CLIMATE CHANGE AND FOODSHED DYNAMICS: A PILOT STUDY ON REDEFINING FOODSHED BOUNDARIES AND PROJECTED FOOD INSECURITY

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ABSTRACT
Global food production and its associated processes account for approximately 25% of greenhouse gas emissions, which significantly contribute to climate change (Poore and Nemecek, 2018). These emissions, quantified through Representative Concentration Pathways (RCPs) and projected into future scenarios, are negatively affecting the nutritional quality of our food (IPCC, 2014). In response to this dual challenge, this research revisits and aims to redefine the geospatial concept of a "foodshed"—a framework developed in the 1990s to promote health and sustainability by mapping local food systems. This concept, akin to an Ecoregion (Omernik and Griffith, 2014), along with analytical work on food deserts (McEntee and Agyeman, 2010), provides the foundation. This project therefore establishes and conducts a pilot test to examine how foodshed boundaries can be redefined in light of contemporary data and climate projections.

The project employs a mixed-methods approach, integrating qualitative and quantitative analyses across three sequential phases to concatenate data and evaluate spatial outcomes. Phase 1 involves foundational data collection through a systematic literature review and geospatial analysis to understand current production and distribution dynamics. Phase 2 conducts detailed geospatial analysis of existing conditions within a U.S. pilot region to delineate revised foodshed boundaries. Finally, Phase 3 evaluates these new delineations by applying specific performance indicators and assessing future agricultural scenarios under projected climate change impacts. This methodology bridges spatial analysis with contextual interpretation for a nuanced understanding.

The results of this study demonstrate tested criteria for identifying conditions that affect both the quantity and quality of crops within a foodshed. It presents a region-specific foodshed delineation and proposes remediation strategies for an area facing agricultural and food system vulnerabilities. The research imparts a transferable framework and a set of geospatial tools that future researchers can use to identify, analyze, and evaluate key patterns and drivers within food systems.

Keywords
Foodsheds, Geospatial Analysis, Climate Change, Food Security

1 INTRODUCTION

Food systems, increasingly recognized as both a driver and victim of climate change, are facing unprecedented challenges in the 21st century. Globally, food production and its associated processes account for nearly one-quarter of all greenhouse gas (GHG) emissions, significantly contributing to planetary warming (Poore & Nemecek, 2018). Ironically, while agriculture plays a substantial role in driving climate instability, climate change is already undermining the very systems of food production, distribution, and consumption that it supports (Scanlon et al., 2017). Projected impacts extend beyond reduced yields to encompass severe degradation in the nutritional quality of food staples. For example, model projections indicate that staple crops such as wheat, rice, and maize could experience a 17–30% decrease in key nutrients including zinc, protein, iron, and vitamin B by mid-century under current emissions pathways (Ault et al., 2016; Poore & Nemecek, 2018).

These nutritional declines are particularly concerning given the growing global population and the widening inequality in access to healthy and sustainable food. Traditional policy tools and analytical frameworks such as "foodsheds" were initially developed to address food security through spatial planning and localized food systems (Tobey, 1930; Kloppenburg et al., 1996; Zazo-Moratalla et al., 2019). Foodsheds provide individuals involved in food system management, food purveyors, policymakers and end-users with a sense of proximity to sources of food production and processing. The mapping of foodsheds also helps to identify and visualize areas with limited access to food, often referred to as ‘food deserts,’ within a geospatial context. Since the 1990s, the foodshed concept has offered a geographical lens to analyze food system flows, emphasizing regional self-reliance, the ability of communities to meet food needs from nearby sources, while addressing the ecological footprint of food transport (UN FAO, 2025). However, self-reliance does not ensure resilience and adaptability to disturbance or disruption. More recent approaches such as ‘food system resilience,’ which refers to a system’s capacity to withstand and adapt to shocks such as climate change, supply chain disruptions, and socio-economic stressors (Tendall et al., 2015). Defined spatially like ecoregions (Omernik & Griffith, 2014), early foodshed models aimed to support sustainability and food justice. However, as climate conditions, land use, and dietary patterns have shifted, the utility of these original boundaries (Snetselaar et al., 2021) has become increasingly contested.

As climate change intensifies and the nutritional quality of staple crops declines, traditional foodshed boundaries, which were originally defined by proximity and production volume (e.g., Defined as ‘Applesheds’ in Tobey, 1930), are no longer adequate for guiding food system planning. This research responds to these emerging challenges by redefining foodshed boundaries through a system-enriched, climate change lens. We incorporate climate projections, soil importance categorization indicator, and the role of underutilized crops into a new geospatial framework, which reflects both vulnerable and adaptive foodshed boundaries. This redefinition is grounded in a mixed-methods approach that includes geospatial analysis, literature review, and a pilot study within one U.S. region, the Columbia River Basin. By doing so, we aim to integrate social-ecological resilience, spatial justice, and nutritional adequacy into the foodshed paradigm.

The central research question guiding this inquiry is: *How can foodshed boundaries be redefined to reflect climate-adaptive food system conditions, nutritional resilience, and social equity under future conditions and externalities of climate change?* Through projective geospatial modeling and stakeholder-informed analysis, this study offers a methodological pathway and theoretical rationale for reshaping landscape architecture and planning perceptions of the foodshed concept to align with contemporary climate-food challenges.

1.1 Origins and Evolution of Foodshed Concept

The notion of a "foodshed" first gained traction in the 1990s as a means to analyze and promote the spatial organization of food systems (Kloppenburg et al., 1996). Borrowed from hydrology, where a watershed defines the area draining into a water body (Kremer & Schreuder, 2012), a foodshed represents the area that supplies food to a given population (Kremer & Schreuder, 2012). Early applications of the foodshed framework emphasized localization, regional self-reliance, and food system sustainability. This spatial concept helped visualize where food comes from, how far it travels, and what ecosystems support its production.

Initial efforts to define foodsheds used physical and administrative boundaries to demarcate zones of food production and consumption. Omernik and Griffith (2014) advanced hierarchical frameworks for ecoregions that inspired similar spatial logics in foodshed delineation. Meanwhile, GIS-based studies, such as McEntee and Agyeman's (2010) mapping of rural food deserts in Vermont, helped identify areas of inadequate access and analyze the socio-spatial dimensions of food insecurity. These works marked a critical shift toward integrating food justice into spatial planning.

However, as global supply chains have expanded and urban-rural dynamics shifted, driven by suburbanization (Lichter et al., 2021), farmland conversion (López-Goyburu et al., 2018; Feng et al., 2021), and labor migration, the static nature of early foodshed boundaries became less relevant. From impacts ranging from lack of resource resource management, development on prime and unique agricultural soil classes, and ground water shortages, the goal of foodshed delineations has not proven to be successful to justify solutions such as agricultural protection zoning (Reganold, 1986; Eagle et al., 2015) thus utilizing foodshed analyses. Critics pointed out that early foodshed models often failed to account for climate variability, market volatility, and socio-political constraints (Ljungqvist, 2022). Climate variability in this context refers to a non-stable state differing from the stable regional climate patterns driven by fluctuations in anthropogenic processes (IPCC, 2014). Early models also underemphasized market volatility and socio-political constraints that shape access and equity within food systems (Ericksen, 2008). Additionally, traditional foodshed definitions rarely included nutritional metrics, focusing instead on caloric yield or land use efficiency (Kremer & Schreuder, 2012). These limitations point to the need for a more dynamic, multivariate, and anticipatory approach to foodshed analysis that includes ecological, climatic, and social variables.

1.2 Climate Change and Nutritional Decline

Beyond spatial proximity and agricultural productivity, climate change is increasingly altering the quality of what food systems can deliver. According to Poore and Nemecek (2018), agriculture's contribution to GHG emissions is both direct (e.g., enteric fermentation, fertilizer use) and indirect (e.g., land conversion, deforestation). These emissions have feedback effects that degrade agricultural systems, not only in terms of yield but also in the nutritional value of crops. Ault et al. (2016) found that elevated atmospheric CO2 levels, temperature stress, and shifting precipitation patterns reduce micronutrient concentrations in key grains.

These reductions pose a significant threat to global food and nutritional security. In regions where rice and wheat are dietary staples, micronutrient malnutrition could become more widespread. Furthermore, future Representative Concentration Pathways (RCPs), developed by the IPCC (2014), projected scenarios where crop quality declines are not only likely but persistent under high-emissions trajectories. This presents an urgent call for revising the parameters by which we evaluate food systems, moving beyond yield per acre to include soil value categorizations (SSURGO, n.d.) as a key metric.

By embedding climate variables and nutritional indicators into spatial foodshed frameworks, this study shifts the conversation beyond local and regional self-reliance (UN FAO, 2025) to include nutritional and systemic resilience. While proximity to food sources can reduce dependency on external systems, resilience entails the capacity to maintain nutritional adequacy and functional integrity amid climatic and socio-economic disruptions.

1.3 Research Objectives, Intent and Rationale

The overarching objective of this study is to develop and test a methodology for redefining foodshed boundaries that integrate climate change projections, and nutritional quality indicators. Through this redefinition, we seek to enhance the relevance and utility of the foodshed concept in the face of rapidly changing environmental and socio-political conditions. The research objectives of the project include:

- Identifying and evaluating geospatial indicators that reflect climate-adaptive food production capacities.
- Incorporating nutritional metrics, including projected changes in soil categorization, into spatial foodshed modeling.

- Integrating underutilized crops into a spatial framework that reflects food system resilience and dietary diversity.
- Pilot testing the redefined foodshed methodology across one region with varying agroecological and socio-demographic conditions.
- Assessing the effectiveness of redefined foodsheds through scenario-based modeling and policy-relevant performance indicators.

This research contributes a novel, climate-responsive framework for foodshed delineation by aligning spatial boundaries with projected climate risks and evolving food system needs. The framework is designed to support future-oriented planning and to move beyond static, proximity-based definitions of foodsheds. The framework also operates through a multidimensional lens which includes ecological viability, nutritional adequacy, and cultural relevance. The intent is to develop a transferable and adaptive methodology that researchers, planners, and policymakers can use to understand and manage food system vulnerabilities under diverse and uncertain food futures.

This study responds to current system vulnerabilities and issues by advancing a redefined foodshed framework to better inform planning, sustainability science, and policy. The rationale for this work is rooted in the goal of building adaptive capacity, the ability of food systems to anticipate and respond to disturbance, integrating concepts of ecological nutritional, and cultural dimensions of resilience (Hinkel et al., 2011; Li et al., 2015; Seaborn et al., 2021). The work differentiates between self-reliance (UN FAO, 2025) and resilience (Tendall et al., 2015): self-reliance focuses on local sourcing and regional autonomy, whereas resilience captures the system's adaptive capacity in the face of climate, market, or social stressors.

2 METHODS

This study applied a mixed-methods geospatial analysis to redefine foodshed boundaries for a single pilot region: the Columbia River Basin. The methodology was designed to integrate socio-economic vulnerability, food access metrics, climate change projections, land use vulnerability, crop production trends, and health-related food insecurity indicators. In addition, it incorporated proxies for nutritional quality that yield stability and crop suitability data, including the role of underutilized but nutritionally significant crops. The primary objective was to construct a climate scenario-based, foodshed boundary that reflects adaptive food system conditions under projected climate and socio-political and economic stressors. This methods section outlines the data sources, geospatial workflow, and criteria used in the delineation and evaluation of climate and nutrition-adaptive foodsheds.

2.1 Study Area: the Columbia River Basin

The Columbia River Basin (CRB) was selected as the pilot region due to its agroecological diversity, significance in national food production, and documented vulnerability to climate change. Encompassing parts of Washington, Oregon, Idaho, and Montana, the CRB includes a variety of agricultural zones, ranging from high-value irrigated croplands in areas like the Yakima and Snake River Valley to dryland wheat systems in the Palouse. The basin is expected to face increasing climate stress, including higher average temperatures, declining snowpack, altered runoff timing, and greater water scarcity. These conditions threaten crop yields and irrigation-reliant systems (Elsner et al., 2010; Hamlet et al., 2010). The region is also socio-spatially heterogeneous, with both urban centers and rural communities facing food insecurity. Rural areas frequently experience limited access to full-service grocery outlets due to infrastructure constraints, while urban populations in cities such as Spokane, Pasco, and Yakima are subject to persistent issues of food access and economic hardship (USDA ERS, 2023; Centers for Disease Control and Prevention, 2023). This makes it a representative landscape, and potential catalyst for future studies as a means for testing geospatial criteria and climate-informed foodshed redefinition.

Figure 1 illustrates the Columbia River Basin boundary alongside a spatial overlay of food insecurity prevalence at the census-tract level. This map highlights variation in food access across the region, showing particularly high prevalence in parts of southeastern Washington, northeastern Oregon, and rural counties of Idaho. The areas mentioned often overlap with agricultural production zones but experience limited access due to income disparities, limited infrastructure and lack of retail options. The map provides a spatially explicit illustration of regional socio-economic vulnerability and food access limitations as a core component within our geospatial analysis. The visual is not only intended to provide context, but also to reinforce the study's rationale for redefining foodshed boundaries not solely on production trends, but also patterns of unequal distribution and access.

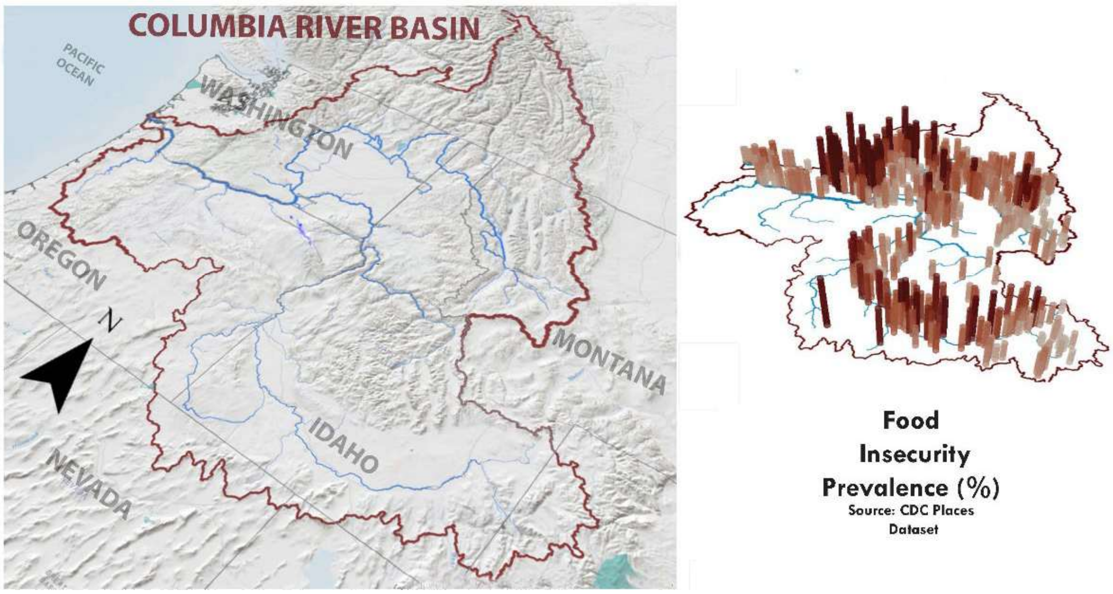

Figure 1. Columbia River Basin (CRB Context. Diagram illustrating location of the CRB along with Food Insecurity Prevalence across the region. Diagram by the author.

2.2 Analytical Framework

The methodology followed a sequential, scenario-driven geospatial framework composed of five interrelated criteria layers:

- Socioeconomic Vulnerability (Composite Index: Households below poverty level)
- Food Access (Network-Based Proximity)
- Climate Risk (RCP 8.5 Projections for 2050)
- Land Cover Vulnerability (Land Use and Land Cover Change projection for 2050)
- Agricultural Area Trends (Soils and land of agricultural importance)

Each layer was constructed as a raster or vector dataset and analyzed using ESRI ArcGIS Pro version 3.3.0. These layers were individually standardized through normalization and then combined using a weighted overlay (ESRI, 2021) approach to define a composite foodshed boundary. The weights were derived from a preliminary literature review and sensitivity analysis.

2.3 Data Sources and Preprocessing

(a) Census Tract Poverty-Level Households: Socioeconomic vulnerability was mapped using American Community Survey (ACS) 5-Year Estimates (U.S. Census Bureau, 2022). This layer included multiple indicators, including: (a) percent of households below the federal poverty threshold, (b) unemployment rate (age 16+), and (c) percent of population without a high school diploma. These variables align with the established socioeconomic vulnerability index used by other regional models (California and OEHHA, 2023) and the CDC's Social Vulnerability Index (Flanagan et al., 2011). Each variable was normalized to a common scale and aggregated using equal weights to construct a composite raster surface for use in the weighted overlay. This approach provides a more comprehensive measure of socio-economic stress than simply poverty alone. The approach attempts to better identify communities at risk of food access challenges under future climate and land use change issues and conditions.

(b) Food Access (USDA Atlas Criteria + Network Distance): Food access was defined using USDA Food Access Research Atlas criteria (USDA ERS, 2023), supplemented by OpenStreetMap (OpenStreetMap contributors, 2024) and TIGER/Line road data (U.S. Census Bureau, 2023 for SNAP authorized stores which typically identify low-access areas based on proximity to grocery stores. In this study, access was measured through a network-based approach rather than Euclidean distance to improve accuracy. Using OpenStreetMap and TIGER/Line road data, we calculated access at two scales:

- **Urban/Walking Scale: 0.25-mile network buffer**
- **Rural/Driving Scale: 10-mile network buffer**

Areas outside of these thresholds were classified as low-access zones. These polygons were then intersected with census tracts to capture areas with compounded vulnerability. These criterion were based on previous research with the USDA Food Access Research Atlas (USDA ERS, 2023) on proximity in rural and urban areas.

(c) Climate Exposure via RCP 8.5: Climate vulnerability was measured using the IPCC's RCP 8.5 scenario projections derived from CMIP6 datasets (IPCC, 2021) for plant-heat tolerance zones (IPCC, 2021), which represents a high-emissions, business-as-usual scenario. Downscaled data on future temperature and precipitation anomalies were accessed via CMIP6 datasets and averaged for the 2040–2060 period. Spatial interpolation and reclassification were used to highlight areas of significant exposure within the CRB.

(d) Land Cover Change Vulnerability: Land use change potential was analyzed using ESA CCI Land Cover data (European Space Agency, 2017) and Clark Labs' Land Change Modeler (Clark Labs, n.d.). ESA CCI Land Cover data provided baseline land use classifications, while Clark Labs' land change probability surfaces were used to identify areas at high risk for conversion from agricultural to non-agricultural uses. A vulnerability index was created based on these probabilities (Clark Labs, n.d.).

(e) Agricultural Lands and Soils of Importance: Crop yield data were obtained through USDA CropScape and the National Agricultural Statistics Service (NASS). Time-series data from 2010 to 2022 were collected for key crops in the Columbia River Basin (CRB), including wheat, barley, potatoes, and alfalfa. Though not a direct proxy for nutritional quality, agricultural lands of importance at this scale represent nutritional quality seen as needed for preservation for statewide or regional importance (USDA NRCS, 2014). Yield anomalies and production trends were calculated and spatially mapped, with higher weighting assigned to stable, high-output zones. To enhance the analysis of agricultural productivity, soil characteristics were integrated using the USDA NRCS SSURGO (USDA NRCS, 2014) database. Soils of agricultural importance were identified based on parameters such as land capability class, hydrologic soil group, drainage class, and available water capacity. Areas containing Prime Farmland, Farmland of Statewide Importance, and soils with high agronomic suitability were prioritized. These soil attributes were cross-referenced with crop yield patterns to better understand the role of edaphic factors in supporting long-term agricultural viability under conditions of inter-annual climate variability and shifting crop suitability.

Figure 2 presents the five spatial layers used to construct the climate-adaptive foodshed model. Each layer represents a key criterion relevant to food system resilience and has been standardized to reflect relative vulnerability or suitability. Socioeconomic vulnerability is shown using poverty rate data, where darker shades indicate areas with higher concentrations of households below the federal poverty line. Food access is represented through a network-based proximity analysis, with darker areas signifying reduced accessibility to grocery stores and farmers' markets, particularly in rural or underserved zones. Climate exposure is visualized using projected heat tolerance under the RCP 8.5 scenario for 2050; in this layer, darker shades indicate areas more resilient to climate-induced stress on crop productivity. Agricultural suitability combines crop yield stability and soil quality data into a single index ranging from 0 (low suitability) to 1 (high suitability), prioritizing areas with long-term agronomic value. Finally, land use vulnerability illustrates projected risks of agricultural land conversion, with lighter areas representing higher susceptibility to future development or fragmentation. Collectively, these layers provide the analytical basis for delineating foodsheds that are responsive to climate, ecological, and socio-economic conditions.

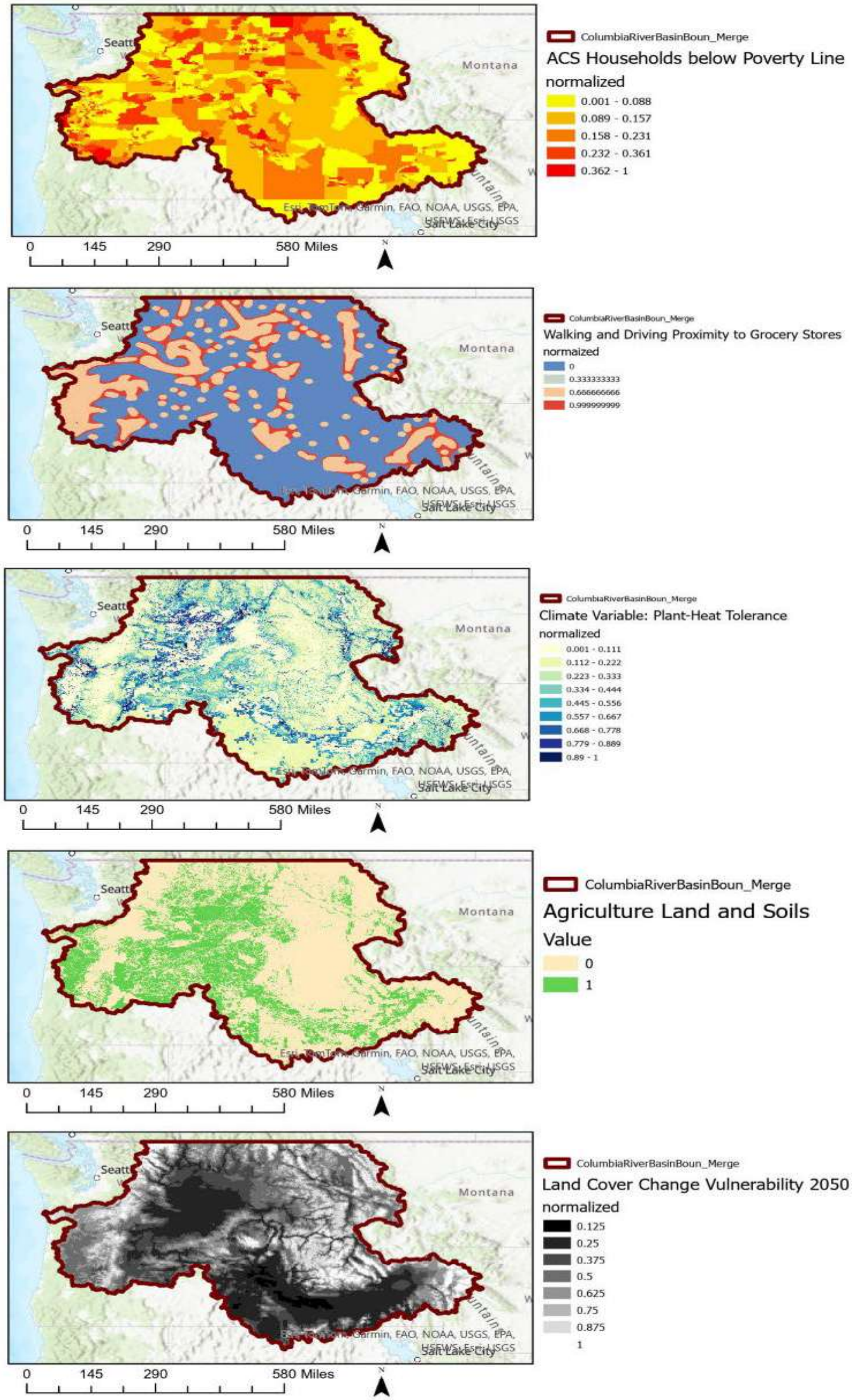

Figure 2. Data and Criteria for Foodshed Analysis. Diagram by the author.

2.4 Geospatial Processing Workflow

The geospatial workflow was executed in three major phases to generate a composite foodshed suitability raster:

Phase 1: Criteria Standardization and Reclassification. All raster and vector layers were standardized on a 0–1 scale using linear fuzzy membership functions in ArcGIS Pro. Higher values were assigned to grid cells or polygons representing greater vulnerability or importance. For example, vulnerability or risk areas were coded closer to 1. For example, census tracts at higher poverty levels were assigned values near 1, as well as areas with high projected land conversion probabilities or extreme climate exposure.

Phase 2: Weighted Overlay and Suitability Modeling. Each standardized criterion was assigned a weight based on its relevance to foodshed resilience, as identified through a preliminary literature (Kremer & Schreuder, 2012Ericksen, 2008) and sensitivity analysis. A preliminary weight distribution proportional to sensitivity analysis (Table 1) was as follows:

- Socioeconomic vulnerability: 20%
- Food access: 25%
- Climate risk: 25%
- Land use vulnerability: 15%
- Agricultural yield stability: 15%

Weights reflect both theoretical and practical relevance to current challenges in the CRB. The weighted overlay tool in ArcGIS Pro (ESRI, 2021) was used to synthesize these inputs into a continuous composite surface representing spatial suitability for resilient foodshed delineation.

Prior to conducting the weighted overlay analysis, multicollinearity among criteria layers was assessed to ensure that highly correlated variables did not disproportionately influence the composite suitability raster. Pearson's correlation coefficients were calculated between rasterized values of each criterion. Moderate correlation was identified between socioeconomic vulnerabilities and food access layers (r = 0.62). Correlation results for all criteria are included in Table 1. Weights were justified using the correlation matrix.

Table 1. Correlation Table of Geospatial Criteria.

	Socioeconomic Vulnerability	Food Access	Climate Risk	Land Use Vulnerability	Agricultural Yield
Socioeconomic Vulnerability	1.0	0.62	0.35	0.28	0.3
Food Access	0.62	1.0	0.22	0.18	0.25
Climate Risk	0.35	0.22	1.0	0.45	0.4
Land Use Vulnerability	0.28	0.18	0.45	1.0	0.55
Agricultural Yield	0.3	0.25	0.4	0.55	1.0

Numbers within Table 1 represent Pearson's correlation coefficients between the pair of criteria layers used in the analysis. The following explains the geospatial interpretation of each r value. Perfect positive correlation is represented as '1.00.' Less than a '1' illustrates reduced correlation whereas a '0' represents variables illustrating no linear correlation. Weaker correlations illustrate that the two layers are relatively independent of each other within the model.

Phase 3: Boundary Delineation: A thresholding technique was applied to the composite raster to extract high-suitability zones, which were vectorized to define core foodshed boundaries. Scenario generation was then used to explore implications of different planning priorities. For example, each level or categorization of suitability defines the range of the food shed and the scenario that it may encompass. In other works, a status quo scenario would be defined by a 'high suitability' demarcation, whereas a high emissions climate change scenario would include 'high suitability', 'medium suitability', and 'low suitability.'

2.5 Evaluation and Validation

The resulting foodshed boundaries were assessed using both qualitative and quantitative methods. Quantitatively, overlap with current agricultural production zones, food access buffers, and public health metrics were measured. Qualitatively, we conducted expert validation with a food system researcher who creates and applies indicators for large-scale mapping tools to influence policy at the governance and policy level. Additionally, a vulnerability-to-resilience index was developed from the inverse of the composite raster, highlighting areas where interventions (e.g., policy incentives, agroecological support) can possibly be most effective.

2.6 Limitations

Several limitations should be acknowledged:

- The model does not account for seasonality of production.
- The RCP 8.5 scenario represents a worst-case projection, which may overestimate climate risk.
- The resolution of data (e.g., county-level health data) may limit local specificity.
- The model is limited by data consistency on the Canadian side of the CRB.
- Incorporation of a Monte Carlo randomization could have improved the sensitivity analysis or served as a proxy for the sensitivity analysis.

Future iterations of this work will seek to integrate these additional variables and refine stakeholder-informed weighting approaches.

3 RESULTS

The geospatial analysis produced a set of redefined foodshed boundaries for the Columbia River Basin, guided by six integrated criteria reflecting socio-economic, environmental, and infrastructural dimensions of food system vulnerability. This section presents the outputs of the composite suitability model, the delineation of core foodshed areas under different scenario assumptions, and an evaluation of spatial alignment with key performance indicators.

3.1 Composite Suitability Surface

The composite raster surface generated from the weighted overlay revealed a heterogeneous pattern of suitability across the Columbia River Basin.

High suitability zones, coded 0.75 and above, were concentrated in regions with:

- Stable, high-yield agricultural production (based on CropScape data)
- Moderate-to-low projected land conversion risk
- Proximity to existing food distribution infrastructure
- Relatively lower socioeconomic vulnerability and higher health access

Conversely, low-suitability zones (below 0.25) were typically located in areas with:

- High land use conversion probabilities (based on Clark Labs projections)
- Limited road access to grocery stores (especially rural tracts beyond 10-mile network buffers)
- Elevated poverty rates and intersecting low-access designations

A visual representation of the composite suitability surface (Figure 3) illustrates the spatial gradients and clustering of suitability values.

3.2 Vulnerability-to-Resilience Gradient

The inverse of the composite raster was classified into a four-tier gradient representing intervention priority:

- Very High Priority (Score: 0.9-1.0)
- High Priority (0.75-0.89)
- Moderate Priority (0.5-0.74)
- Low Priority (<0.5)

Figure 3 displays this vulnerability-to-resilience index. Areas in the southeastern portion of the Basin, along with specific tracts in Yakima and Grant counties (Central band within Figure 3), were classified as very high priority, suggesting an urgent need for food system intervention and policy support. These zones were characterized by multi-criteria overlap: low food access, high food insecurity rates, projected land use change, and declining yield trends.

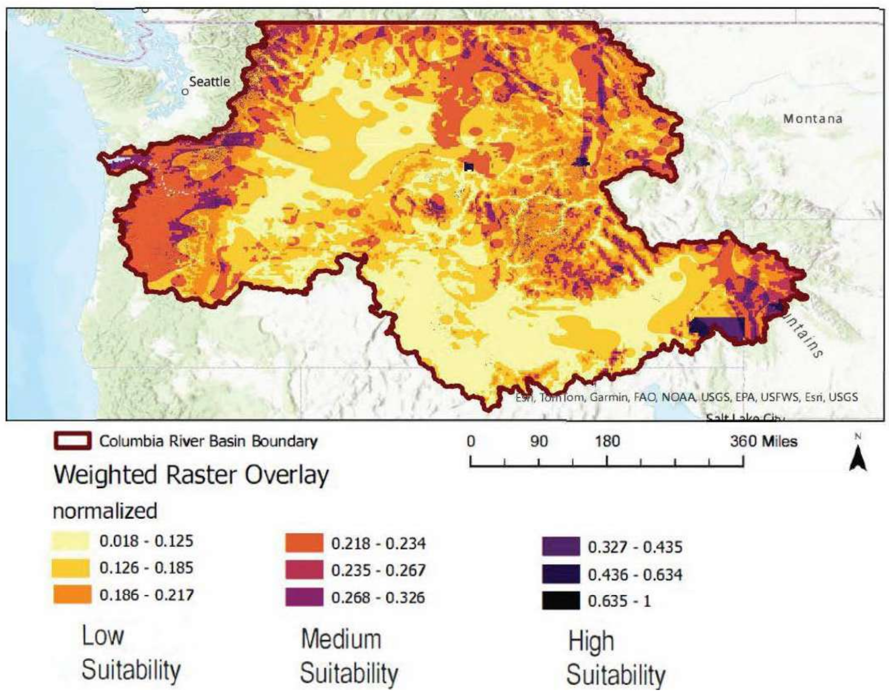

Figure 3. Weighted Overlay Analysis of Foodshed Suitability and Vulnerability. Diagram by the author.

3.3 Stakeholder and Expert Validation

Validation with regional stakeholders from a federal organization confirmed the perceived utility of the redefined foodshed boundaries. Stakeholders noted that the inclusion of health and infrastructure metrics added practical value for local planning. Several commented that the maps reflected "on-the-ground" realities often overlooked in traditional foodshed planning.

Comments from stakeholders also emphasized the importance of including native, underutilized, and culturally significant crops in future iterations, particularly in Tribal Nation contexts. Though not explicitly mapped in this pilot, this feedback will inform future iterations of the model.

4 DISCUSSION

The redefinition of foodshed boundaries presented in this study offers a novel and adaptive approach to understanding food system resilience under conditions of social, environmental, and climatic vulnerability. This discussion unpacks the implications of the results, reflects on methodological contributions, explores tradeoffs inherent in spatial scenario modeling, and identifies areas for future research and policy development.

4.1 Reconceptualizing Foodsheds for Adaptive Food Systems

The redefined foodshed boundaries in this study move beyond traditional proximity-based models and instead embrace a multidimensional lens that incorporates climate projections, access-based vulnerabilities, and public health data. This reconceptualization supports a more holistic framing of food systems as dynamic, socio-ecological systems rather than static supply regions. The Columbia River Basin case study demonstrates that foodshed boundaries, when treated as scenario-responsive and policy-informing tools, can help illuminate both opportunities and risks in long-term planning.

By integrating metrics such as food insecurity prevalence, projected land conversion risk, and yield variability under RCP 8.5 scenarios, the resulting boundaries represent not only current patterns of food access and production but also emerging threats and adaptive capacity. As such, the framework supports climate-resilient regional planning that recognizes food security as both a spatial and systemic issue.

4.2 Balancing Equity and Productivity in Spatial Planning

One of the central tensions revealed by this analysis is the tradeoff between maximizing agricultural productivity and enhancing food equity. The climate-adaptive scenario preserved high-yield croplands, but at the expense of covering fewer food-insecure or low-access populations. Conversely, the 'high and moderate suitability' zones prioritized vulnerable communities, yet retained a lower proportion of productive farmland. The balanced scenario mediated between these outcomes, offering a practical baseline for decision-making.

This tradeoff underscores the need for planners and policymakers to explicitly articulate goals when delineating food planning regions. If food security interventions are driven primarily by equity concerns, boundaries must be restructured to include underserved populations, even if those areas are not optimal in terms of yield. If food self-sufficiency is prioritized, policies may need to supplement these areas with improved transport or targeted food access programming. In either case, our approach enables these tradeoffs to be visualized and quantified.

4.3 Methodological Contributions

This study contributes a replicable geospatial methodology for climate-informed foodshed modeling. Several methodological advancements deserve attention:

- The use of network-based proximity (rather than Euclidean distance) provides a more accurate representation of access constraints, especially in rural areas where infrastructure is sparse (ESRI, 2023).
- Integration of land cover vulnerability data introduces a forward-looking dimension into foodshed planning, accounting for future land conversion risks and spatial instability.
- The weighted raster overlay technique allows multiple, non-commensurate datasets to be combined into a unified spatial decision support surface, enabling scenario testing.

Furthermore, the inclusion of public health indicators such as CDC-reported food insecurity (Centers for Disease Control and Prevention, 2023) strengthens the social relevance of the model and bridges disciplinary gaps between public health, geography, and environmental planning.

4.4 Implications for Policy and Governance

The scenario-based modeling approach presented here can support a range of decision-making contexts, including regional food planning, climate adaptation strategy development, and equity-based public health interventions. Local governments, Tribal Nations, and food policy councils can use the vulnerability-to-resilience gradient to prioritize zones for intervention, whether through infrastructure investments, zoning protections, or direct food assistance programs. For example, an agriculture protection zoning map based on scenarios can provide policy makers with use cases of where to geospatially plan for areas predicted to affected by climate change (Cronan et al., 2023).

Importantly, stakeholder validation confirmed the perceived utility of the model, with many regional actors indicating that the results aligned with lived experiences and previously undocumented challenges. These findings underscore the importance of embedding stakeholder perspectives and validating geospatial outputs within local knowledge systems.

The flexibility of the scenario framework also aligns with principles of anticipatory governance, allowing decision-makers to plan for multiple futures rather than relying solely on deterministic models. For example, future iterations could incorporate agricultural best management practices and strategies, regenerative agriculture policies, or shifts in consumer behavior to further refine foodshed boundaries.

4.5 Integrating Underutilized and Culturally Significant Crops

While the current model focuses primarily on conventional agricultural data and infrastructure metrics, stakeholder feedback emphasized the importance of incorporating underutilized, and culturally significant foods. These crops, often critical to Indigenous foodways and rural foraging practices, represent a significant but under-mapped dimension of food system resilience.

Incorporating these food sources into spatial modeling efforts requires new data collection strategies, such as participatory mapping, ethnobotanical inventories, and the integration of Traditional Ecological Knowledge (TEK). Doing so would further strengthen the social and cultural dimensions of foodshed planning, particularly in Tribal Nation contexts where sovereignty and self-determination are essential considerations (Kuhnlein and Receveur, 1996).

4.6 Limitations and Areas for Future Research

Several limitations merit reflection. First, while the weighted overlay method offers transparency and flexibility, the assignment of weights is inherently subjective. Future research could explore participatory weighting methods using expert elicitation, stakeholder workshops, or Bayesian belief networks to improve validity.

Second, the reliance on RCP 8.5 as a climate scenario reflects a worst-case trajectory. While useful for stress-testing systems, it may not reflect the full range of plausible futures. Including additional RCPs or Shared Socioeconomic Pathways (SSPs) could enrich future scenario comparisons.

Third, the exclusion of seasonality, crop diversity, and distribution logistics from this model represents a missed opportunity to explore temporal food system dynamics. Future models could integrate farm-to-market flow data, cold chain infrastructure, or policy variables such as SNAP retail location density.

Finally, there is a continued need to connect geospatial models like this one to community-engaged governance processes. This includes aligning outputs with land use regulations, planning statutes, and community food assessments.

5 CONCLUSION

This study offers a methodological and conceptual advancement in the way foodsheds are defined and applied to contemporary food system challenges. By integrating geospatial analysis with climate projections, food access data, socio-economic indicators, and public health metrics, we developed a replicable framework to support climate-adaptive and equity-informed foodshed delineations.

The case study of the Columbia River Basin demonstrates how spatial food planning can evolve beyond proximity-based definitions toward dynamic, multidimensional models that account for vulnerability, resilience, and future uncertainty. The weighted overlay approach enabled transparent scenario development and revealed critical tradeoffs between optimizing food production and maximizing access for vulnerable populations. In particular, the incorporation of RCP 8.5 climate data, CDC-reported food insecurity (Centers for Disease Control and Prevention, 2023), and USDA yield trends into a single modeling framework showcases a systems-level perspective needed for 21st-century food planning.

Scenario and characterization comparisons (e.g., high to low suitability) show that redefined foodsheds can serve both as tools for understanding existing conditions and as platforms for planning policy interventions under alternative futures. The ability to visualize and compare the spatial consequences of different priorities, climate adaptation, food equity, or productivity, offers utility to a range of stakeholders from planners to public health officials. This framework also has the potential to advance food justice by incorporating spatially explicit key performance indicators such as food access, poverty concentration, and land use vulnerability. The methodology is designed to include participatory approaches in future applications, therefore this approach may enrich the voices and perspectives of local community members to illustrate the problems and conditions that they experience within their specific regions.

The broader impacts of this work lie in its ability to inform practice across sectors and geographies. First, this study contributes to food systems scholarship by demonstrating how spatial analysis can inform definitions of food access, vulnerability, and resilience. Second, it provides public agencies and local governments with a replicable and adaptable toolkit for assessing and responding to food system risks. Third, it reinforces the need to align food planning tools with justice-oriented frameworks, particularly in Tribal and underserved communities.

Moreover, the project responds to global calls for climate-resilient development by providing a pathway for integrating food system planning into broader sustainability and adaptation agendas. As food systems are increasingly recognized as both a cause and casualty of climate change, tools like redefined foodsheds offer tangible ways to design more resilient, equitable, and nutritious futures.

Future directions should prioritize participatory modeling approaches, cross-scalar implementation strategies, and the formal inclusion of underutilized and culturally significant crops. Doing so would not only strengthen the resilience of food systems but also restore and affirm the place-based knowledge systems that sustain communities across generations.

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