VISUALIZING NUTRITIONAL TERRAIN: AN ATLAS OF PRODUCE ACCESSIBILITY IN LANSING, MICHIGAN, USA

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Abstract
We present a new interactive atlas summarizing the "nutritional terrain" of Lansing, Michigan, USA. We define nutritional terrain as a continuous, fine-scale geographical characterization of food availability and accessibility. Recent public health research indicates that the incidence of diet-related health outcomes such as obesity, heart disease, and diabetes is more prevalent in areas with inadequate access to affordable, nutritious food; people have significantly different access to retail locations offering this food based on their geographic situation. Studies have shown that lower income, minority-dominated, rural, and inner-city neighborhoods all generally have lower access to large retailers such as supermarkets, than more affluent suburban areas (Booth and Pinkston 2005; Cummins and Macintyre 2006; Lake and Townshend 2006; Morland et al. 2002; Smoyer-Tomic et al. 2008). Although geographically coarse in nature, this previous research has exposed links between 1) built environments, 2) socioeconomic inequality, and 3) diet-related health outcomes. This progress represents a vital advance in the understanding of public health, but more research is needed to fully understand these phenomena. As a step in that direction, this paper addresses an emerging need for precise geospatial characterizations of availability and accessibility in urban food environments. We demonstrate how the combined abilities of geospatial technologies and geovisualization can reveal important nutritional inequalities in densely populated metropolitan areas.

Objectives: The long-term goal is to establish methods that both *quantify* and *visualize* "nutritional terrain," thus enabling health officials to identify at-risk zones (previously referred to as "food deserts") within a study area. We demonstrate that by employing field-sampling methods, contemporary geospatial and geovisual technologies it is possible to identify inequalities in produce access at fine spatial resolutions. With this in mind, this work addresses unknowns in food environment research; by combining a direct-observation sampling strategy with advanced accessibility measurements and visualization we will generate results that offer newfound richness and precision. To date, other examinations of food environments have relied on coarse inputs and produced coarse results. Our results will improve the status quo by improving the answers to three critical public health questions:
1. What produce items are available at what locations?
2. Which geographic areas have access to what produce items?
3. How can we use geovisual techniques to uncover and communicate the answers to the first two questions?

Methodology: The methodology is divided into two parts: 1) an accessibility modeling stage, and 2) a visualization stage. Prior to the first stage, we sampled produce availability by visiting every retail produce outlet in the study area (n = 94) and cataloged its entire produce inventory, item-by-item. In the first methodological stage we use GIS and network analysis to model accessibility in six different ways:

> 1) Pedestrian and 2) Automobile access to different categories of retail produce outlets (e.g. Supermarkets, convenience stores, etc.).
> 3) Pedestrian and 4) Automobile access to every individual produce item (n =447) available within the study area.
> 5) Cumulative pedestrian and 6) cumulative automobile access to individual produce items (total number of unique produce item accessible from a given location).

The output from this stage includes an immense amount of geographic information. In the second methodological stage, we design an interactive atlas consisting of over 1,100 individual maps reflecting the results of our accessibility analyses. Each map within the atlas presents a unique glimpse of the nutritional terrain of the study area detailing a specific aspect of produce accessibility in our study area.

Results: We report on results from both of the methodological stages. The accessibility modeling results include hundreds of geo-statistical surfaces detailing accessibility variability throughout the study area. The second stage results include an interactive atlas designed to organize and effectively disseminate the geovisual depictions of produce accessibility. Several example maps from the atlas are included in this paper.

Conclusions: This paper details a new means to present visual characterizations of urban food environments. We introduce methods to improve data collection, accessibility modeling, and visualization strategies, the sum of which empowers health officials to identify areas within a study area that will have elevated risks of obesity, heart disease, and diabetes. Furthermore we believe inherent in this project are novel visualization techniques that:

1. Extend traditional terrain mapping concepts into a metaphorical domain. This extension raises important new questions about the application of traditional topographic mapping techniques to abstract terrains (statistical surfaces).
2. Re-evaluate the role of thematic atlas concepts in the era of geovisualization. Atlases, whether interactive and online or in traditional hard copy form, enable cartographers to organize and communicate vast amounts of geographic information in a structured format. They also provide analysts in other fields with the ability to investigate relationships between spatially dependent variables (e.g. produce accessibility and incidence of diabetes).

Introduction and Background

Obesity in America is rising at alarming rates; 34% of adults over 20 years old are now considered obese. This population is at increased risk for a number of health outcomes including heart disease and diabetes. The incidence of obesity is more prevalent in minority ethnic neighborhoods and limited access to healthy foods, such as fresh produce, is hypothesized to contribute to these disparities. Recent research characterizing “food environments” suggests that low income and ethnic minority populations are less likely to live near sources of fresh produce. However, much of this research has been conducted at coarse geographic scales (e.g., the county level or zip code level) and therefore there is an emerging need to visualize food environments at finer resolutions.

The health consequences of a poor diet are well known; inadequate consumption of nutritious foods, such as fresh fruits and vegetables, is a contributor to weight problems, obesity and related health conditions such as diabetes, hypertension and heart disease (He et al. 2004, Schulz et al. 2005, Morland et al. 2006, Shai et al. 2006, Adebawo 2006, Jen et al. 2007). It is also well known that rates of obesity and weight problems are increasing in the United States, but these increases are disproportionately affecting certain populations, such as ethnic minorities and lower income Americans, more than other more affluent groups. One hypothesis is that more affluent neighborhoods have greater access to healthy retail food locations, while poorer areas have limited access. Some researchers have linked spatial accessibility inequalities to the previously noted health disparities (Boyle et al. 2007, Papas et al. 2007). Unfortunately, our understanding of these links is limited by the quality of our geographic information and analyses; in this paper we attempt to enhance public health research by improving data collection procedures and accessibility modeling methodologies.

Americans normally acquire fresh produce from retail locations such as supermarkets and grocers. However, depending on where they live and their mode of transport, some populations have easier access to retail food sources than others. Recent research has begun to target the spatial distribution of retail food locations (Shaw, 2006). One notable finding is that both quality and quantity of retail food locations varies with the demographic characteristics of neighborhoods (Cummins & Macintyre 2006). More specific findings include the observation that African-American neighborhoods and areas with lower average incomes possess fewer sources of fresh produce than non-Hispanic white neighborhoods (Chung & Meyers 1999, Morland et al. 2002, Zenk et al. 2005b, Baker et al. 2006, Block & Kouba 2006, Algert et al. 2006, Powell et al. 2007). Although these initial findings are important, their value is constrained by methodological limitations; we identify the following six recurring limitations with recent food-environment-studies:

1. **Coarse spatial analysis** – The majority of food-environments research has been conducted at coarse aggregate levels, such as census tracts, ZIP codes, or counties (Morton et al. 2005, Powell et al. 2007). These aggregate tactics result in misleading or suboptimal results. We argue that accessibility is a continuous phenomenon and that some portions of aggregate units (e.g. Ingham County) may have ready access to produce while other portions do not. With this type of intra-unit variability, it is unwise to analyze access at such coarse scales.

2. **Simplified definitions of access**. Most Americans purchase fresh produce at retail locations and travel these locations via transportation networks. With each journey to a retail location, an individual consumer overcomes a cost of separation. This cost is frequently viewed as a function of time or distance. Unfortunately, most recent research fails to accurately model separation costs. For example, some studies use Euclidean ("as-the-crow-flies") distance, or Manhattan-block distance (Zenk et al. 2005) to model accessibility. These measures do not mimic the lived experience of consumers, and potentially contribute to misleading results.

3. **Simplified definitions of retail food sources** – Some studies have utilized proximity to the nearest retail location as a measure of access (Zenk et al. 2005, Laraia et al. 2004, Hatfield & Gunnell 2005). This is problematic because proximity to a small grocer is unlikely to be equivalent in terms of availability to proximity to a large

supermarket. Instead of lumping all retail sources together in a singular category as "sites," it is necessary to differentiate them based on variable inventories.

4. **Inadequate retailer identification** – Many studies rely on the Standard Industrial Classification (SIC) codes to identify food retailers. Unfortunately, these codes are rife with problems. For example, some gas stations are coded as grocery stores. Also, these data sources regularly include businesses that are no longer operating, or fail to include recently opened businesses. These flaws in the data result in inaccurate analyses of access.

5. **Imprecise location data** – To this point no study of food access has accurately modeled the actual locations of retail locations. Previous investigations rely heavily on geocoded addresses (Laraia et al. 2004, Hatfield & Gunnell 2005) that others have repeatedly demonstrated to be significantly inaccurate (Zandbergen & Green, 2007). These errors propagate when included in network accessibility analyses.

6. **Poor communication of results** – Perhaps the most disappointing limitation in a cartographic context involves the communication of these important findings. These phenomena are clearly spatially dependent and one of the core motives behind many of these studies is to expose spatial inequalities in accessibility. With that in mind, it is unfortunate that the summaries of the spatial inequalities fail to take advantage of cartographic and geospatial technologies capable of thorough communication of such spatial inequalities.

Methods

Our objective in this paper is to introduce methods can reduce each of the six limitations identified above. This section outlines our approach.

Study area. Lansing, Michigan, USA, (42°44' N, 84°33'W) is a city with a population of about 450,000 in its metropolitan area, which includes several suburban towns. Our study area includes 94 produce outlets. Each belongs to one of nine classes (based on our inventory analysis described below).

Data collection and Availability. This section describes the methods of the sampling stage that enabled the modeling and visualization stages. We sampled produce availability in early 2008 (February-April). We compiled a list of all food retail locations (excluding restaurants) in the Lansing area, using commercial data purchased from ESRI (Redlands, California) supplemented with Internet searches, phone book listings, and on-the-ground searches of local streets. Next, we determined whether each location in this list (n = 246) was operational and offered any fresh produce, through telephone calls and in-person visits. We defined 'fresh produce' as any plant food offered for sale in an uncooked and un-dried form. We identified 94 food retail locations that offered fresh produce.

In each location offering fresh produce, we recorded every type of fresh produce offered. We recorded each item priced separately in every store, with these exceptions: a) multiple sizes of fruits, such as large and small navel oranges, which were recorded as a single item; b) minimally prepared items, such as sliced watermelon, unless a given item was offered only in a minimally prepared form; c) packaged spices, such as sage leaves, because of the difficulty determining whether a given item was dried or otherwise preserved; and d) packages containing more than one type of produce item, such as bags of oranges and apples, unless a given item was offered only in such packaging. Notably, we recorded organic produce items separately from conventionally produced items, because these are priced separately and carry different social meanings (Guthman 2004). These data collection efforts result in a data matrix that recorded the presence-absence of each produce item (n = 447) in all 94-sample sites. These techniques differ from the simplified approaches that dominate previous food-environment investigations (Figure 1).

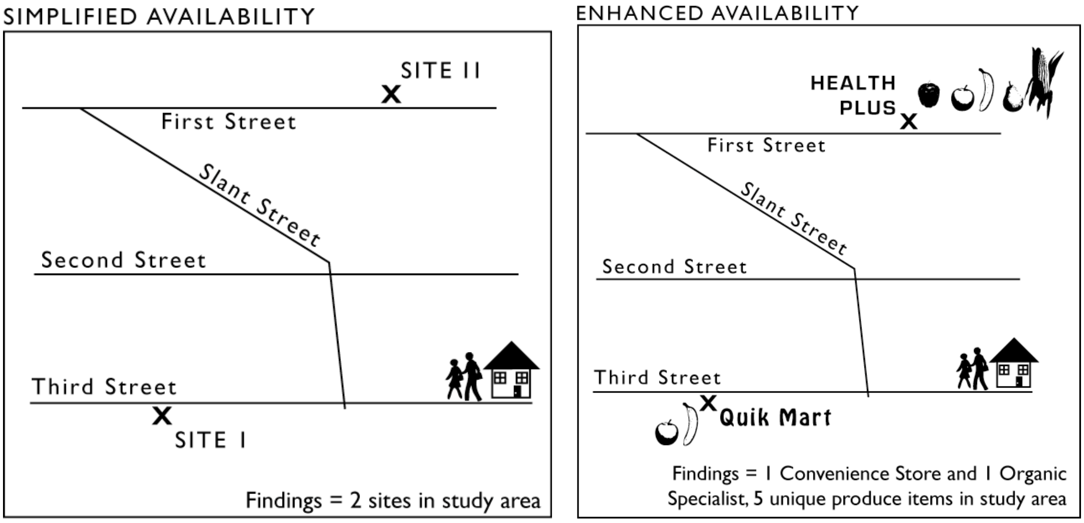

Figure 1: Previous investigations of urban food environments often depend on coarse definitions of potential destinations. Some studies view only supermarkets as viable sources of healthy food. Others include grocery stores and other markets. Our data collection strategy attempts to overcome this by cataloging entire produce inventories at every produce outlet in the study area. Our methods attempt to create an enhanced representation of availability in a food environment by cataloging actual produce inventories.

Accessibility. Previous research investigating food environments has been coarse in nature. Geographic analyses of food access have typically involved aggregate enumeration units such as zip codes, counties, or US Census units. Definitions of the costs of separation have also been simplified. For example, a recent study (Zenk et al. 2005) in Detroit defines a given neighborhood's access by measuring Manhattan-block distance to the nearest "supermarket." We believe this is inadequate, and may produce misleading results. Instead, we measured network distances and travel times outward from retail locations. This enabled the calculation of an estimated "service area" for each location. For example, using network analysis, we can determine all network locations within a half-mile, or even a ten-minute drive to individual retail locations. Furthermore, our availability geodatabase enables us to model access not only to retail locations, but also to individual items (e.g. bananas, green beans, organic spinach). We modeled service areas for both *automobile* and *pedestrian* access to all 94 retail locations as well as each of the 447 individual produce items. By using Boolean overlay approaches, we calculated cumulative produce accessibility by summing each individual produce item accessible (by car or on foot) from any location in the Lansing study area (Research Question 2).

Access can be defined and formalized in countless ways, but the intricacies of the definition are critical to the eventual results. For this reason we have surveyed the literature to attain a logical and realistic access definition, as it relates to the availability to produce. Fundamentally, "access" is determined by 1) the spatial distribution of potential destinations, 2) the cost of reaching each destination, and 3) the magnitude, quality, and character of activities found there (Handy and Niemeier 1997). Access measures increase as the number of suitable destinations within some prescribed cost-bound area increases. The most basic measures of access are sometimes called "container" measures; they simply count the number of destinations within some maximum distance. These measures do not account for destination quality, but do account for location and mode of travel. In the context of food/produce access, basic container measures would fail to differentiate a supermarket from a farmers' market or a convenience store; each would be considered an equally viable destination.

Previous food-access research has almost unanimously relied on these overly simplified container measures of access (Algert et al. 2006; Apparicio et al. 2007). Notably, Zenk et al (2005) explored access to supermarkets in Detroit, Michigan, USA. The study is a great start, but their methods fall short for two reasons; 1) travel mode differences are ignored, and 2) many important food outlets including farmers' markets, independent grocers, co-operatives, and convenience stores were not included in their calculations. They define cost of separation simply as Manhattan-block-distance, which neglects the varying costs of driving versus busing, biking, or walking. In terms of the fundamental access definition above, their study only accounts for a subset of potential destinations (supermarkets), fails to adequately describe costs of reaching destinations (Manhattan-block-distance), and ignores the magnitude, quality, and character differences of individual destinations. Our methods include a complete set of potential produce outlet locations, more accurate travel costs (network analysis), as well as magnitude and quality parameters (our availability data).

It is important that algorithmic approaches to access mimic the "lived experience" as much as possible. People in urban areas access food retail sources using transportation networks. It is insufficient to simply measure distance "as-the-crow-flies" – these Euclidean approaches to access are unrealistic (Figure 2).

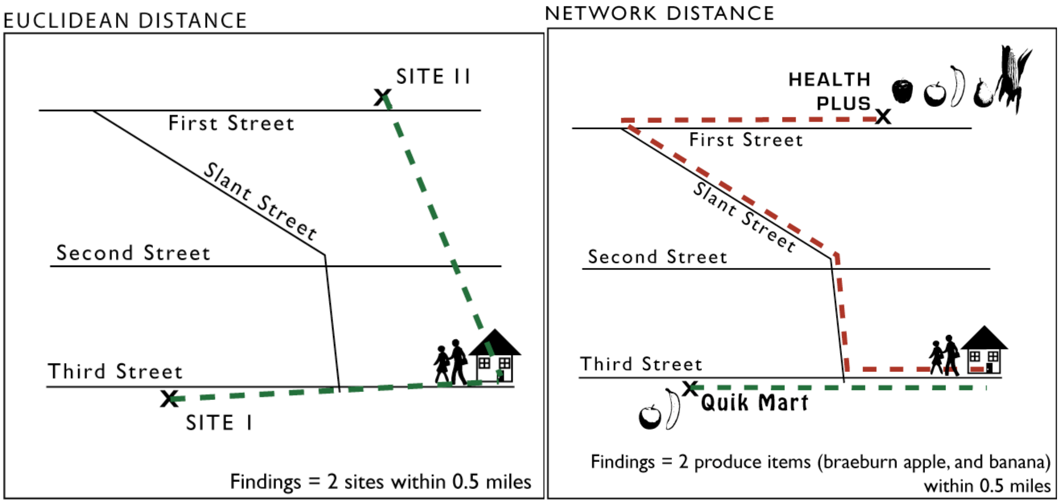

Figure 2: Previous food-environment investigations have measured access using simplified cost metrics, such as Euclidean (as-the-crow-flies) distance. In this example, these simplified methods would mistakenly deem two sites accessible. We argue that network distance and estimated travel times more realistically capture the costs separating consumers from retail locations. In this example, only the convenience store with two unique produce items, "Quik Mart," is accessible to these pedestrians.

Our methods measured space-time accessibility within the transportation network to derive more realistic cost estimations (Miller, 1999), and more differentiation between potential retail food destinations. We incorporated two separate cost-of-separation calculations, one for walking, and one for driving. Because of enhanced mobility, individuals with access to automobiles have greater retail accessibility than those who are limited to other modes of transport, especially walking. We defined both costs in terms of estimated travel time as opposed to Euclidean or Manhattan-block distances. The walking cost (in minutes or hours) was formulated by simply dividing the length of the optimal network route (in miles) by an average walking speed (three miles per hour). Using GIS (ESRI Network Analyst, ESRI, 2008), and detailed network data provided by the Michigan Center of Geographic Information, we are able to estimate realistic distance costs that separate consumers from retail locations.

The drive cost was more complex. We assumed that automobile velocity on the road network was at or near speed limits, and assigned each road link in the study area an "impedance" value based on the functional class of the road (road data from Michigan Center for Geographic Information). For example all network links classified as "rural interstate" were assigned an impedance value of 70 miles per hour, while "urban minor" roads were assigned an impedance value of 20 miles per hour. We then calculate service areas outward from retail locations. Service areas (like circles) extend from a central point with a specified radius. Areas within the service area are "served" and have access to the location, while areas that fall outside of the area are not served and do not have access.

Service area formulation is not optimal and includes several important limitations. For instance, it fails to take into account individual mobility differences – some people walk or drive more slowly than others. Similarly, it does not account for pedestrian shortcuts, stoplights, slowdowns, road construction, or other congestion events that hinder mobility. Lastly, different individuals have different tolerances for travel; some may be willing to drive fifteen minutes to the grocery store, others only ten. But despite these limitations, we are confident that these methods are a step in the right direction.

Results

The result of the accessibility stage was an immense collection of geographic information. We modeled the service areas for each unique produce item (n = 447) for two modes of travel resulting in 994 unique service areas. Furthermore, we modeled service areas for each category of retail outlet (n = 9) for both modes resulting in 18 more service areas. Lastly, we calculated cumulative produce accessibility for both automobile and pedestrian modes of travel. These cumulative measures summarize the total number of unique items accessible from each point in the study area. We organized these results in an interactive atlas using prominent GIS and graphic design software packages including ESRI ArcGIS, Adobe Illustrator, and Adobe Flash. The end result was a digital atlas featuring over 1,100 maps and other statistical graphics. Below are examples of maps included within the atlas.

There are two ways of analyzing the accessibility output. First, we can visually identify areas that have high or low accessibility. In figure 3 we have layered the walksheds of our supermarket (retail outlets with highest produce variety) class on top of a population distribution map. This enables us to visually identify areas that are densely populated yet underserved by supermarkets. For example, one of the densest populated areas in our study area – the predominantly student-oriented neighborhoods around the Michigan State University campus – is not within walking distance to a supermarket. Using visual analysis alone, analysts are able to determine which Lansing neighborhoods are most or least served by different categories of produce outlets. Aside from visual evidence, we are also able to use GIS to conduct more statistical analyses. For example we can use the GIS to test spatial correlations between produce distributions and health, ethnic, or income statistics. Also, we can overlay, or perform "map algebra," on the 447 service area layers to determine the total number of produce items accessible from any street location, or address within the study area.

Figure 5 includes the pedestrian service areas for six individual produce items, while figure 4 includes the results of the overlay of the individual produce-item-service-areas.

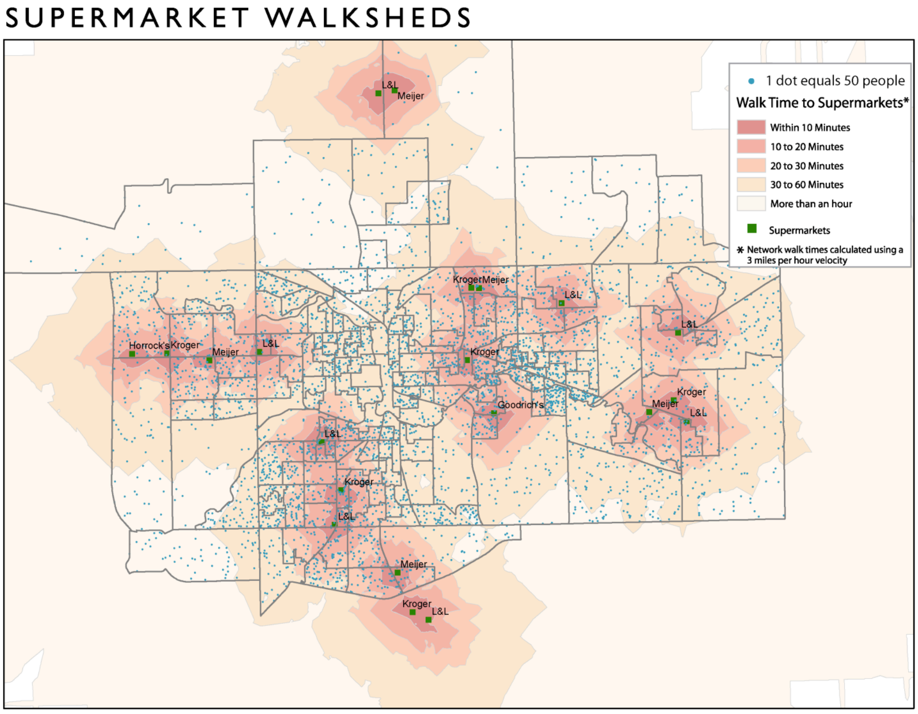

Figure 3: An example of "categorical access" - we have classified each produce retailer into one of nine categories (e.g. supermarket, convenience store. This map depicts pedestrian access to the supermarket category and it demonstrates that thousands of residents have at least a 30-minute walk to the nearest supermarket.

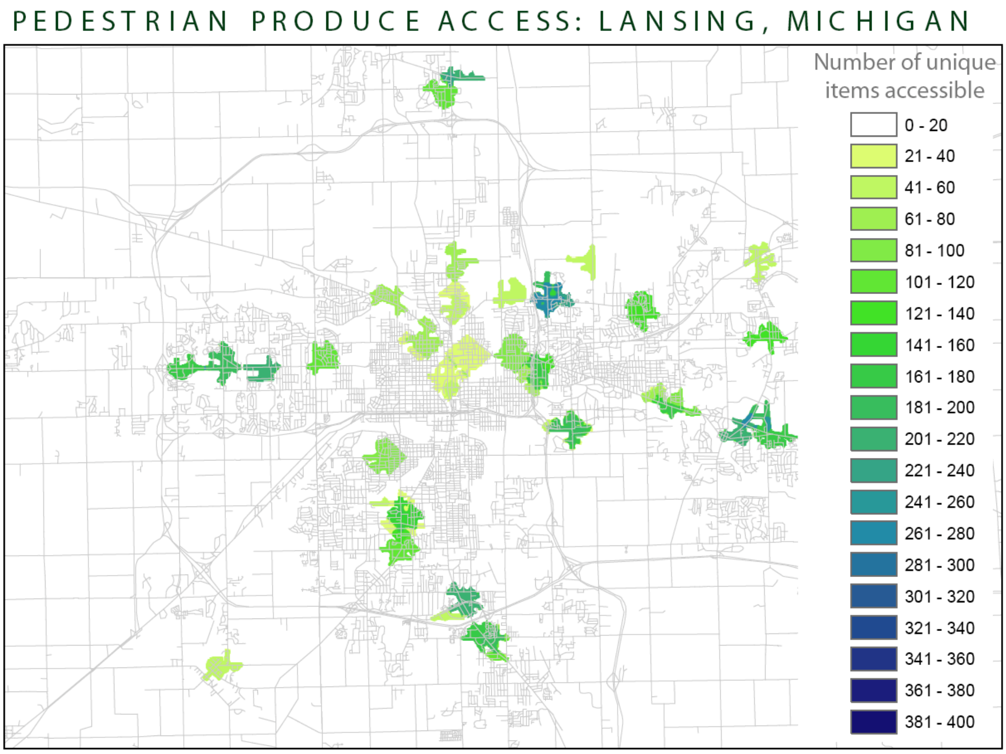

Figure 4: This map summarizes the cumulative pedestrian produce access measure. The total number of fresh produce items accessible depends on an individual's geographical situation. Many residents within our study

area do not have automobile access and frequently walk to acquire food. This map demonstrates that only a minority of locations within the study area offers produce access to pedestrians.

Conclusions

Our methods enable a new, more detail-oriented approach to urban food environments. Unlike previous studies, this research examines actual inventories of known commodities and more realistically assess access to those individual commodities. Although not flawless, we believe this approach will result in the most thorough depiction of a food environment to date. Our methodology is transferable by design, and we believe that it can easily be adapted to other study areas. This is important because it will eventually enable the first comprehensive multi-city comparison of urban food environments. Efforts are already underway to apply this methodology in Albuquerque, New Mexico.

Perhaps the most significant outcome of our research involves public health. We believe our depictions of nutritional terrain will enable higher confidence in epidemiological hypothesis testing. Our methods can identify at-risk zones within study areas with improved precision. We believe our results can be used to investigate potential correlations between accessibility to produce and diet-related health outcomes such as hypertension, heart disease, and diabetes.

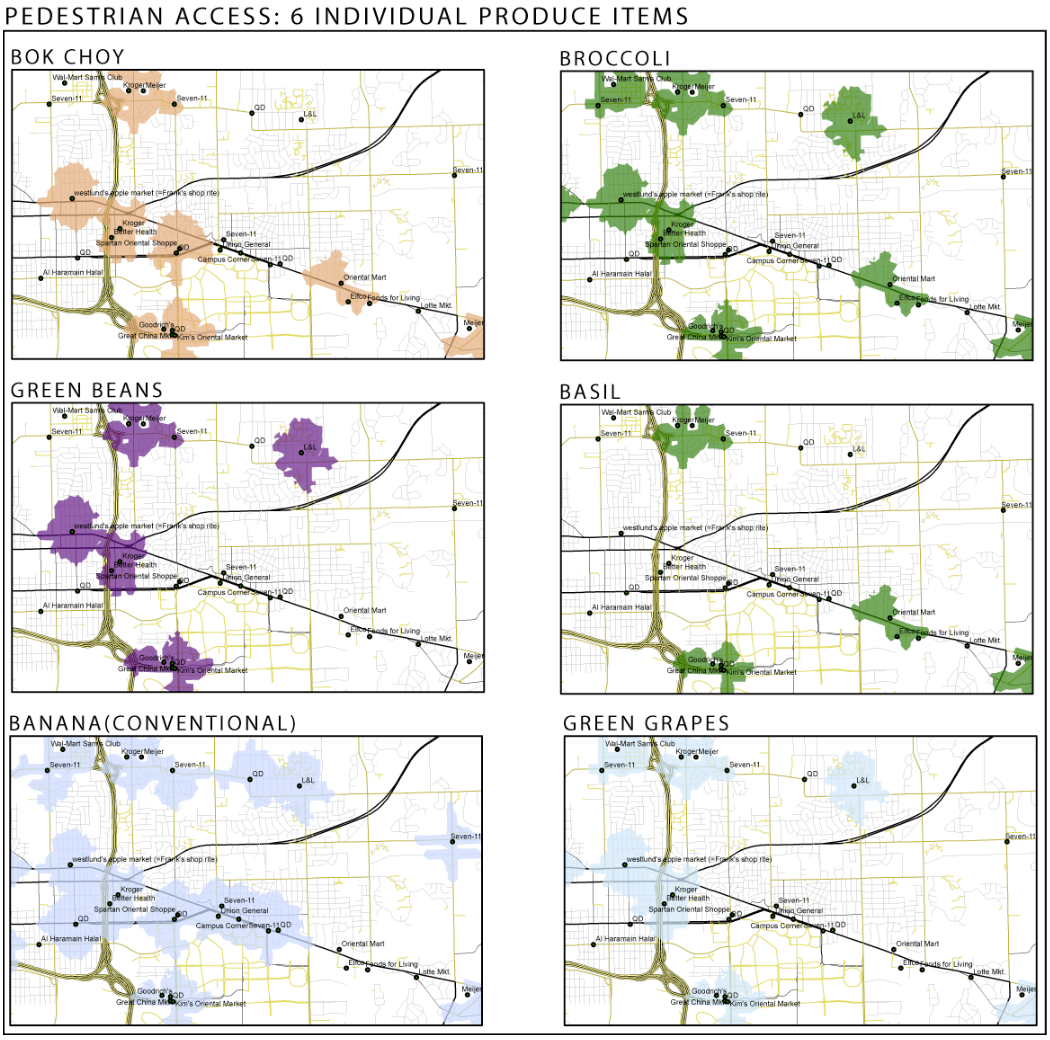

Figure 5: Individual-item-accessibility - Our methods enabled us to determine the service areas of individual produce items. This map series depicts the service areas (10-minute walksheds) of six individual produce items. Since different retailers stock different items, every individual produce item has its own accessibility-signature.

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