kg ha^{-1}). ISA revealed that three of the top associates in PA may be especially useful for identifying calcium-rich sites meeting the 3,360 kg ha^{-1} threshold suggested by Beyfuss (2000) and others (Persons and Davis 2005). These are white ash as a dominant over-story tree and Jack-in-the-pulpit and rattlesnake fern as "resident" (c.f. Gilliam and Roberts 2003) herbaceous layer components.

Sugar maple continues to be a noteworthy over-story indicator tree since it has been found to be a common associate with ginseng in many regions of eastern North America. Sugar maple has frequently been linked with high calcium sites and Horsley et al. (2008) found that ginseng could be used as an indicator of "healthy" sugar maple stands in Pennsylvania, New York, Vermont and New Hampshire, in part because high soil calcium correlated with both ginseng and healthy sugar maple. Beyfuss (2000) found an association of ginseng with sugar maple and similarly suggested this may be due to a predilection by both species for soils high in calcium. In this study, sugar maple was the most common associated over-story tree although there was unexpectedly no statistically significant association observed between this species and calcium-rich soils.

Although sugar maple and many other plants were observed among the top ginseng associates, and thus may be useful "indicators," the results obtained in this study suggest that the presence of white ash, Jack-in-the-pulpit and rattlesnake fern on a prospective forest farming site is especially helpful for improving landowner chances of establishing ginseng using a wild-simulated approach at least in part because these species appear to indicate favorable calcium levels and soil calcium appears to be one of the few recognized soil traits important to ginseng growth and quality. Additionally, both Jack-in-the-pulpit and rattlesnake fern are similar to ginseng in that both are slow-growing, shade-obligate perennials (c.f., Bierzychudek 1982b; Wagner and Wagner 1993) that are encountered predominantly as "resident" members (c.f., Gilliam and Roberts) of the forest herbaceous layer. These plant species also have the added benefit of being fairly easy to recognize in the field.

While imperfect, the study and use of floristic associates or "plant indicators" to identify ginseng forest farming sites with high success potential is nevertheless a practical approach for landowners. Once instructed as to how to recognize these species, use of floristic indicators by landowners could be a rapid and inexpensive approach to selection of ginseng forest farming sites throughout many areas of the eastern United States.

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