

Title: Identification of goldenseal (*Hydrastis canadensis* L.) habitat and indicators in Pennsylvania, U.S.A: the influence of climate and site on *in situ* conservation of an edge of range plant species.

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Online Resource 1. List of all variables used in initial Maxent model run.

Variable	Description/Source
<u>Climatic Predictors</u>	
BIO1	Annual Mean temperature (°C)
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter
<u>Edaphic Predictors</u>	
Band_1.1	Available water capacity (cm)
Band_1.2	Bedrock type
Band_1.3	Soil bulk density (g/cm ³)
Band_1.4	Percent clay
Band_1.5	Depth to bedrock
Band_1.6	Soil erodability factor, rock fragment free
Band_1.7	Length of the frost free period
Band_1.8	Organic matter content (% by weight)
Band_1.9	Soil permeability rate (cm/hr)
Band_1.10	Soil pH
Band_1.11	Percent sand
Band_1.12	Percent soil passing sieve no.10 (coarse)
Band_1.13	Percent soil passing sieve no.200 (fine)
Band_1.14	Percent silt
Band_1.15	Soil slope(%) of a soil component
Band_1.16	Soil order based on USDA soil taxonomy
Band_1.17	Soil suborder based on USDA soil taxonomy

<u>Topographic Predictors</u>	
Band_1.1.1	Transformed aspect according to Beer et al. (1966)
Band_1.2.1	Elevation relief ratio (15-pixel neighborhood)
Band_1.3.1	Integrated soil moisture index (Iverson et al. 1997)
Band_1.4.1, 1.5.1	Variance of elevation (15-pixel, 27-pixel neighborhood)
Band_1.6.1	Slope x COS(Aspect)
Band_1.7.1	Slope x SIN(Aspect)
Band_1.8.1, 1.9.1, 1.10.1, 1.11.1, 1.12.1	Topographic position indices at scales of 150m, 300m, 500m, 1000m, and 2000m
Band_1.13.1	Topographic radiation index

Testing AUC: 0.843

Initial Model Run: 49 Variables

Climatic Predictors

Annual Precipitation
Max Temperature of Warmest Month
Mean Temperature of Coldest Quarter
Mean Temperature of Driest Quarter
Mean Temperature of Warmest Quarter
Mean Temperature of Wettest Quarter
Min Temperature of Coldest Month
Precipitation of Coldest Quarter
Precipitation of Driest Month
Precipitation of Driest Quarter
Precipitation of Warmest Quarter
Precipitation of Wettest Month
Precipitation of Wettest Quarter
Precipitation Seasonality (Coefficient of Variation)
Temperature Annual Range (BIO5-BIO6)
Temperature Seasonality (standard deviation *100)
Annual Mean temperature (°C)
Isothermality (BIO2/BIO7) (*100)
Mean Diurnal Range (Mean of monthly (max temp - min temp))

Edaphic Predictors

Available water capacity (cm)
Bedrock type
Depth to bedrock
Length of the frost free period
Organic matter content (% by weight)
Percent clay
Percent sand
Percent silt
Percent soil passing sieve no.10 (coarse)
Percent soil passing sieve no.200 (fine)
Soil bulk density (g/cm3)
Soil erodibility factor, rock fragment free
Soil order based on USDA soil taxonomy
Soil permeability rate (cm/hr)
Soil pH
Soil slope(% of a soil component
Soil suborder based on USDA soil taxonomy

Topographic Predictors

Elevation relief ratio (15-pixel neighborhood)
Integrated soil moisture index (Iverson et al., 1997)
Slope x SINK(Aspect)
Slope x SINK(Aspect)
Topographic position indices at scales of 150m, 300m, 500m, 1000m, and 2000m
Topographic radiation index
Transformed aspect according to Beer et al., (1966)
Variance of elevation (15-pixel, 27-pixel neighborhood)

Testing AUC: 0.855

-Removed variables with correlation coefficient > 0.7, retaining that with higher permutation importance.
-Removed variables which showed dependency.
-Removed variables with permutation importance of 0.

Second Model Run: 16 Variables

Climatic Predictors

Mean Temperature of Coldest Quarter
Temperature Seasonality (standard deviation *100)
Isothermality (BIO2/BIO7) (*100)

Edaphic Predictors

Bedrock type
Depth to bedrock
Organic matter content (% by weight)
Soil erodibility factor, rock fragment free
Soil order based on USDA soil taxonomy
Soil permeability rate (cm/hr)
Soil pH
Soil suborder based on USDA soil taxonomy

Topographic Predictors

Elevation relief ratio (15-pixel neighborhood)
Integrated soil moisture index (Iverson et al., 1997)
Topographic position index at scale of 2000m
Transformed aspect according to Beer et al., (1966)
Variance of elevation (27-pixel neighborhood)

Testing AUC: 0.859

-Removed variables which showed dependency.
-Removed Topographic position index and permutation importances of 0.

Third Model Run:10 Variables

Climatic Predictors

Mean Temperature of Coldest Quarter

Edaphic Predictors

Bedrock type
Organic matter content (% by weight)
Soil order based on USDA soil taxonomy
Soil permeability rate (cm/hr)
Soil suborder based on USDA soil taxonomy

Topographic Predictors

Elevation relief ratio (15-pixel neighborhood)
Integrated soil moisture index (Iverson et al., 1997)
Topographic position index at scale of 2000m
Transformed aspect according to Beer et al., (1966)

Testing AUC: 0.873

-Removed Soil Order due to redundancy with Soil Suborder.
-Removed Topographic Position index due to Dependency.
-Removed aspect, which was difficult to interpret.

Final Run: 7 Variables

Climatic Predictors

Mean Temperature of Coldest Quarter

Edaphic Predictors

Bedrock type
Organic matter content (% by weight)
Soil permeability rate (cm/hr)
Soil suborder based on USDA soil taxonomy

Topographic Predictors

Elevation relief ratio (15-pixel neighborhood)
Integrated soil moisture index (Iverson et al., 1997)

Online Resource 2: Variable selection process for the goldenseal suitability model in Maxent.

Online Resource 3. Study sites, population traits and habitat characteristics associated with goldenseal in Pennsylvania.

Site Name	Population Size and Area	Number of sample plots	Site Description	Aspect	Elevation (M)	Topographic position
Allegheny-SH	500 ramets, 20% reproductive, <1 hectare	3	Moist lower-slope	W, SW	251	lower-slope
Beaver-CM	1,000 ramets, 20% reproductive, >1 hectare	2	Moist side-slope bench	N, NW	235	upper-slope
Bedford-BM	5,000 ramets, 5% reproductive, >1 hectare	3	Mid-slope, recent logging	W	423	mid-slope
Bedford-WW	10,000 ramets, 15% reproductive, >1 hectare	4	Moist forest farmed site	none	348	flat
Bucks-QT	5,000-10,000 ramets, 10% reproductive, >1 hectare	4	Moist lowland	none	119	flat
Butler-JE	100-500 ramets, 30% reproductive, <1 hectare	1	Moist lower-slope	W	341	lower-slope
Cambria-GL	100-500 ramets, 5% reproductive, <1 hectare	1	Moist ridgetop	none	733	ridgetop
Cambria-JK	500-1,000 ramets, 25% reproductive <1 hectare	1	Upland forest farmed site	none	521	top of a hill
Centre-ST	>10,000 ramets, 5% reproductive, >1 hectare	4	Moist side-slope on drainage bench	NW	336	mid-slope
Chester-LF	>10,000 ramets, 5% reproductive, >1 hectare	4	Moist lower-slope to dry ridge	N, NE	104	lower, mid, and upper-slope

Clarion-LH	50-100 ramets, <5% reproductive, <1 hectare	1	Mid-slope in steep ravine	E	319	mid-slope
Dauphin-JM	50-100 ramets, 60% reproductive, <1 hectare	1		none	213	flat
Huntingdon-MG	5,000 ramets, 15% reproductive, >1 hectare	4	Moist lowland	none	232	hollow bottom
Indiana-PR	5,000-10,000 ramets, <5% reproductive, >1 hectare	4	Gently sloping mountain hollow	N	357	lower-slope, valley bottom
Lancaster-BW	1,000 ramets, 15% reproductive, <1 hectare	4	Moist lowland	none	115	flat
Lancaster-MV	1,000-5,000 ramets, 15% reproductivem <1 hectare	1	Moist lowland	none	176	flat
Lebanon-GD	10-50 ramets, <5% reproductive, <1 hectare	1	Moist lowland	none	201	flat
Lebanon-GL	100 ramets, 5% reproductive, <1 hectare	1	Moist flat site	none	188	flat
Mifflin-JB	1,000 ramets, 10% reproductive, <1 hectare	3	Wet lowland	SE	196	lower-slope
Montgomery-BL	1,000-5,000 ramets, <5% reproductive, 1 hectare	1	Moist sinkhole	N	40	lower-slope
Montgomery-CD	100 ramets, <5% reproductive, <1 hectare	1	Moist lower-slope	none	57	flat

Montgomery-GL	100-500 ramets, 15% reproductive, 1 hectare	1	Moist mid- slope	NE	58	mid-slope
Montgomery-SX	100-500 ramets, 10% reproductive, <1 hectare	1	Moist mid- slope bench	NW	33	mid-slope
Westmoreland- DP	100-500 ramets, 10% reproductive, <1 hectare	1	Moist mid- slope	N	329	mid-slope
Westmoreland- MA	>10,000 ramets, 5% reproductive, 1 hectare	2	Moist flat site	none	287	flat
Westmoreland- PM	500-1,000 ramets, 15% reproductive, <1 hectare	1	Wet lowland	none	377	flat
York-AB	1,000 ramets, 5% reproductive, 1 hectare	1	Wet lowland	none	183	flat
York-GP	5,000 ramets, 5% reproductive, >1 hectare	3	Dry side- slope and moist bench	SE, NW	133	mid-slope

Online Resource 4. Frequency of species identified as being associated with goldenseal in Pennsylvania (n = 53 plots).

Scientific name ⁺	Common name	# of plots
<i>Lindera benzoin</i> (L.) Blume	Spicebush	44
<i>Parthenocissus quinquefolia</i> (L.) Planch	Virginia Creeper	43
<i>Arisaema triphyllum</i> (L.) Schott	Jack-in-the-pulpit	42
<i>Berberis thunbergii</i> DC.*	Japanese barberry	31
<i>Podophyllum peltatum</i> L.	Mayapple	31
<i>Botrypus virginianus</i> (L.) Michx.	Rattlesnake fern	29
<i>Dryopteris marginalis</i> (L.) A. Gray	Marginal wood fern	29
<i>Amphicarpa bracteata</i> (L.) Fernald	American hogpeanut	27
<i>Rosa multiflora</i> Thunb. ex Murray *	Multiflora rose	27
<i>Toxicodendron radicans</i> (L.) Kuntze	Poison ivy	27
<i>Actaea racemosa</i> L.	Black cohosh	25
<i>Microstegium vimineum</i> (Trin.) A. Camus *	Japanese stiltgrass	25
<i>Polystichum acrostichoides</i> (Michx.) Schott	Christmas fern	24
<i>Solidago/Symphiotrichum</i> spp.	Goldenrod or aster spp.	24
<i>Uvularia perfoliata</i> L.	Perfoliate bellwort	24
<i>Galium circaezens</i> Michx.	Licorice bedstraw	23
<i>Liriodendron tulipifera</i> L.	Tulip-poplar	23
<i>Viola pubescens</i> Ait.	Downy yellow violet	23
<i>Acer saccharum</i> Marshall	Sugar maple	22
<i>Geranium maculatum</i> L.	Wood geranium	22
<i>Viola hirsutula</i> Brainerd	Southern woodland violet	22
<i>Alliaria petiolata</i> (M. Bieb.) Cavara & Grande *	Garlic mustard	21
<i>Circaea canadensis</i> L.	Enchanter's nightshade	21
<i>Sanicula</i> spp. L.	Black snakeroot	21
<i>Asarum canadense</i> L.	Wild ginger	19
<i>Persicaria longiseta</i> (Bruijn) Kitagawa *	Bristled knotweed	19
<i>Sanguinaria canadensis</i> L.	Bloodroot	19
<i>Maianthemum racemosum</i> (L.) Link	False Solomon's seal	18
<i>Agrimonia</i> spp. Tourn. ex L.	Agrimony	17
<i>Osmorhiza claytonii</i> (Michx.) C.B. Clarke	Clayton's sweetroot	17
<i>Nabalus</i> spp. Cass.	Rattlesnake root	17
<i>Persicaria virginiana</i> (L.) Gaertn.	Virginia jumpseed	15
<i>Uvularia sessilifolia</i> L.	Sessile bellwort	15
<i>Geum canadense</i> Jacq.	White avens	14
<i>Hepatica americana</i> (DC.) Ker Gawl.	Round-lobed hepatica	14
<i>Osmorhiza longistylis</i> (Torr.) DC.	Wild anise	14
<i>Phyrma leptostachya</i> L.	Lopseed	14
<i>Thalictrum thalictroides</i> (L.) A.J. Earnes & B. Boivin	Rue-anemone	14

<i>Dioscorea villosa</i> L.	Wild yam	13
<i>Eurybia divaricata</i> (L.) G.L. Nesom	White wood aster	13
<i>Galium triflorum</i> Michx.	Sweet bedstraw	13
<i>Juglans nigra</i> L.	Black walnut	13
<i>Collinsonia canadensis</i> L.	Stoneroot	11
<i>Oxalis acetosella</i> L.	Wood sorrel	11
<i>Pilea pumila</i> (L.) A. Gray	Clearweed	11
<i>Galearis spectabilis</i> (L.) Raf.	Showy orchid	10
<i>Ageratina altissima</i> (L.) King & H.E. Robins.	White snakeroot	9
<i>Cardamine concatenata</i> (Michx.) O. Schwarz	Cutleaf toothwort	9
<i>Quercus alba</i> L.	White oak	9
<i>Quercus rubra</i> L.	Northern red oak	9
<i>Carya glabra</i> (Mill.) Sweet	Pignut hickory	8
<i>Erythronium americanum</i> Ker-Gawl.	Yellow trout-lily	8
<i>Hackelia virginiana</i> I.M. Johnston	Beggar's lice	8
<i>Impatiens capensis</i> Meerb.	Common jewelweed	8
<i>Viburnum acerifolium</i> L.	Maple-leaf viburnum	8
<i>Adiantum pedatum</i> L.	Maidenhair fern	7
<i>Claytonia virginica</i> L.	Virginia springbeauty	7
<i>Monarda didyma</i> L.	Scarlet beebalm	7
<i>Monotropa uniflora</i> L.	Ghost pipe	7
<i>Panax quinquefolius</i> L.	American ginseng	7
<i>Prosartes lanuginosa</i> (Michx.) D. Don	Yellow mandarin	7
<i>Prunus serotina</i> L.	Black cherry	7
<i>Smilax hispida</i> Raf.	Bristly greenbriar	7
<i>Vitis</i> spp. L.	Wild grape	7
<i>Cryptotaenia canadensis</i> (L.) DC.	Canadian honewort	6
<i>Lonicera japonica</i> Thunb. *	Japanese honeysuckle	6
<i>Polygonatum biflorum</i> (Walt.) Ell.	Smooth Solomon's-seal	6
<i>Smilax herbacea</i> L.	Smooth carrionflower	6
<i>Tilia americana</i> L.	American basswood	6
<i>Allium tricoccum</i> Aiton	Ramps	5
<i>Carya ovata</i> (Mill.) K. Koch	Shagbark hickory	5
<i>Carya tomentosa</i> (Poir.) Nutt.	Mockernut hickory	5
<i>Fragaria vesca</i> L. *	Wild strawberry	5
<i>Maianthemum canadense</i> Desf.	Canada mayflower	5
<i>Polygonatum pubescens</i> (Willd.) Pursh	Hairy Solomon's-seal	5
<i>Polygonatum</i> sp. (<i>P. biflorum</i> or <i>P. pubescens</i>) Mill.	Solomon's-seal species.	5
<i>Trillium erectum</i> L.	Purple trillium	5
<i>Ulmus rubra</i> Muhl.	Slippery elm	5
<i>Carya cordiformis</i> (Wang) K. Koch	Bitternut hickory	4
<i>Celastrus orbiculatus</i> Thunb. *	Oriental bittersweet	4
<i>Desmodium</i> spp. Desv.	Tick trefoil	4

<i>Mitchella repens</i> L.	Partridge berry	4
<i>Onoclea sensibilis</i> L.	Sensitive fern	4
<i>Rubus phoenicolasius</i> Maxim. *	Wineberry	4
<i>Sedum ternatum</i> Michx.	Woodland stonecrop	4
<i>Smilax rotundifolia</i> L.	Greenbriar	4
<i>Amauropelta noveboracensis</i> (L.) S.E. Fawc. & A.R. Sm.	New York fern	4
<i>Actaea pachypoda</i> Elliott	White baneberry	3
<i>Acer platanoides</i> L. *	Norway maple	3
<i>Anemone quinquefolia</i> L.	Wood anemone	3
<i>Caulophyllum thalictroides</i> L.	Blue cohosh	3
<i>Clinopodium vulgare</i> L.	Wild basil	3
<i>Euonymus alatus</i> (Thunb.) Siebold *	Winged euonymus	3
<i>Fagus grandifolia</i> Ehrhart	American beech	3
<i>Fraxinus pennsylvanica</i> Marshall	Green ash	3
<i>Impatiens</i> sp. (<i>I. pallida</i> or <i>I. capensis</i>) L.	Jewelweed species	3
<i>Laportea canadensis</i> (L.) Wedd.	Wood nettle	3
<i>Phegopteris hexagonoptera</i> (Michx.) Fée	Beech fern	3
<i>Quercus montana</i> Willd.	Chestnut oak	3
<i>Solidago flexicaulis</i> L.	Broadleaved goldenrod	3
<i>Trillium grandiflorum</i> (Michx.) Salisb.	Large-flowered trillium	3
<i>Tussilago farfara</i> L. *	Coltsfoot	3
<i>Aralia racemosa</i> L.	American spikenard	2
<i>Artemisia</i> sp. L. *	Mugwort	2
<i>Erechtites hieracifolius</i> (L.) Raf. ex DC.	Pilewort	2
<i>Eutrochium</i> spp. Raf.	Joe-pye weed	2
<i>Fraxinus americana</i> L.	White ash	2
<i>Fraxinus nigra</i> Marshall	Black ash	2
<i>Hamamelis virginiana</i> L.	Witch-hazel	2
<i>Helianthus</i> spp. L.	Sunflower	2
<i>Magnolia acuminata</i> L.	Cucumber tree	2
<i>Packera aurea</i> (L.) W.A. Weber & Á. Löve	Golden ragwort	2
<i>Pinus strobus</i> L.	Eastern white pine	2
<i>Ranunculus abortivus</i> L.	Littleleaf buttercup	2
<i>Sassafras albidum</i> (Nutt.) Nees	Sassafras	2
<i>Tiarella cordifolia</i> L.	Heartleaf foamflower	2
<i>Viburnum prunifolium</i> L.	Blackhaw	2
<i>Viola rostrata</i> Pursh	Longspur violet	2
<i>Viola striata</i> Aiton	Striped violet	2
<i>Acer pensylvanicum</i> L.	Striped maple	1
<i>Anemone canadensis</i> L.	Canada anemone	1
<i>Anemone virginiana</i> L.	Tall thimbleweed	1
<i>Aplectrum hyemale</i> (Muhl. ex Willd.) Torr.	Putty-root orchid	1
<i>Blephilia ciliata</i> (L.) Benth.	Downy wood mint	1

<i>Campanula americana</i> L.	Tall bellflower	1
<i>Clintonia umbellulata</i> (Michx.) Morong	White clintonia	1
<i>Crataegus</i> sp. L.	Hawthorn	1
<i>Cynoglossum virginianum</i> L.	Wild comfrey	1
<i>Daucus carota</i> L. *	Wild carrot	1
<i>Desmodium nudiflorum</i> (L.) DC.	Naked-flowered tick trefoil	1
<i>Dicentra cucullaria</i> (L.) Bernh.	Dutchman's breeches	1
<i>Eupatorium altissimum</i> L.	Tall boneset	1
<i>Fallopia</i> sp. Adans.	Bindweed species	1
<i>Galium aparine</i> L.	Sticky willy	1
<i>Galium lanceolatum</i> (Torr. & A. Gray) Torr.	Lanceleaf wild licorice	1
<i>Hesperis matronalis</i> L. *	Dame's rocket	1
<i>Hydrophyllum virginianum</i> L.	Virginia waterleaf	1
<i>Impatiens pallida</i> Nutt.	Yellow jewelweed	1
<i>Lysimachia ciliata</i> L.	Fringed loosestrife	1
<i>Menispermum canadense</i> L.	Common moonseed	1
<i>Medeola virginiana</i> L.	Indian cucumber-root	1
<i>Obolaria virginica</i> L.	Virginia pennywort	1
<i>Persicaria perfoliata</i> (L.) H. Gross *	Mile-a-minute weed	1
<i>Phytolacca americana</i> L.	American pokeweed	1
<i>Phlox divaricata</i> L.	Woodland phlox	1
<i>Picea abies</i> (L.) H. Karst. *	Norway spruce	1
<i>Plantago</i> sp. L.	Plantain	1
<i>Prunus avium</i> L. *	Bird cherry	1
<i>Prunella vulgaris</i> L.	Self-heal	1
<i>Robinia pseudoacacia</i> L.	Black locust	1
<i>Rubus occidentalis</i> L.	Black raspberry	1
<i>Staphylea trifolia</i> L.	American bladdernut	1
<i>Symplocarpus foetidus</i> Salisb.	Skunk cabbage	1
<i>Teucrium canadense</i> L.	American germander	1
<i>Thalictrum dioicum</i> L.	Early meadow-rue	1
<i>Tsuga canadensis</i> (L.) Carrière	Eastern hemlock	1
<i>Verbena urtisiifolia</i> L.	Nettle-leaved vervain	1
<i>Viola blanda</i> Willd.	Sweet white violet	1
<i>Viola canadensis</i> L.	Canadian white violet	1

Asterisks (*) denote non-native, exotic species.

*All taxonomy follows Weakley, 2023.