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Capability Analysis of Suitable Natural Habitat for Wild American Ginseng:
A Sensitivity Analysis of Main Growing Factors

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ABSTRACT

This article presents a sensitivity analysis of the main growing factors for wild American ginseng in North Carolina, USA. This study examines the influence and importance of ginseng's natural growing factors in the predictive models generated through the method of weighted linear combination by conducting a sensitivity analysis over the relative importance of growing factors. By identifying these factors, government agencies can more effectively plan law enforcement activities and streamline their preservation efforts to protect this valuable species. The results of our sensitivity analysis indicate that the shade-related factors and spatial factors play very important roles in predicting suitable areas for wild American ginseng to grow in nature in the context of North Carolina. This finding implies that the proper consideration of these factors substantially enhances model predictability and consistency of predictions with real-world observations.

KEYWORDS:

Ginseng, GIS, Natural Habitat, Wild American Ginseng, Suitability Analysis, Main Growing Factors, and Sensitivity Analysis, Weighted Linear Combination

INTRODUCTION

Ginseng is a root part of the Panax plant family, which stands out for its notable presence of ginsenosides and gintonin. With a rich history as a traditional medicine in China, this popular herb is found exclusively in North America, Korea, Manchuria, and Siberia, all situated in the Northern Hemisphere. In the annals of American history, ginseng has long held a prominent role, and nestled within this botanical saga unfolds, for example, the riveting chronicle of Daniel Boone—a frontiersman whose exploits stretched beyond the untamed frontiers. Boone, renowned as a scout, hunter, and patriarch, navigated a diverse array of pursuits, from legislative roles to managing a tavern, store, and warehouse, according to Morgan (2008). Amidst this dynamic life, Boone's connection to the forest's treasures led him to become a ginseng digger, supplementing his earnings. Known informally

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as “sang” in the southern Appalachians, ginseng was not merely a medicinal herb, but it also held commercial allure, especially in the expanding China market.

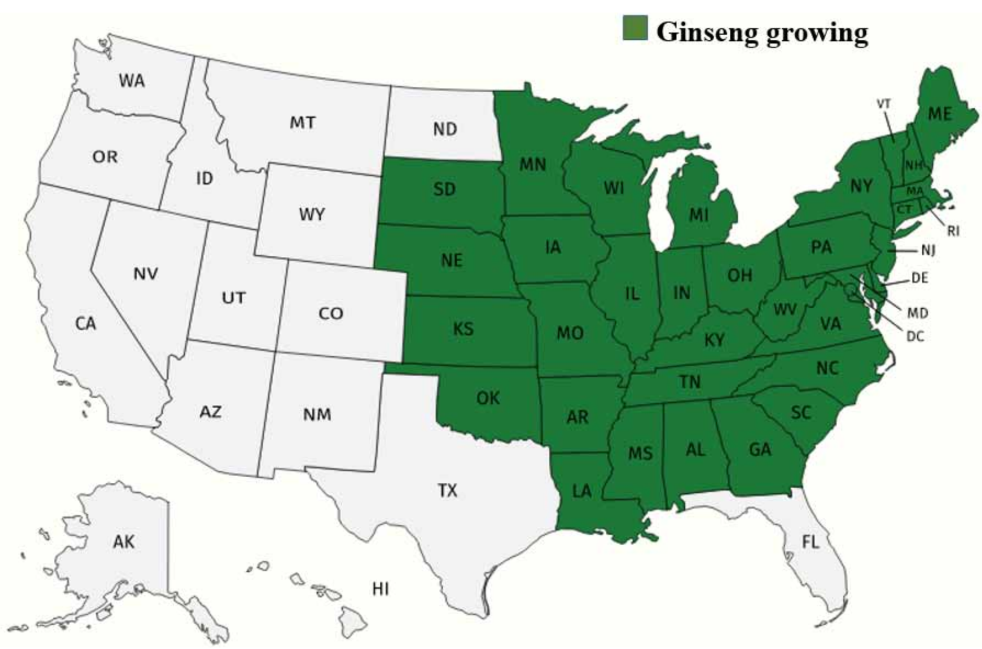
Flourishing predominantly in the understory of eastern deciduous forests, wild American ginseng is a resilient perennial herb. It shares remarkable similarities with Chinese ginseng, particularly in its elevated ginsenoside content, setting it apart from Siberian ginseng, which lacks this valuable component. The coveted high level of ginsenoside in wild American ginseng renders it exceptionally sought after in the Chinese market. Ginseng has been exported from the United States since the 18th century. For instance, in 1860, Wisconsin exported 120 tons of wild American ginseng root to China. It is still in high demand, to the extent that wild American ginseng is nowadays priced around $400–800 per pound.

Ginseng is sold in more than 35 countries. Only four countries, China, South Korea, Canada, and the United States, produced 99% of the world’s ginseng in the early 21st century (Baeg & So, 2013). Almost 95% of the wild American ginseng harvested in the United States is shipped for the Asian market. China is the largest consumer of this plant in the world. Several states export their harvested wild American ginseng to the Chinese market. North Carolina is one of the major exporters of wild American ginseng to China. Annually, over three million dollars in revenue is brought to North Carolina by trading this plant. Due to such high prices, excessive harvests of American ginseng from the wild for export to Asian medicinal herb markets have raised concerns over the survival of American ginseng in the wild. This is primarily because harvesting the root of the plant is deadly to the individual plant, and it subsequently impacts this species’ population size, structure, as well as its genetic diversity (Van der Voort et al., 2003; Cruse-Sanders et al., 2005).

Wild American ginseng grows mostly in the deciduous forests of the eastern United States, such as the Appalachian and Ozark regions, mainly because of suitable shade and soil moisture (Compton, 2006). Figure 1 shows ginseng-growing areas in the United States.

Figure 1. Areas in the United States where ginseng root grows

Note: From “How to Find and Sell American Wild Ginseng,” by M. Watson, 2022, Owlcation (https://owlcation.com/stem/How-to-Find-and-Sell-American-Wild-Ginseng). Copyright 2022 by The Arena Media Brands, LLC.



Wild American ginseng (*Panax quinquefolius*) is native to North Carolina. Wild American ginseng in North Carolina is mostly found in the Great Smoky Mountains National Park, the Appalachian Mountains, and the upper Piedmont (National Parks Conservation Association, 2011). Economically and socio-economically in North Carolina, ginseng was the second largest source of income for settlers coming from Europe (Manget, 2012). North Carolina is well-known for its high-quality wild American ginseng. In North Carolina, wild American ginseng is a plant species of special concern, in danger of extinction, and subject to certain regulations.

Researchers from the Great Smoky Mountains National Park as well as the North Carolina U.S. Forest Service are currently working to monitor the wild population of American ginseng throughout North Carolina. The North Carolina Department of Agriculture and Consumer Services and Plant Conservation Program has a special program to determine in what areas harvesting wild American ginseng is prohibited.

From 2001–2002, the North Carolina Department of Agriculture and Consumer Services started issuing permits for buying wild American ginseng grown or collected in North Carolina. According to Creager (2016), it is estimated that around 2,000–4,000 people each year make requests for ginseng permits in North Carolina. It seems that the growing number of people harvesting ginseng is motivated by its growing price.

Wild American ginseng is typically found on the north slopes of heavily shaded coves and has distinctive whorls of five leaves, bright red berries, and yellow leaves in the fall, which make it easily distinguishable from other plants.

Wild American ginseng takes 4–8 years to completely mature. Figure 4 illustrates the life cycle of this species. Ginseng seeds usually begin to sprout between April and June. The ginseng plant looks like a wild strawberry plant in its first growth season and develops a small skinny root over the summer season under the ground, which survives the winter, and freezes as the ground freezes.

Figure 2. Mature wild american ginseng plant with berries

Note: The mature root of wild American ginseng is eight inches long and looks like a human body. It is also known as man root because it includes a thick body with leg-like roots. Figure 3 shows the typical shape of the man root.

Figure 3. Ginseng "man root" has a thick "body" with leg-like roots extending from it

During the fall, the leaves turn a yellow-orange color. In the second year, the plant becomes at least 5 inches, and eventually, the ginseng plant will grow to over 2 feet tall. In early summer, a cluster of green blossoms will grow on plants that are at least 3 years old which eventually turn into green berries. Each ripe berry contains about 1–3 seeds, which usually germinate and sprout after 18–20 months from the time they fall from the plant. During the growing seasons, the ginseng root continues to develop and may double or triple its size during the first few growing seasons, but when the plant starts to fruit heavily, its growth rate slows down gradually.

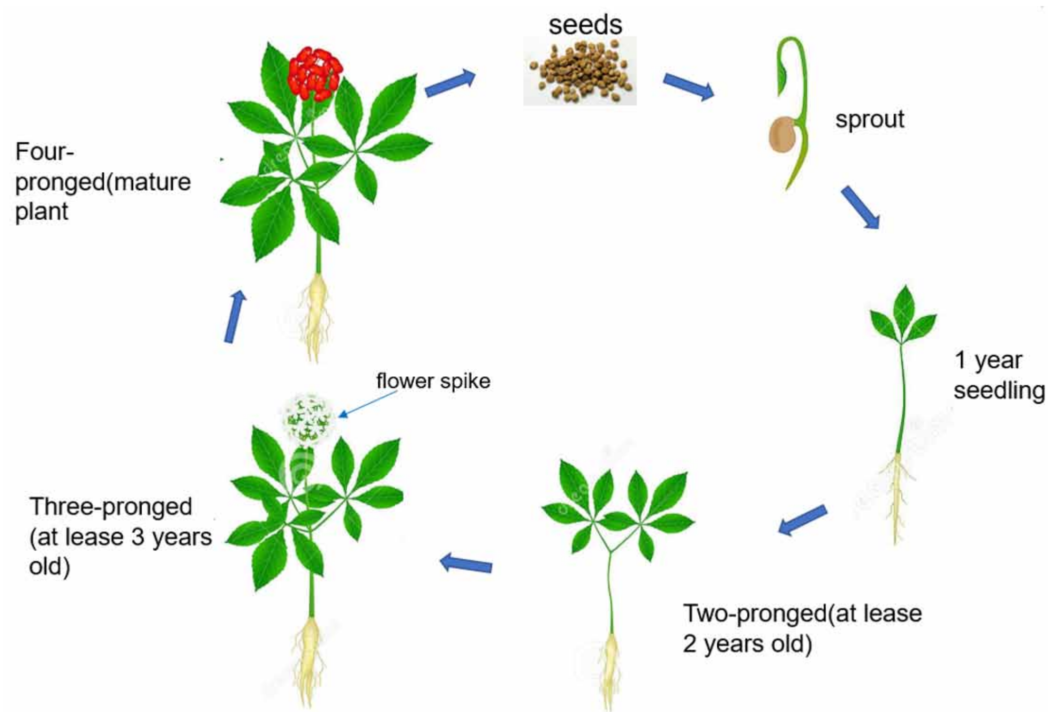
LITERATURE REVIEW

According to Anderson et al. (1993), "Ginseng favors a habitat ranging from 30 to 50 degrees north latitude and minimum cold cycles of 45 days with temperatures below 2 degrees Celsius." Anderson et al. (1993) also point to other criteria such as adequate shade (locations with full shade in deciduous hardwood forests), 25 inches of annual precipitation, and loamy, well-drained, and slightly acidic soil. Cool and moist conditions within coves are regions where wild American ginseng tends to grow.

To avert the threat of the extinction of wild American ginseng, research must center on the geographical aspects of wild American ginseng. Such studies should be aimed at detecting the plant's spatial habitat and its primary growth determinants within North Carolina to enhance our understanding of the natural distribution and essential growth factors of ginseng. This information can contribute to more effective law enforcement initiatives to safeguard ginseng from illicit harvesting and better guidance on the requisite conditions and suitable regions for cultivating the plant in controlled environments as a viable alternative to wild harvesting. This substitution approach could

Figure 4. Life cycle of wild American ginseng

Note: Adapted from American Ginseng GREEN GOLD, by W. S. Persons, 1994. Copyright 1994 by Bright Mountain Books. Adapted with permission.



effectively alleviate the harvesting pressure on the wild variant, thereby disrupting the detrimental cycle described earlier.

Khademian and Bunch (2023) have employed four popular geospatial methods, including the binary screening (BS) method, ordinal ranking method (both graduated screening [GS] and addition-of-factors [AF] methods), and weighted linear combination (WLC) method to carry out a capability analysis and mapping for wild American ginseng in North Carolina. They have shown that western North Carolina counties such as Jackson, Haywood, Transylvania, Henderson, Cherokee, and Ash are some of the most suitable geographical areas for wild American ginseng. The result of their model validation analysis and comparing their models' predictions with the observations made of wild American ginseng in nature show that the BS method's predictions match with almost 96% of the observations made and reported in nature by the North Carolina Department of Agriculture and Consumer Services in their harvest data for wild American ginseng in North Carolina counties in 2018. As for their WLC method, they have considered a specific set of weights inferred from the respective literature for the growing factors. Building on that design, the objective of the present study is to investigate the relative importance of different growing factors to develop a predictive WLC-based model that captures geographical areas possessing the most suitable habitat for wild American ginseng growth in North Carolina. This task is to be done by using the data of known locations of wild American ginseng in North Carolina while calibrating the weights of the relative importance of growing factors to achieve higher levels of compatibility between the predictions of the WLC model and the known locations of the plant in the real world. Therefore, this study examines the influence and importance of ginseng's natural growing factors in the predictive models generated through the method of WLC by conducting a sensitivity analysis of the relative importance of growing factors.

By identifying these factors and improving predictive models accordingly, government agencies can more effectively plan law enforcement activities and streamline their preservation efforts to protect this valuable species and promote sustainable cultivation as an alternative to wild harvesting.

Several studies have contributed to understanding the cultivation and habitat suitability of wild American ginseng through diverse methodologies. Kang et al. (2016) conducted an investigation in Jinangun, South Korea, utilizing GIS and geo-temperature to accurately identify suitable cultivation sites. Their findings emphasized the improvement in suitability identification with the inclusion of geo-temperature. Webinger (2015), focusing on the Southern United States, designed a habitat model for American ginseng using various variables to locate potential growth sites. The effectiveness of his model was evaluated through statistical analysis of point data. Snow and Snow (2009) explored optimal growing conditions for ginseng, employing remote sensing and climate data. They proposed an economic alternative to clear-cutting deciduous forests. In Virginia, Van Manen et al. (2005) created habitat models for American ginseng using Mahalanobis distance and GIS layers, demonstrating their effectiveness for plant protection. Kim et al. (2015) studied soil properties of mountain-cultivated ginseng in Hamyang-gun, Korea, concluding that it can thrive in acidic, nutrient-depleted forest soils. Cruse-Sanders and Hamrick (2004) explored the spatial and genetic structure of American ginseng in the United States, identifying favorable microhabitats and highlighting limited seed dispersal in their spatial structure analysis. Sheban et al. (2022) investigate the impact of environmental factors on wild-simulated American ginseng plantings. Emphasizing the crucial role of sunlight in ginseng establishment and growth, the study proposes integrating silvicultural techniques, like forest thinning, to enhance productivity sustainably, meeting international demand amid changing global conditions. These studies collectively contribute valuable insights into ginseng cultivation suitability, habitat modeling, and ecological considerations. However, none of them presents a sensitivity analysis of the main growing factors for wild American ginseng to identify the relative importance of each factor in building suitability models, which is the important task that the present paper is to pursue.

The present research delves into variables crucial for the optimal growth conditions of wild American ginseng, encompassing factors like shade, elevation, annual precipitation, loaminess, soil moisture, temperature, and soil acidity. The data utilized is sourced from diverse outlets, including the United States Department of Agriculture/Natural Resources Conservation Service Soil Series database and the Soil Survey Geographic Database, providing locally described soil characteristics at the county level. These datasets are introduced and detailed in Appendix A. Methodologically, the study employs an approach to identify crucial growing factors for wild American ginseng, aiding in the selection of appropriate variables and the assignment of proper importance weights to the variables to be included in capability analyses. The term "capability" refers to a land unit's physical potential to support an activity, such as the growth of wild American ginseng. In brief, this paper provides a sensitivity analysis of the main growing factors for wild American ginseng.

The subsequent sections of this paper will follow this structured path. The next section will delve into a sensitivity analysis concerning the weights applied in the WLC method and attend to factors that play more important roles in predicting suitable natural habitats for wild American ginseng to grow in nature. In this analysis, the BS model will serve as the benchmark for comparison, enabling a comprehensive understanding of the deviations (from real-world observations) that each set of weights introduces to our results. This comparison will shed light on which factors exert a more significant influence on predicting the suitable natural habitat for wild American ginseng. Following this, a conclusive summary will be presented, coupled with an exploration of potential avenues for future research. The paper will then conclude, accompanied by appendices providing detailed insights into the intricate facets of procedures and methodologies.

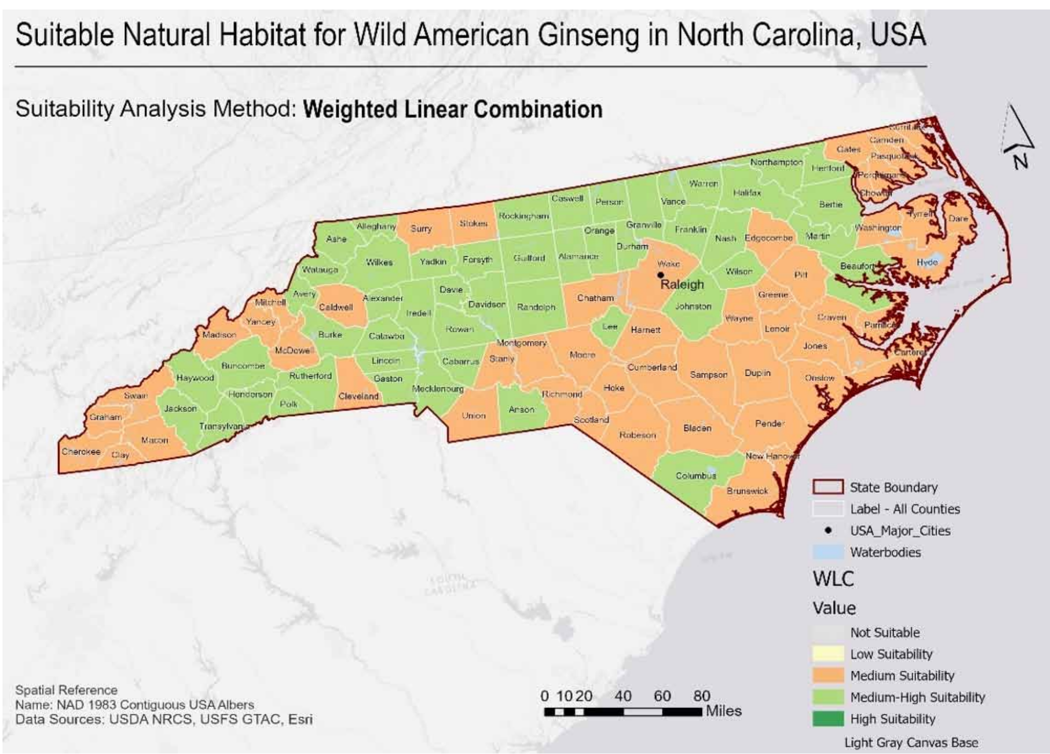
SENSITIVITY ANALYSIS

The results of the BS method (which have 96% consistency with real-world observations) are used as the benchmark of our sensitivity analysis. To create suitability maps using the BS method, Khademian and Bunch (2023) used the information reported in Appendix B. That table presents the factor constraints that represent growing conditions for wild American ginseng in nature. To create suitability maps using the WLC method applied in this paper, the factor ratings introduced in Appendices C and D have been used. This method helps us create suitability maps in which each land unit is given a suitability rating. Accordingly, each land unit is given a suitability score at the end that represents how suitable the land unit is for wild American ginseng to grow in North Carolina, which helps in the conduct of our sensitivity analysis.

The BS results are provided as a basis for comparison, since it was the model with the highest predictability power in Khademian and Bunch (2023). Its resulting map is provided in Appendix E for the sake of comparison. Then, this paper provides a sensitivity analysis on the WLC results and checks the result with those of the BS results. Figure 5 shows the suitability map for wild American ginseng using the WLC methods where the weights given to each factor in this method were determined by looking at the growing conditions of wild American ginseng, as reported by Khademian and Bunch (2023).

Figure 5 presents the suitability map that is generated using the WLC method by Khademian and Bunch (2023). The assigned weights for each factor in this technique were determined by reviewing the literature on the growth conditions of wild American ginseng. The factors and their corresponding weights utilized in our WLC approach are presented in Appendix D. The findings from the WLC method reveal that most of the western counties in North Carolina, which were previously identified as suitable environments by the BS, AF, and GS methods, have also been identified by the WLC

Figure 5. Suitability map of WLC



method as possessing a medium-high or medium level of suitability for wild American ginseng growth. Nevertheless, several counties have also been categorized as having medium-high or medium suitability levels, which is in contrast with both the outcomes of prior methods and, more significantly, real-world observations. This disparity largely stems from the fact that the WLC method aggregates the weighted factors' products, resulting in consistently high suitability scores for each county. Even in scenarios where a crucial natural factor is absent (resulting in a zero FR), the WLC method still aggregates the other nine weighted FRs, yielding a considerable suitability score for wild American ginseng in that county. However, the absence of that singular vital factor is sufficient to render wild American ginseng unable to thrive in that region.

In this study, we perform a sensitivity analysis to explore the intricacies of the WLC method, focusing on the selection of weights and identifying the pivotal growing factors that significantly influence the prediction of suitable natural habitats for wild American ginseng in its natural environment. Conducting this analysis will provide insights into both the sensitivity of WLC model suitability scores to changes in the assumed importance of factors, elucidating the critical factors influencing the suitability of an area for wild American ginseng, and the extent to which our model predictions deviate from real-world observations under different weight configurations.

The WLC method is based on a composite suitability score, which in turn depends on both the "factor rating" of each factor as well as the respective "weights" that the researcher attributes to each factor and follows Equation 1.

$$\boldsymbol{Score_{WLC}} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}=\#\ \boldsymbol{of\,factors}} \left(\boldsymbol{W_i} \times \boldsymbol{FR_i}\right) \tag{1}$$

In Equation 1, $Score_{WLC}$ denotes the suitability score obtained using the WLC method, FR_i denotes factor rating for factor *i*, and W_i denotes the weight (relative importance) assigned to factor *i* in the WLC method (subject to the constraint $\sum_{i=1}^{n=\#\,of\ \ factors} \left(W_i\right) = 1$).

Although the task of setting factor ratings and parameters is rather straightforward (they are usually determined biologically, experimentally, or observationally), the task of allocating relative importance to each factor (i.e., assigning weights to factors) can be complex at times. In general, the latter can be objective, subjective, subject to the status of other factors, or subject to many other criteria. To take one step further forward toward better understanding the interdependencies of the suitability scores and weights within the construction of the WLC method, one can investigate and show the sensitivity of suitability levels regarding the choice of the weights. Although there are statistically many possibilities to set up different scenarios for weights in our WLC model to assess the interplay of suitability scores and weights, here five scenarios are investigated, as described below. More details on the breakdown of weights under each scenario are provided in Appendix F.

- Equally weighted factors
- Spatial factors weighted more heavily (latitude and elevation)
- Shade-related factors weighted more heavily (slope, aspect, and shade percentage)
- Meteorological/Climate-related factors weighted more heavily (annual average temperature, precipitation, and number of cold days)
- Soil-related factors weighted more heavily (soil type, soil pH)

The summarizing table presented below provides a step-by-step procedure for our sensitivity analysis and visual representation.

Table 1. A Summary of the step-by-step procedure for our capability analysis, sensitivity analysis, and visual representation

Step	Description
1. Data Input	- Use factor constraints from Appendix B for the BS method.
	- Extract factor ratings (FRs) from Appendices C and D for the WLC method.
	- Define weights for the WLC method based on mainstream literature on wild American ginseng-growing conditions.
2. Create Initial Suitability Maps	- Generate a suitability map using the BS method based on suitable/unsuitable classifications.
	- Construct the initial suitability map using the WLC method with predetermined weights.
3. Comparison Basis	- Present the BS results as a baseline for comparison, including the map in Appendix E.
	- Highlight the predictability power of the BS model as the foundation for sensitivity analysis.
4. WLC Suitability Map Presentation	- Display the WLC suitability map generated by Khademian and Bunch (2023) in Figure 5, showing suitability levels for wild American ginseng.
	- Provide a detailed breakdown of the factors and their corresponding weights used in the WLC approach in Appendix D.
5. Discrepancies and Insights	- Analyze the WLC results, noting differences from prior methods and real-world observations.
	- Identify disparities arising from the aggregation issue in the WLC method, leading to consistently high suitability scores.
6. Sensitivity Analysis	- Conduct a sensitivity analysis to understand the impact of changing weights on WLC suitability scores.
	- Investigate five scenarios for weight distribution: equally weighted factors, spatial factors weighted more heavily, shade-related factors weighted more heavily, meteorological/climate-related factors weighted more heavily, and soil-related factors weighted more heavily.
7. Visualization of Scenarios	- Create visual representations (Appendix F) for each sensitivity scenario, illustrating the breakdown of weights and their impact on suitability scores.
8. Conclusion and Recommendations	- Summarize insights gained from the sensitivity analysis regarding the factors crucial for predicting suitable habitats for wild American ginseng.
	- Offer recommendations based on the most influential factors to enhance the predictability power of the WLC model.

This tabular procedure outlines a step-by-step procedure for conducting a sensitivity analysis and visually representing the impact of changing weights in the WLC method for predicting the suitability of natural habitats for wild American ginseng. The subsequent five figures showcase the resulting suitability maps generated by the WLC method, each corresponding to a distinct weighting scenario outlined earlier.

Examining each map individually on separate pages can impede a comprehensive grasp of the overall pattern of our results at once. Therefore, following the presentation of individual maps, all WLC suitability maps are consolidated in one single view in Figure 11, offering a unified view that facilitates the observation of changes in predicted suitable areas as weights undergo adjustments. The arrangement of these maps follows the order of their resemblance to our benchmark comparison (i.e., the BS model and real-world observations).

The upper middle map presents our BS model together with the real-world observations of wild American ginseng, which is used as the basis for our comparisons throughout the sensitivity analysis of this study. As shown above, our results suggest that the most important factors in determining suitable areas for wild American ginseng to grow in nature are spatial factors (i.e., latitude and elevation). When these factors are weighted more heavily, the results of the WLC method resembles greatly those of our BS method and real-world observations, in a way that most of the counties identified by either method will be the same. Additionally, our results imply that the next most important set

Figure 6. WLC method (equally weighted factors)

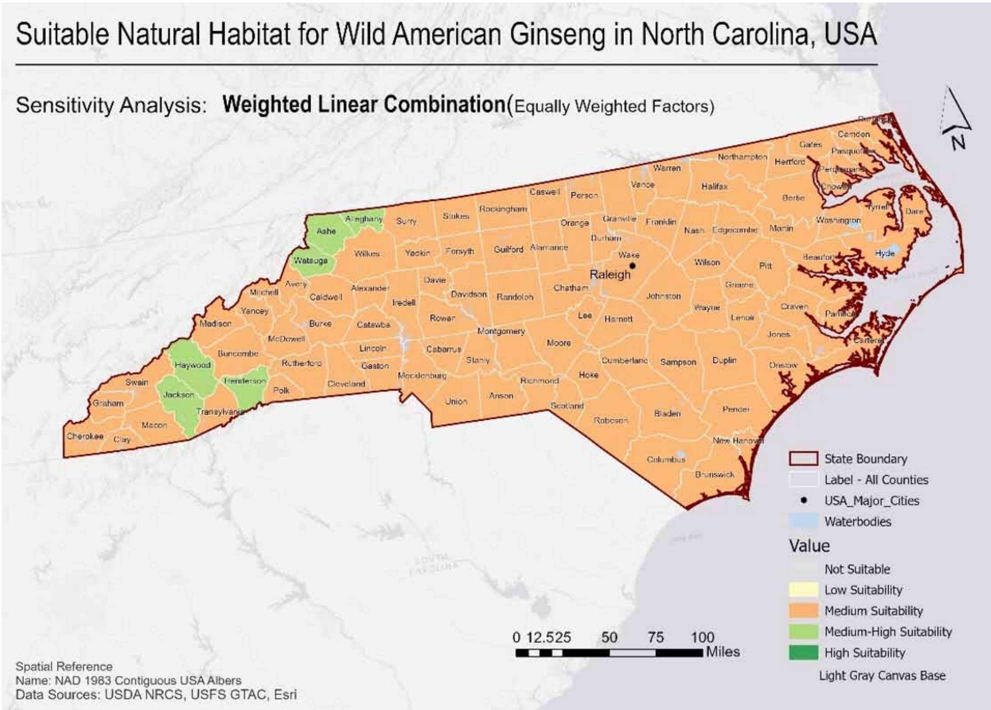


Figure 7. WLC method (spatial-related factors more heavily weighted)

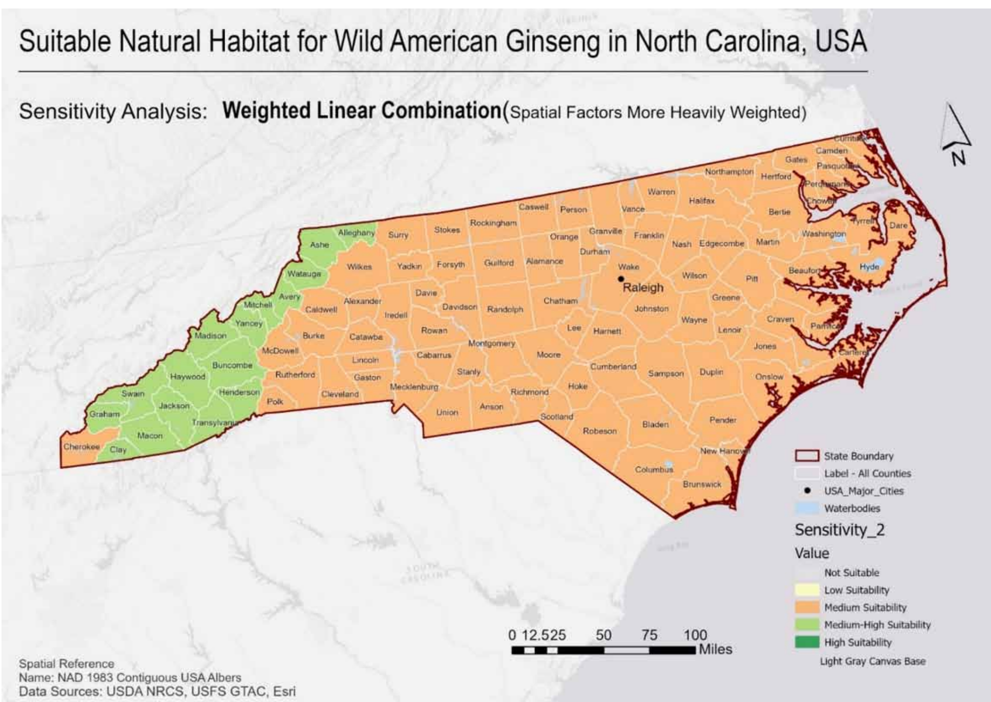


Figure 8. WLC method (shade-related factors more heavily weighted)

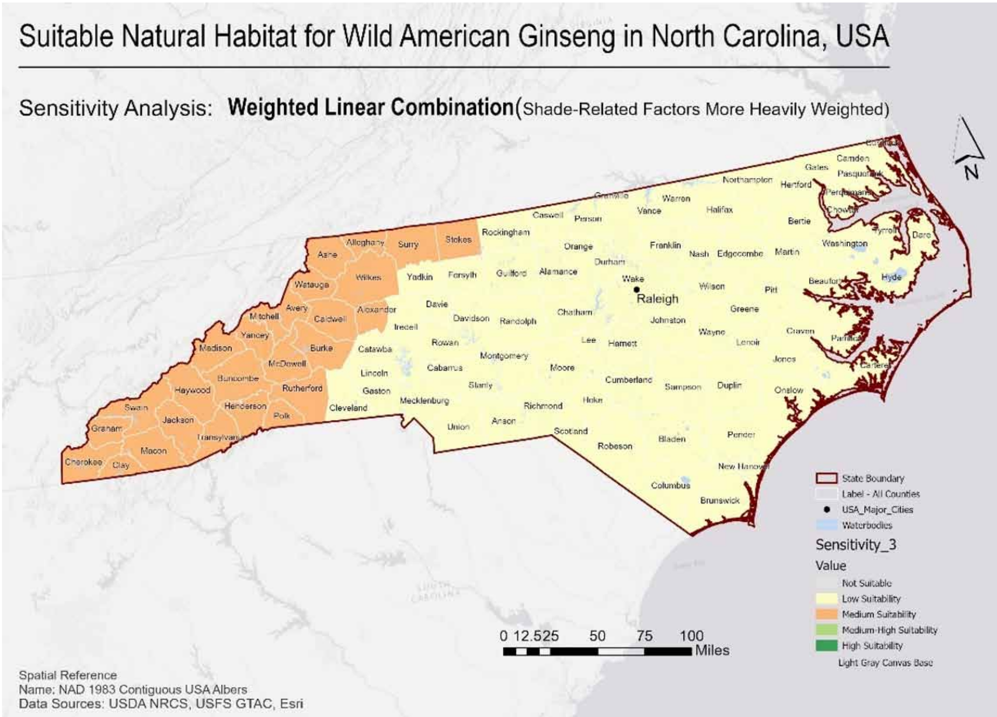


Figure 9. WLC method (meteorological\climatic factors more heavily weighted)

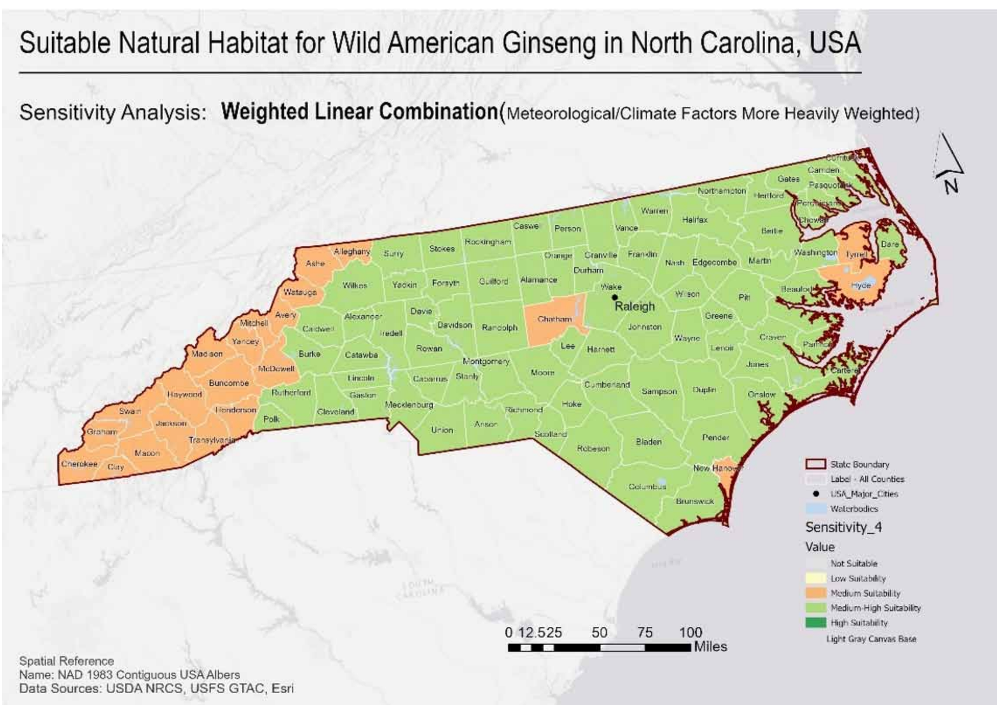


Figure 10. WLC method (soil-related factors more heavily weighted)

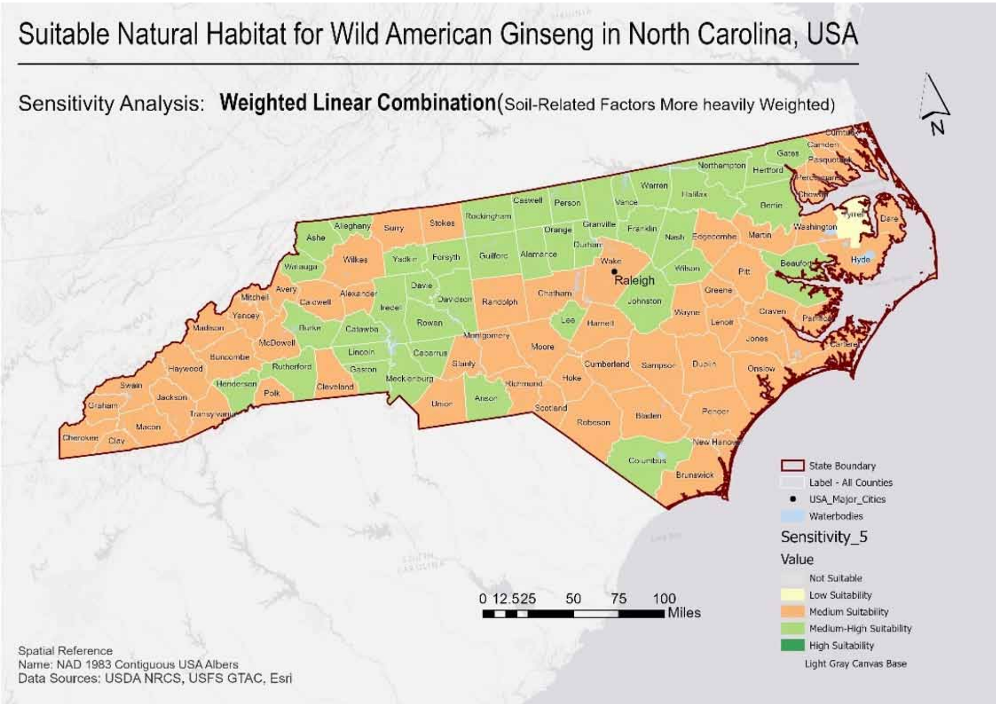
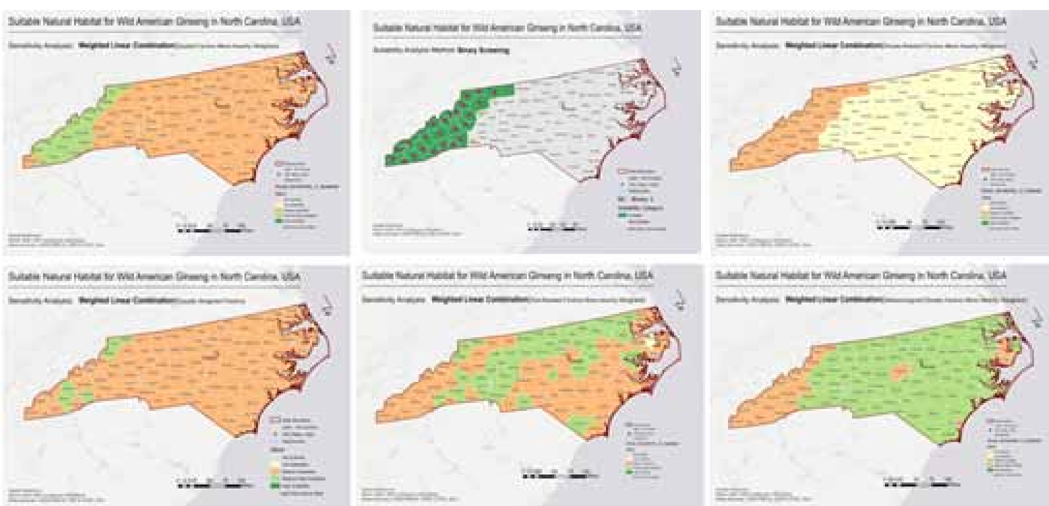


Figure 11. All sensitivity analysis maps vs. BS map in one view



of factors in predicting suitable natural habitat for wild American ginseng are shade-related factors, such that when these factors are weighted more heavily, the WLC suitability map resembles almost fully our BS suitability map, but at a lower level of suitability, holding the set of suitability score ranges constant for both methods.

In the subsequent scenario, we explored an equally weighted factors setting, assigning identical weights to all factors. As depicted in the above figures, this equal weighting resulted in certain counties, identified as suitable by the BS model, still being categorized as medium-high suitable by the WLC model. However, a notable discrepancy emerged, indicating that all other North Carolina counties were uniformly labeled as having a medium level of suitability, diverging from both the BS model predictions and real-world observations. Subsequently, we examined the suitability of North Carolina counties for wild American ginseng by elevating the weights assigned to soil-related factors. The outcomes of this scenario, as illustrated in the figures above, exhibited some inaccuracies and even contradictions with their corresponding real-world observations.

Finally, as we assigned greater weights to meteorological and climate-related factors, a noteworthy shift occurred. Almost all the outcomes exhibited contradictions with both real-world observations and our BS model. Specifically, the WLC model identified counties as medium-high suitable, a designation in stark contrast to the BS model, which deemed these areas unsuitable—especially notable as no real-world observations of wild American ginseng were documented in these locales. Similarly, the WLC model classified counties as medium suitable, contradicting the BS model's assessment of suitability in these regions, despite real-world observations supporting wild American ginseng cultivation in those very areas.

These findings suggest the potential advantage of sensitivity analysis in informing the calibration of weights within a WLC method. By carefully considering the outcomes of such an analysis, one might explore the possibility of refining the weights of a WLC suitability map to enhance alignment with observed real-world conditions. This proposition warrants further investigation and could offer valuable insights for improving the objectivity and accuracy of weight assignment in the WLC method.

Khademian and Bunch (2023) demonstrated the robust predictive capabilities of the BS method in identifying suitable natural habitats for wild American ginseng, boasting an impressive 96% predictability power. This method, by necessitating the presence of all relevant factors within the designated area, yields results closely aligned with real-world observations. In an extension of their research, our sensitivity analysis suggests that for those inclined to adopt the WLC method for suitability analysis, strategic consideration of factor importance is crucial for aligning predictions with reality. Our findings propose the following hierarchy of factor importance for wild American ginseng within the WLC method:

- Spatial factors (latitude and elevation)
- Shade-related factors (slope, aspect, and shade percentage)
- Soil-related factors (soil type and soil pH)
- Meteorological/Climate factors (annual average temperature, precipitation, and number of cold days)

Our sensitivity analysis underscores the pivotal roles played by spatial and shade-related factors in predicting suitable areas for wild American ginseng growth. Consequently, assigning greater weights to these factors enhances the predictability power of the model, ensuring a higher consistency level between model predictions and real-world observations.

CONCLUSION AND SUMMARY

Ginseng, a root component of the Panax plant family distinguished by its ginsenoside and gintonin content, holds historical significance as a traditional medicine in China. This sought-after herb is endemic to North America, Korea, Manchuria, and Siberia in the Northern Hemisphere, thriving mainly in the undergrowth of eastern deciduous forests. Wild American ginseng shares a resemblance with Chinese ginseng, notably in its high ginsenoside levels, setting it apart from Siberian ginseng, which lacks this feature. The demand for the ginsenoside-rich wild American ginseng in the Chinese market has fueled its export from the United States since 1860, with current prices ranging from $400 to $800 per pound. This high demand has triggered concerns about its overharvesting, which has endangered the plant because harvesting the root of the plant is deadly to the whole plant and decreases its population size over time.

The conservation of wild American ginseng hinges on understanding its habitat and growing conditions. Research endeavors are required to discern its suitable habitats, vital growth factors, and feasible alternatives to wild harvesting, which can alleviate the strain on its survival. Khademian and Bunch (2023) utilized a specific set of weights that they had inferred from the respective literature for the growing factors in their geospatial methods to pinpoint suitable regions for ginseng growth in North Carolina. However, the present paper delves into a sensitivity analysis to ascertain the relative importance of these factors. By identifying the pivotal growth determinants, this study aims to enhance law enforcement efforts and advocate sustainable cultivation as an alternative to wild harvesting, ultimately preserving the valuable species.

Indeed, an important advantage of the WLC method lies in the fact that it helps researchers conduct a sensitivity analysis over the weights of factors to investigate different scenarios of relative importance for each determining factor in the activity under investigation. A benefit of conducting a sensitivity analysis is to give insight into how a modeler can calibrate the model by changing the weights of parameters to better match the real-world observations that have been made. As discussed in the paper, the suitability analysis conducted through the BS method presents the most accurate predictions for suitable natural habitats for wild American ginseng. This accuracy can be attributed primarily to the fact that this method ensures that all the determining factors exist in the area of interest. However, if one still tends to choose the WLC method to do a suitability analysis, they must conduct a model validation together with a sensitivity analysis to identify vital factors in the activity of interest and accordingly attribute proportionally significant weights to those determining factors.

In our sensitivity analysis, we compared the results of the BS model, based on real-world observations of wild American ginseng (extracted from wild American ginseng harvest data in North Carolina counties in 2018 as reported by the North Carolina Department of Agriculture and Consumer Services), with variations in weightings applied to different factors in the WLC method. The study revealed that spatial factors, particularly latitude and elevation, emerged as the most critical determinants of suitable areas for wild American ginseng growth. When these factors were given higher weights, the WLC method closely aligned with the BS model and real-world observations, indicating a shared identification of suitable counties. Additionally, shade-related factors played a significant role in predicting suitable habitats, with higher weights leading to a convergence between the WLC and BS suitability maps, albeit at a lower suitability level. The equal-weight scenario showed discrepancies, highlighting the importance of prioritizing certain factors. Notably, the sensitivity analysis emphasized that, for those opting for the WLC method, the order of importance for factor sets, in terms of predicting reality, should prioritize spatial, shade-related, soil-related, and meteorological/climate factors.

This paper contributes methodologically to the literature by proposing a type of sensitivity analysis that can give insight into how modelers can calibrate their suitability models by changing the weights of parameters to better match the real-world observations that are made when the observations constitute a fair, representative sample of the whole population. For future research, it is suggested that a geo-statistical method should be formalized that considers a large number of possible combinations for weights in the WLC method and automatically compares the suitability results of each weight set to the observations made in the real world and utilizes optimization methods to calibrate the WLC method's weights objectively in such a way that it makes its results the closest possible to the real-world observations.

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APPENDIX A

A list of data sources

#	Variable/ Dataset	Data Source	Year	Link
1	Latitude (L)	Esri		Accessed through Living Atlas https://services.arcgis.com/P3ePLMYs2RVChkJx/arcgis/rest/services/World_Latitude_and_Longitude_Grids/FeatureServer
2	Elevation (E)	USDA Natural Resources Conservation Services, National Cartography & Geospatial Center		https://gdg.sc.egov.usda.gov/GDGHome_DirectDownLoad.aspx The 30m elevation data for the conterminous United States is the primary initial source data
3	Slope (S)			Using Slope Tool
4	Aspect (A)			Using Aspect Tool
5	Shade Percentage (Sh)	USFS Geospatial Technology and Applications Center (GTAC)	2016	https://www.mrlc.gov/data/nlcd-2016-land-cover-conus
6	Annual Average Temperature (T)	USDA Natural Resources Conservation Service, National Geospatial Management Center	1981-2010	https://gdg.sc.egov.usda.gov/GDGHome_DirectDownLoad.aspx
7	No. of Cold Days (NOCD)	USDA Natural Resources Conservation Service		https://gdg.sc.egov.usda.gov/GDGOrder.aspx?order=QuickState
8	Precipitation (P)	USDA Natural Resources Conservation Service, National Geospatial Management Center	1981-2010	https://gdg.sc.egov.usda.gov/GDGHome_DirectDownLoad.aspx
9	Soil pH (pH)	USDA Natural Resources Conservation Service		https://gdg.sc.egov.usda.gov/GDGOrder.aspx?order=QuickState Soil Survey Geographic Database (SSURGO) dataset
10	Soil Type (ST)	USDA Natural Resources Conservation Service	2020	https://gdg.sc.egov.usda.gov/GDGOrder.aspx?order=QuickState The Soil Survey Geographic Database (SSURGO) dataset
11	County Boundary	Esri	2018	Accessed through ArcGIS Living Atlas https://services.arcgis.com/P3ePLMYs2RVChkJx/arcgis/rest/services/USA_Boundaries_2018/FeatureServer
12	State Boundary	Esri	2018	Derived from County boundary layer using the Dissolve Tool

APPENDIX B

Table schedules of factor constraints (binary analysis)

#	Variable	FC
1	Latitude (L)	30° =< L =< 50°
2	Elevation (E)	2000ft =< E =< 4000ft
3	Slope (S)	10% =< S =< 40%
4	Aspect (A)	22.5° =< A =< 67.5°
5	Shade Percentage (Sh)	Sh >= 75% & in deciduous hardwood forests
6	Annual Average Temperature (T)	40° =< T =< 60°
7	No. of Cold Days (NOCD)	NOCD >= 45 days per year
8	Precipitation (P)	P >= 25 inches
9	Soil pH (pH)	5 =< pH =< 7
10	Soil Type (ST)	Sandy Loam (SaLo) and Loam (Lo)

APPENDIX C

Table Schedules of Factor Ratings

Table C1 rating schedule for latitude

Latitude (L)	Range (°)	FR
	L < 20°	0
	20° =< L < 30°	8
	30° =< L =< 50°	10
	50° < L =< 60°	8
	L > 60°	0

Table C2 rating schedule for elevation

Elevation (E)	Range (ft)	FR
	E < 2000ft	0
	2000ft =< E =< 4000ft	10
	4000ft < E =< 5000ft	8
	E > 5000ft	0

Table C3 rating schedule for slope

Slope (S)	Range (%)	FR
	S < 10%	2
	10% =< S =< 40%	10
	40% < S =< 60%	6
	S > 60°	0

Table C4 rating schedule for aspect

Aspect (A)	Range (%)	FR
	A < 22.5°	5
	22.5° =< A =< 67.5°	10
	67.5° < A =< 112.5°	5
	112.5° < A < 360°	2

Table C5 rating schedule for shade percentage

Shade Percentage (SH)	Range (%)	FR
	Sh < 60%	0
	60% =< Sh < 70%	5
	70% =< Sh =< 80%	10
	80% < Sh =< 90%	8
	Sh > 90%	0

Table C6 rating schedule for annual average temperature

Annual Average Temperature (T)	Range (°F)	FR
	T < 40	0
	40 =< T < 45	5
	45 =< T =< 55	10
	55 < T =< 60	5
	T > 60	0

Table C7 Rating schedule for the number of cold days

No. of Cold Days (NOCD)	Range (Day)	FR
	NOCD < 35	0
	35 =< NOCD < 45	5
	NOCD >= 45 days per year	10

Table C8 Rating schedule for annual average precipitation

Annual Average Precipitation (P)	Range (in)	FR
	P < 10	0
	10 =< P < 25	5
	25 =< P =< 30	10
	30 < P =< 40	8
	P > 40	0

Table C9 rating schedule for soil pH

Soil pH (pH)	Range (pH)	FR
	pH > 7	0
	5 =< pH =< 7	10
	4 =< pH < 5	5
	pH < 4	0

Table C10 rating schedule for soil type

Soil Type (ST)	Range (Soil Name)	FR
	ST = ClLo	5
	ST = SiLo	5
	ST = SaLo	10
	ST = Lo	10
	ST = SaClLo	5
	ST = LoSa	5
	ST = Otherwise	0

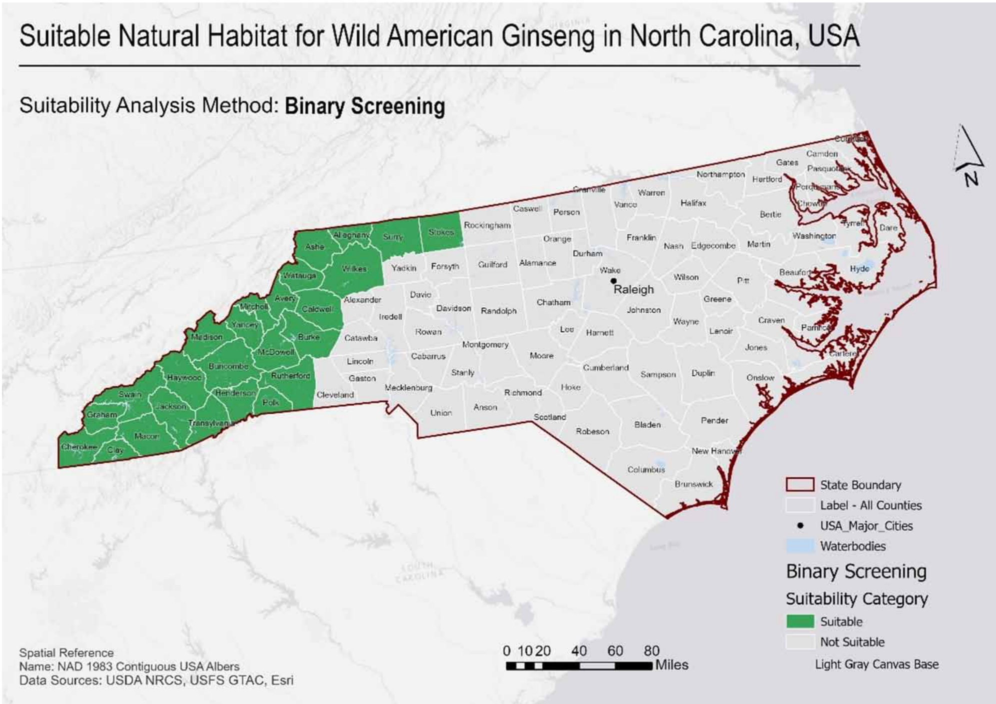
APPENDIX D

Table schedules of factor ratings for the first WLC method

#	Variable	Weight
1	Latitude (L)	10%
2	Elevation (E)	10%
3	Slope (S)	5%
4	Aspect (A)	5%
5	Shade Percentage (Sh)	10%
6	Annual Average Temperature (T)	15%
7	No. of Cold Days (NOCD)	10%
8	Precipitation (P)	5%
9	Soil pH (pH)	15%
10	Soil Type (ST)	15%

APPENDIX E

Figure 12. Map of BS method as a point of comparison for the WLC maps



APPENDIX F

Detailed Information on Sensitivity Analyses

Figure 13. Sensitivity analysis: All equally weighted factors

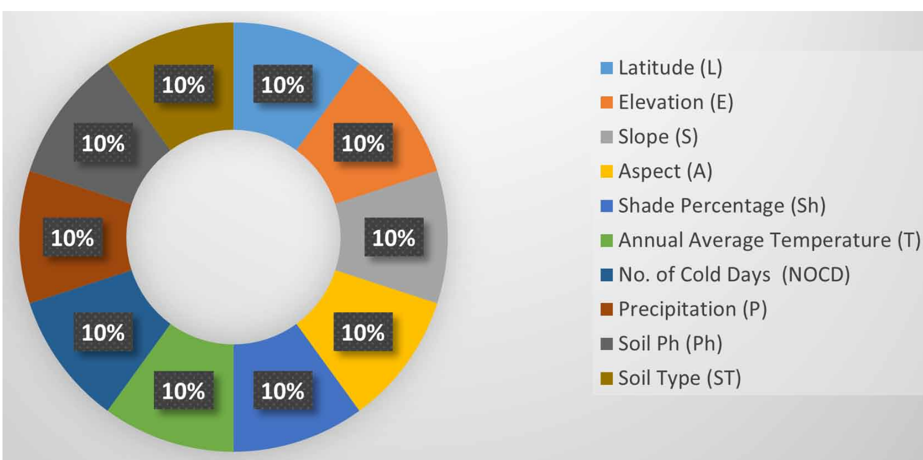


Figure 14. Sensitivity analysis: Spatial factors more heavily weighted

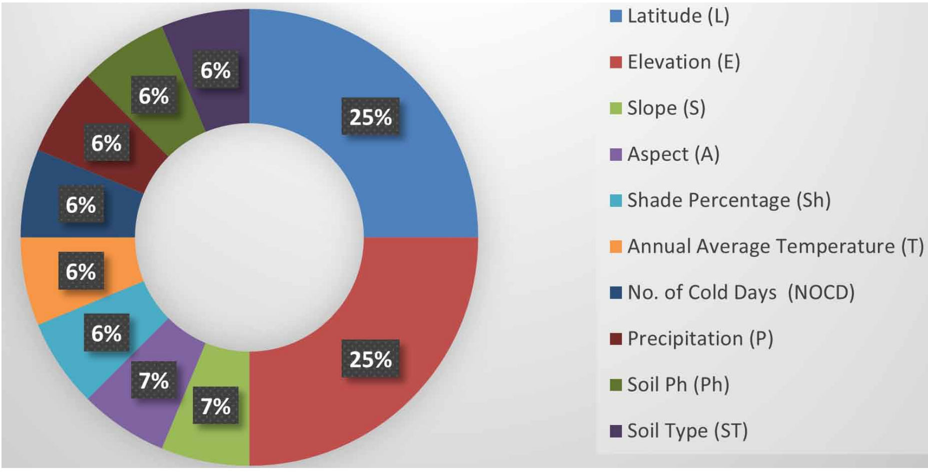


Figure 15. Sensitivity analysis: Shade-Related factors more heavily weighted

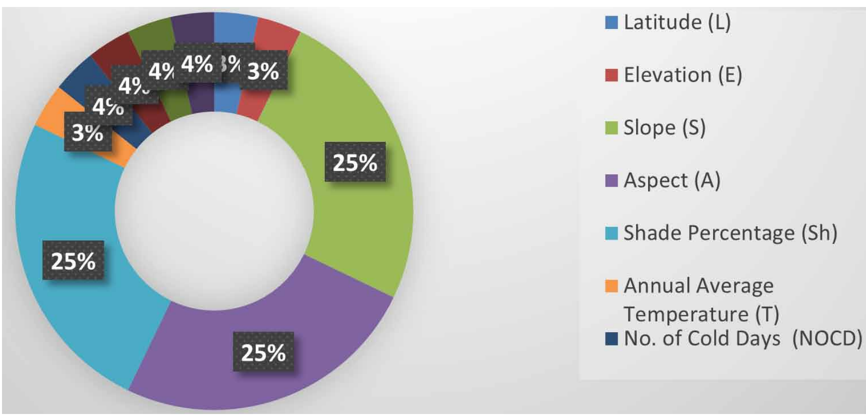


Figure 16. Sensitivity analysis: Meteorological/Climate factors more heavily weighted

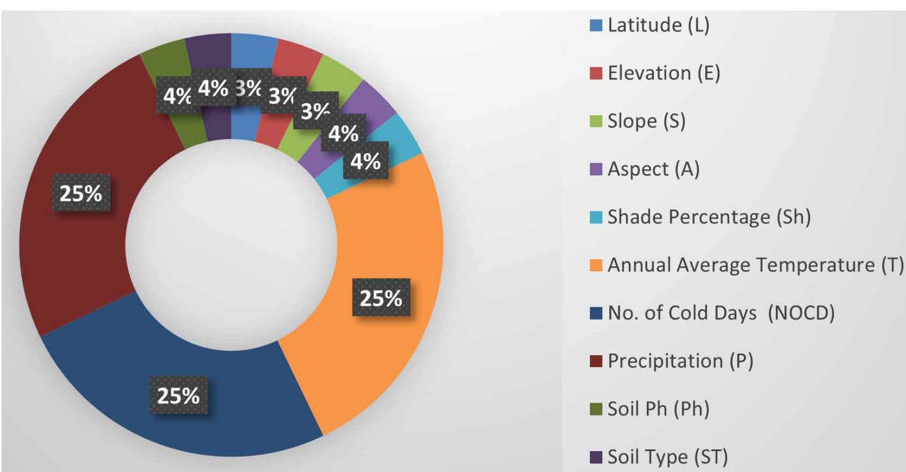
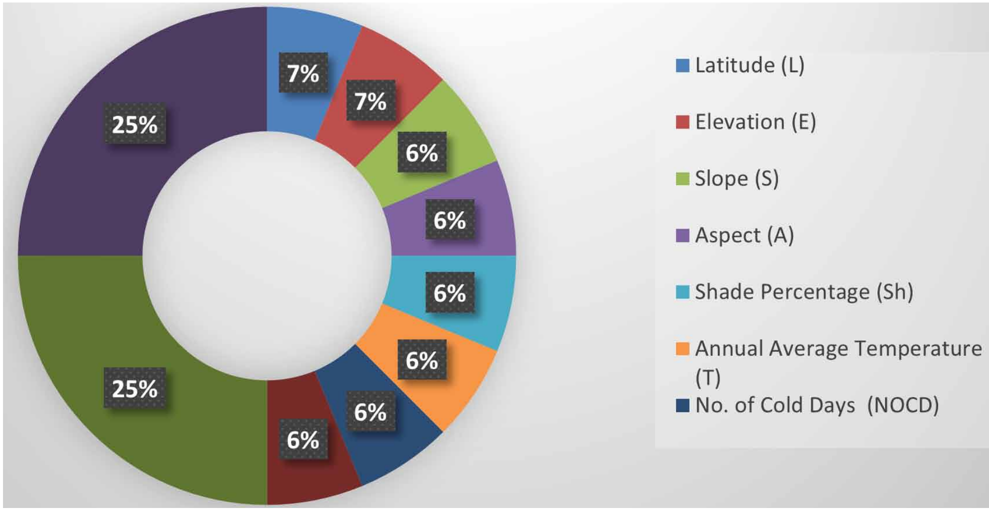


Figure 17. Sensitivity analysis: Soil-Related factors more heavily weighted



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