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Using Geospatial Technologies to Characterize Relationships between Travel Behavior, Food Availability, and Health

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USING GEOSPATIAL TECHNOLOGIES TO CHARACTERIZE RELATIONSHIPS BETWEEN TRAVEL BEHAVIOR, FOOD AVAILABILITY, AND HEALTH

DISSERTATION

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in the
College of Arts and Sciences at the
University of Kentucky

By
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Lexington, Kentucky

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ABSTRACT OF DISSERTATION

USING GEOSPATIAL TECHNOLOGIES TO CHARACTERIZE RELATIONSHIPS BETWEEN TRAVEL BEHAVIOR, FOOD AVAILABILITY, AND HEALTH

Epidemic obesity in the U.S. has prompted exploration of causal factors related to the built environment. Recent research has noted statistical associations between the spatial accessibility of retail food sources, such as supermarkets, convenience stores, and restaurants, and individual characteristics such as weight, socioeconomic status, and race/ethnicity. These studies typically use residential proximity or neighborhood density to food sources as the measure of accessibility. Assessing food environments in this manner, however, is very limiting. Since most people travel outside of their neighborhood on a daily basis, the retail food sources available to individuals residing in the same area could vary widely.

This research developed new techniques for describing food accessibility or food environments based upon individuals' activity and travel patterns, or their activity spaces. Researchers have previously used travel diaries to study activity and travel behavior, but these are burdensome for participants, and are prone to recall error and other inaccuracies. This study explored use of global positioning system (GPS) to identify participants' activity spaces, and employed a geographic information system (GIS) to assess the retail food sources located within these spaces. This produced 'activity-based' measures of individual retail food accessibility that do not rely on areal units, nor require travel diaries.

Participants included 121 residents of a census tract in Lexington, Kentucky who agreed to carry GPS trackers for three workdays, and complete surveys regarding weight, socioeconomic and demographic characteristics, and diet and food purchasing habits. The types and relative frequencies of food locations within their activity spaces were compared to those within close proximity to the census tract. Dietary and food purchasing habits were subsequently analyzed in relation to activity-based food environment measures.

The results of this study demonstrate substantial potential for misclassification bias in food accessibility research based on residential proximity or neighborhood density. Furthermore, this study observed statistically significant relationships between the new activity-based food accessibility measures and some personal characteristics and food-related behaviors. Despite some limitations, the techniques developed in this research show great potential for future research, which should be explored further in a variety of contexts.

KEYWORDS: Food Accessibility, Food Environment, Activity Space, Global Positioning System, Geographic Information System

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For Clara, and for Kentucky

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TABLE OF CONTENTS

CHAPTER 1: Introduction

This work explores the accessibility of food and its relationship to the health of individuals and populations. It is especially relevant for overweight and obesity, health-related conditions which have become quite common in the United States and, increasingly, around the world. Like a medical investigation might, this research addresses one of the well established physiological causes of weight gain—a poor diet characterized by processed foods high in fat and sugar, and little whole grains, fruits, or vegetables. But this research is very different from a medical investigation in that it does not address human physiology, but rather human geography. There can be little doubt that what humans eat is conditioned to a great degree by their environment, and what is available within it. The existence of distinctive national and regional cuisines is evidence of this at one scale, but the work presented here examines this idea at an intra-urban scale, where the food-related behaviors of individuals interact with their built environment. This research explores food accessibility through quantitative characterization of the retail food environment—that portion of the built environment that addresses the basic human need for sustenance. Among other things, the built environment encompasses food stores and restaurants and the transportation infrastructure necessary to connect people with these places. It necessarily, therefore, exerts a powerful influence on the food shopping and dietary habits of individuals.

Previous research has already demonstrated that there are significant differences in the variety of food stores and restaurants present within neighborhoods of the same city, and many have presented convincing arguments showing obesity to be more common in neighborhoods without supermarkets, or demonstrating that fast food restaurants are more numerous in poor, or predominantly minority neighborhoods. The present work, however, endeavors to look beyond discrete neighborhoods, and rather to the mobile lives of individuals as they navigate unique paths through a shared built environment. The question implicit in much neighborhood food environment research is simply stated: How does where you live affect your diet and weight? This is actually a pretty complex question, though, considering that one does not accomplish all of the tasks necessary for modern life at home, or even in one's own neighborhood, but also at work, in the car, on the sidewalk, in parks, at the mall, and in a multitude of other places. Furthermore, note that every single person experiences this shared built environment from a unique perspective, which is determined in large part by their own everyday experiences traveling through it and living within it. Considerations such as these drive the innovation of this research, but ultimately its reason for being is the recent explosion in rates of overweight and obesity in the U.S.

Overweight and obesity in the U.S.

The prevalence of overweight and obesity in the U.S. increased dramatically in the latter half of the 20th century, and has continued to increase into the 21st, albeit at a slower pace (Flegal et al. 2010, Ogden et al. 2006, Flegal et al 2002). Medical and public health professionals have conducted much research into this phenomenon in recent years because obesity is a recognized risk factor for a number of chronic illnesses. These include heart disease, stroke, diabetes, kidney disease, hypertension, osteoarthritis, gallbladder disease, sleep apnea, incontinence, and depression (Nguyen & Hsu 2007, NHLBI 1998, Pi-Sunyer 1993). Epidemiological data also demonstrate a link between obesity and the incidence of multiple types of cancer (Wang & Dubois 2012, Khandekar et al. 2011), as well as between obesity and cancer prognosis (Sinicrope et al. 2010, Majed et al. 2008). A recent review estimated the direct medical care costs related to overweight and obesity in the U.S. were over $113 billion dollars per year, almost 5% of total health spending (Tsai et al. 2011).

Overweight and obesity are usually defined in health-related literature using the body mass index (BMI) calculation (weight [kg] divided by height [m] squared). A BMI of 25 or greater is considered overweight, and 30 or greater is considered obese. Although this measure has been criticized for its potential to misclassify along age, gender, and racial/ethnic background (e.g., see Burkhauser & Cawley 2008, Rothman 2008), the temporal trend in obesity rates based on BMI is unmistakable. The United States government has collected statistics on population weight for several decades. From 1960-1962, the National Health Examination Survey (NHES)—a precursor to the National Health and Nutrition Examination Survey (NHANES), which is now conducted annually—reported that only 13.4% of adults ages 20-74 were found to be obese. By the 2007-2008 NHANES, the obesity rate for adults over 20 was 33.9% (see Table 1.1, adapted from Flegal et al. 2002 and Flegal et al. 2010). There is some indication this trend is slowing, but reversing it will likely remain a public health priority for several decades. Furthermore, while most causes of obesity at the individual level are well understood, structural influences on the collective weights of populations are not. These structural, contextual influences include public policy, food production and delivery systems, and transportation systems, and influence the accessibility of a healthful diet and regular exercise to individuals, but are nevertheless largely out of their control on a day-to-day basis.

The risk of obesity in individuals can be influenced by many individual-level factors, including genetics, age and gender, and even medications, but is most often associated with a lack of 'energy balance'. There are two elements of energy balance: exercise, or expenditure of calories; and diet, or consumption of calories. If the latter exceeds the former, weight-gain generally results. Researchers have thus noted that the portion sizes of foods and drinks, especially those of the calorically dense variety, increased dramatically over the past few decades (Young & Nestle 2002, Rolls 2003). Further, Americans have undoubtedly been spending increasing amounts of time in front of the television (and computers, video games) and in automobiles, which are sedentary behaviors associated with excess body weight (Andersen et al. 1998, Frank et al. 2004, Gable et al. 2007). Diet and exercise are behavioral factors an individual can modify; indeed, researchers have noted that Americans' spending on sporting goods, home exercise equipment, and health club memberships increased dramatically throughout the 1980's and 1990's (French et al, 2001). Of course, such equipment is only effective if used regularly. Similarly, weight loss through dieting can be difficult for many people to maintain. One review of research studies on calorie-restricting diets argues that, in the long-term, the vast majority of dieters regain all the weight they initially lost, and in many cases gain more (Mann et al. 2007). Other evidence, however, suggests weight loss through diet and exercise is possible to maintain (Franz et al. 2007). Regardless, it is likely that supportive environments in terms of physical activity and food opportunities can only improve individuals' chances of success. Thus, more research has begun to focus on the influence of structural factors plausibly related to dietary and physical activity behaviors, including the built environment.

Human built environments that promote a lack of energy balance have been cited as an important contributor to the obesity epidemic (Kushi 2006, French et al. 2001, Hill & Peters 1998). Researchers have even used the term 'obesogenic' to describe those that discourage physical activity and/or encourage consumption of high-calorie foods (e.g., Lydon et al. 2011, Staiano et al. 2011, Pearce et al. 2007, Block et al. 2004, Swinburn et al. 1999). Some scholars have thus focused on how the built environment, and especially the transportation system, might influence the physical activity of individuals, and thus contribute to the obesity epidemic. Much research has demonstrated, for example, that automobile-centric urban development tends to discourage walking and cycling for transportation, leading to an increase in the prevalence of sedentary lifestyles (Dill 2009, Cerin et al. 2007, Frank et al. 2005, Frank et al. 2004, Sallis et al. 2004, Saelens et al. 2003). Furthermore, studies have shown that public transportation options also encourage physical activity, since some walking is usually required between transit stops and destinations (Ewing 2005, Frank et al. 2005). This research reveals a clear association between weight, physical activity levels, and features of the urban transportation environment. Interventions to improve the built environment vis-à-vis opportunities for physical activity might therefore include adding bicycle lanes to existing roads, or altering zoning laws to encourage compact, pedestrian- and bicycle-friendly urban development (Frank et al. 2003).

Food environments and food accessibility research

The research presented here addresses the diet aspect of energy balance. Recent reviews demonstrate sustained scholarly interest over the past decade in understanding how weight and diet are associated with features of the retail food environment (Leal & Chaix 2011, Feng et al. 2010, Papas et al. 2007). The retail food environment, as understood throughout the research presented here, refers to the set of food stores and restaurants that are accessible to an individual in the course of his/her daily life. Since diet plays an important role in the maintenance of a healthy weight, the accessibility of healthy and unhealthy foods in the environment is an important concept for studying overweight and obesity. Measures of accessibility, broadly defined as the ease with which an individual can obtain certain goods or services, could include considerations such as cost or social barriers. For example, Sturm & Datar (2005), in a study of U.S. kindergarteners, determined that lower local costs of fruits and vegetables in their metropolitan areas predicted lower gains in BMI over a three-year period, after adjusting for baseline BMI, age, family income, and other factors. These findings argue that better access in the form of lower costs tends to increase consumption of healthy foods. In the research presented here, however, the focus will be on spatial accessibility, given the proliferation of studies over the past decade suggesting that the locations of retail food stores and restaurants are associated with rates of overweight and/or obesity.

Similar work has also focused on disparities in the neighborhood food environments of racial/ethnic groups and socioeconomic strata, given that African-American and Hispanic residents of the U.S., especially women, are more likely to be obese (Flegal et al. 2010).

Several such studies, for example, have shown that poor spatial accessibility of supermarkets, as measured by neighborhood density or proximity, is associated with overweight/obesity, low socioeconomic status (SES), and/or race/ethnicity (e.g., Zenk et al. 2005, Block et al. 2004, Morland et al. 2002). This is important because supermarkets generally have the widest variety of healthful foods available, including fresh fruits and vegetables, whole grains, and other low-fat items. Research has similarly indicated that neighborhoods with more fast food restaurants, convenience stores, and/or small grocery stores are likely to have a higher proportion of obese, poor, and minority residents (e.g., Moore & Diez-Roux 2006, Zenk et al. 2005, Block et al. 2004). These food locations tend to offer highly processed and high-fat foods, rather than fresh produce, whole grains, or other low-fat options (Franco et al. 2008, Bodor et al. 2008). There are, to be sure, several studies that have noted conflicting evidence, and methodological challenges have limited research findings.

These spatial epidemiologic studies of food environments have almost exclusively employed residence-based assessments of spatial accessibility. That is, the accessibility of food is generally described by the density of different types of retail food locations (per square mile, or per population) within one's neighborhood, or the proximity of these establishments to one's residence or neighborhood generally. These measures are then analyzed in relation to participants' weight status, often using multilevel regression models to distinguish individuals' characteristics from those of their neighborhood or residential contexts.

Research objectives

The research presented here was conceived as an exploration of applying techniques free from the limitations of these residence- or neighborhood-based analyses, and which therefore recognize the reality of individual mobility. It examines and critiques the accessibility assessment methods of food environment studies such as these, develops innovative techniques for characterizing the spatial accessibility of food, and evaluates these methods for utility in future research. These methods contribute to spatial epidemiologic research investigating weight status among individuals, and the contextual factors that might influence their diet and food shopping behaviors. Previous research exploring these issues has provided a great deal of insight into the relationship between food environments and overweight/obesity. As will be demonstrated in the next chapter, however, most of these studies are limited methodologically by residence-based assessments of food environments and accessibility. After discussing the pertinent epidemiologic research to support this assertion, there is a review of recent work on measuring spatial accessibility that ultimately draws from Torsten Hägerstrand's time geography (Hägerstrand 1970). This framework, several decades after its introduction, has guided the development of new techniques enabled by recent advances in geospatial technologies such as GIS and GPS. A full description of the resulting study conducted to implement these techniques for capturing, visualizing, and analyzing individual participants' daily movements through space and time will follow the discussion of time geography. This study, conducted in Lexington-Fayette County, Kentucky, was designed to explore a more realistic conceptualization of how the accessibility of food within the built environment might influence individuals' diet and food purchasing behaviors. The findings are encouraging, but represent only the first few steps in realizing the potential of such research. Lastly, therefore, there is an assessment of the utility of these techniques and a discussion of their potential for future studies of diet and obesity specifically, and health-related behaviors more generally.

Table 1.1. Obesity rate estimates for adults in the U.S., 1960-2008

	NHES I	NHANES I	NHANES II	NHANES III	NHANES Continuous	
	1960-1962	1971-1974	1976-1980	1988-1994	1999-2000	2007-2008*
% Obese	13.4%	14.5%	15.0%	23.3%	30.9%	33.9%

*Age 20+, earlier estimates for ages 20-74

CHAPTER 2: Previous Research

This chapter reviews previous quantitative research that has measured retail food environments or accessibility, presents some conceptual difficulties inherent in the methods employed over the past decade to do this, and explores alternative techniques that incorporate geospatial technologies such as GIS and GPS. The literature review documents some of the limitations of residence- or neighborhood-based methods, which are largely related to a lack of accounting for the daily mobility of individuals. This leads to an explication of the concept of activity space, or the space within which a person conducts the business of daily life, and its potential for building upon previous research. This chapter also describes a variety of techniques others have used for the operationalization of activity space, and compares their relative merits before settling on a particular method for an exploratory implementation using GIS and GPS. This chapter, therefore, proposes alternative methods for measuring the retail food environments of individuals, based upon a critique of previous food environment research, a review of recent geographic research addressing the operationalization of activity space, and the use of geospatial technologies.

Measuring food accessibility

The term 'food desert' was first used in Britain in 1995 by the Low Income Project Team of the British government's Nutrition Task Force to describe areas where there is a lack of accessible food stores to meet local demand for healthy affordable food (Cummins & Macintyre 2002). Since then, the media, policymakers, and even researchers have similarly used this term (e.g., Pearson et al. 2005, Wrigley et al. 2003). Much food environment research has essentially focused on determining whether residents of such areas are more likely to be overweight or obese, or a member of a socioeconomically disadvantaged group with high rates of overweight or obesity. If so, this would have obvious implications for public health and environmental justice. To assess the relative healthfulness of food environments, researchers often examine the number and variety of retail food locations in or near neighborhoods. This chapter questions this notion of 'neighborhood', and that of residential proximity more generally, as the basis for describing the accessibility of retail food locations.

Retail food locations include supermarkets, small groceries, convenience stores, restaurants of all types, and other places where people purchase food. Table 2.1 lists a few categories derived from the North American Industrial Classification System (NAICS).

Marketing firms, other businesses, government agencies, and researchers use codes such as these to distinguish retail food types based on the foods they serve and the manner in which they are served. The accessibility of these retail food locations has thus generally served as a proxy for the accessibility of nutritious foods. Supermarkets and Other Grocery Stores, for example, meet the following criteria, according to the 2007 NAICS definition (U.S. Census 2012):

> "This industry comprises establishments generally known as supermarkets and grocery stores primarily engaged in retailing a general line of food, such as canned and frozen foods; fresh fruits and vegetables; and fresh and prepared meats, fish, and poultry."

Convenience Stores, however, are more limited in the items they offer:

> "This industry comprises establishments known as convenience stores or food marts … primarily engaged in retailing a limited line of goods that generally includes milk, bread, soda, and snacks."

The analytic methods employed to characterize an individuals' access to these retail food locations typically fit into two categories, both of which use proximity to residence or neighborhood as the starting point: (1) studies that calculate the number or density of these retail food types within defined areal units (i.e., neighborhoods), and (2) studies that calculate the number of retail food outlets within a certain distance from individuals' residences, or the distance to the nearest location of a certain type. Some studies have also explored the use of both measures. Table 2.2 displays summaries of several such food environment studies. Those employing the density of food locations as a measure of accessibility include Morland & Evenson (2009), who conducted telephone surveys of individuals in North Carolina and Mississippi census tracts, then used multilevel statistical models to determine if the number of several types of food locations was associated with obesity. They found that individuals with at least one chain supermarket in their census tract were significantly less likely to be obese (prevalence ratio [PR]=0.78). But they noted the opposite for independent groceries (PR=1.31), and franchised fast food restaurants (PR=1.30). Wang et al. (2007) investigated the relationship between weight and the density of several retail food types in their neighborhoods (census tracts and block groups), including supermarkets, small groceries, convenience stores, fast food restaurants, and ethnic markets. They found that the number of small groceries per square mile was significantly and positively associated with BMI. In a study conducted in New Orleans, Block et al. (2004) noted that predominantly black neighborhoods had 2.4 fast food restaurants per square mile, compared to 1.5 per square mile in predominantly white neighborhoods, and suggested this could contribute to higher obesity prevalence in the black population.

Research employing distance-based measures of accessibility includes Zenk et al. (2005), which demonstrated African-American participants lived significantly farther (1.1 miles) from the nearest supermarket, judging by distance from their neighborhood centroid. Burdette & Whitaker (2004) calculated the distance from each participant's residence to the nearest fast food restaurant in their Cincinnati-based study of childhood overweight. They observed no significant relationships between this measure of fast food accessibility and overweight. These studies have thus not always produced readily reconcilable results. While some have noted affirmative results regarding a link between food accessibility and overweight/obesity, SES, and/or race/ethnicity (e.g., Morland & Evenson 2009, Zenk et al. 2005, Block et al. 2004), others have not (e.g., Macintyre et al. 2005, Burdette & Whitaker 2004). Internal inconsistencies are also possible: Pearce et al. (2007), in a New Zealand-based study, found high fast food density and high supermarket density both were associated with 'high deprivation' (i.e., low SES).

Many of these studies suggest retail food environments, as defined by neighborhoods or residential proximity, are associated with overweight/obesity and socioeconomic factors. They are ultimately very limited, however, in that they do not recognize the mobility of individuals. They rely upon residential proximity to characterize the accessibility of food. Such measurements of food environments, often based on census tracts or postal codes, are necessarily arbitrary and static, and thus do not account for the daily movements of individuals. Data from the American Communities Survey show that, in the U.S., the average commute to work takes 25.1 minutes, mostly by automobile (McKenzie & Rapino 2011). Clearly, most residents of the U.S. are likely to encounter a greater number of retail food resources than are present within or even nearby their neighborhood because of this mobility. Using residential or neighborhood proximity as a measure of accessibility assumes that individuals typically purchase and consume food from the retail locations nearest their homes, but in some cases this notion has been demonstrated to be erroneous (Hillier et al. 2011, Inagami et al. 2006, White et al. 2004). White et al. (2004), reporting on a study conducted in Newcastle, England, suggested access to healthful food, including fresh fruits and vegetables, was generally good for all residents, regardless of transport mode, and was not associated with diet. This study is notable because it incorporated transportation modes into the research design. Unlike most of the U.S., however, Newcastle has an extensive light rail network, and its transportation system is generally less automobile-dependent. The results of this study might therefore be difficult to interpret within an American context. Studies in the U.S. have provided more consistent evidence for significant effects of the food environment on diet. Cummins & Macintyre (2006) have even suggested that national context might play the dominant role, given the higher degree of socio-spatial polarization in North American cities; they ask, "Does living in North America make you fat?"

Morland et al. (2002) reported findings from the Atherosclerosis Risk in Communities Study, conducted in the U.S., which demonstrated improvements in diet were associated with a higher number of supermarkets per census tract. This effect was more pronounced among African-Americans, but still evident for white Americans. They concluded that this could be due to better access to personal vehicles among whites. Thus, it seems likely that factors associated with personal mobility—car ownership, public transit, leisure time—could be more important than residential proximity for most Americans. Recent work in the social sciences has encouraged the examination of 'mobilities', or different ways of moving through time, space, and society, as constitutive of social differences (Urry 2007, Sheller & Urry 2006). In the context of quantitative research addressing disparities in the spatial accessibility of food, this could mean defining food accessibility through an individual's movements within the local built environment, rather than by residential proximity alone.

In addition to focusing on residential proximity, many studies of food environments are also subject to analytical problems inherent in the spatial analysis of artificially or arbitrarily bounded areas or areal units. Studies based on neighborhoods represented by census tracts or other areal units, even those that employ multilevel statistical models, are subject to the modifiable areal unit problem (MAUP). This is a particular type of ecological fallacy related to a researcher's choice of areal unit size, shape, and boundary, and thus relates to the framework of analysis. Kwan and Weber (2008) addressed this problem with regard to the analysis of travel and land use, which is not so different from the issue at hand. They note that the MAUP manifests itself through two effects—zoning and scaling. The scaling effect occurs with varying choices in the size of the units—census tract, county, state, region, nation, to give common examples. The zoning effect, alternatively, occurs as a researcher changes the shape of units at a given scale. Of these two effects, the scaling effect is most likely to influence research findings in the literature on the geographical accessibility of food. Consider the following studies from the U.S. and the units they employed: Morland et al. (2006)—census tracts; Sturm & Datar (2005)—metropolitan areas; Maddock (2004)—states. Also, note that census tract sizes are closely related to population density, which creates an inherent bias when urban, suburban, and/or rural tracts are compared. Kwan and Weber (2008) suggest two solutions for handling the MAUP: (1) identifying the appropriate scale for analysis given the phenomenon being studied, or (2) adopting an analytical framework that is scale-independent—i.e., one that does not rely on areal units. Their subsequent analysis used activity-travel diary data from Portland, Oregon, to create activity-based space-time accessibility measures that correspond to individuals' actual movements, therefore eliminating the need for areal units and multilevel statistical models.

Cromley & Shannon (1986) recognized some of these challenges in understanding accessibility over 25 years ago, in a study examining the use of medical care facilities by elderly residents of Flint, Michigan. They developed a set of methods that

> "requires identification of what might be termed the 'dynamic' neighborhood of the elderly based on manifest travel rather than the traditional, elusive, and perhaps illusive 'static' neighborhood based on some ill-defined relationship between residence and geographic and social proximity." (p. 500)

In their research, Cromley & Shannon (1986) used personal interviews and travel surveys to identify individuals' *activity spaces*. Activity space is generally defined as the set of locations regularly visited by an individual in the course of conducting the business of daily living, along with the paths to and from these locations. Travel surveys and diaries have been widely used in transportation research to measure individuals' activity spaces (e.g., Buliung & Kanaroglou 2006, Schonfelder & Axhausen 2003, Newsome et al. 1998), but these require a great deal of commitment and time from research participants to record their movements and activities. This is undoubtedly one reason that most food environment and accessibility studies have employed neighborhood-based measures—primary collection of such data is costly and time consuming, and still subject to recall bias and other inaccuracies. More recently, Chaix et al. (2009) has used terms such as "ego-centred neighbourhoods" (p. 1306) and "personal exposure areas" (p. 1309) to describe a concept that is very similar to that of activity space.

With respect to activity space and food environments in particular, Jeffrey et al. (2006) conducted a study in Minnesota where the food environments near participants' work addresses were examined in addition to their neighborhood food environments. That study noted that proximity of fast food restaurants to participants' homes and work locations was not associated with patronage of these places, but proximity of non-fast food restaurants was. Neither was associated with BMI. This study, despite its modest findings, was nevertheless among the first to include destination-based measures of food accessibility outside participants' neighborhoods. Still, it did not include routes traveled to work, or other common destinations (e.g., schools, shopping, or recreation) to create activity spaces.

A recent Canadian study by Kestens et al. (2010) examined activity spaces to "measure foodscape exposure" in Montreal and Quebec City using web-based travel surveys to identify participants' destinations on the day preceding the survey. While their sample size was very large—they had activity locations for well over a hundred thousand individuals—they collected only a single day of data, and without routes used to access destinations. Additionally, they did not report on potential associations between the 'foodscape' and diet, food purchasing, or weight status. Rather, their focus was on identifying socioeconomic or demographic associations with food accessibility. They noted significant differences in food accessibility related to relative affluence and age, with poor and young participants generally having better access to several different types of food stores and restaurants.

These studies mark important early steps toward the development of more dynamic models of food environments and accessibility. Before continuing, however, further discussion of how the concept of activity space developed and has been operationalized by researchers in other fields will help to illuminate the path going forward.

Activity space

Hägerstand's (1970) work on time-geography was foundational for activity space research, and recent scholarship drawing from this tradition (e.g., Kwan 1999, Weber 2003, Schwanen & de Jong 2008) provides the foundation for developing activity-based food accessibility measures. Hägerstand's major contribution to spatial science was to assert that individual activity choices, such as where to purchase food, could not be reduced to spatial considerations alone. First, because a person cannot exist in more than a single location at once, but also due to human biological needs such as sleep, only a limited amount of time can be allocated for activities and the travel between them. Furthermore, some activities are fixed, while others are flexible with regard to location and time (including duration): employers generally expect their employees to arrive at work at a specific time and location for a particular duration, but one is usually free to purchase food at any number of locations whenever one is able and the store is open. The maintenance of daily life, then, requires individuals to simultaneously deal with limitations on time as well as space. Accordingly, Hägerstand (1970) argued for a geography where time and space are understood as inseparable—hence the term, 'time geography'—and an individual's movements form a space-time *path*. Applying this principle led him to develop the *space-time prism* (Figure 2.1), an analytic construct that essentially describes activity space in three dimensions, two spatial and one temporal.

More recent work by geographers has focused on depicting the space-time prism as a two-dimensional construct, such as the potential path area (PPA; Figure 2.2), in order to assess individual accessibility, or the accessibility of individuals to employment and services (Kwan 1999, Weber 2003). The potential path area is a two-dimensional construct that shows where a person might travel within the time frame suggested by the spatial and temporal limitations related to their fixed activities. Not only does it incorporate space and time into a single description of activity space, but also defines accessibility in disaggregate terms—i.e., the accessibility of a particular location is determined by the fixed destinations and possible routes of each individual. Furthermore, such techniques are scale-invariant and scale-independent, since they do not require the use of areal units.

Characterizing food environments based on individuals' activity spaces, so that they recognize individual mobility, and are disaggregated and scale independent, leads to a more relational understanding of 'place' in health research (Cummins et al. 2007). This means that place is understood as a complex interrelationship between individuals and contexts. Cummins et al. (2007, p. 1830) assert that "extending studies to include the measurement of individual exposure to multiple 'contexts' in time and space would be an important step forward." Activity spaces should thus provide a more relational representation of individuals' food environments. Within this proposed framework, food locations within a person's activity space—as defined by their daily interaction with the built environment—

would be considered geographically or spatially accessible, and part of their unique food environment.

As shown in Table 2.2, researchers have employed a variety of calculations to characterize retail food accessibility within neighborhoods, and most could also be applied to activity spaces. Morland et al. (2002) counted the number of specific retail food locations within census tracts; Block et al. (2004) calculated the number of fast food restaurants per square mile in census tracts; Macintyre et al. (2005) used the number of specific restaurant types per 1000 population. Several more recent studies have calculated a Retail Food Environment Index (RFEI) to assess the relative merits of neighborhood food environments (e.g., Jilcott et al. 2010, Truong et al. 2010, Spence et al. 2009, Babey et al. 2008). This index is essentially a ratio of the number of food locations with unhealthy foods to the number of those with healthy foods. As first described by a study from California (Babey et al. 2008), the RFEI is the number of convenience stores and fast food restaurants, divided by the number of grocery stores (including supermarkets) and produce vendors (i.e., fruit and vegetable markets). Some researchers have made adjustments regarding food locations included in the calculation (e.g., Jilcott et al. 2010, Spence et al. 2009), and Truong et al. (2010) proposed a similar measure they called the Physical Food Environment Indicator (PFEI). All of these measures, except perhaps food locations per population, can feasibly be constructed for participants' activity spaces to investigate the relationship between their unique food environments, their diet, and their food purchasing.

Cromley & Shannon (1986) were among the first to operationalize activity space in this manner for health-related research, using a standard deviation ellipse (SDE) to identify health clinics accessible to the elderly in Flint, Michigan. In recent years, researchers have continued to use the SDE (Zenk et al. 2011, Buliung & Remmel 2008, Buliung & Kanaroglou 2006), but have also explored the use of the minimum convex polygon (MCP) (Buliung & Remmel 2008), daily path area (DPA) (Zenk et al. 2011), and several more (Sherman et al. 2005). Examples of the SDE, MCP, and DPA from the literature are displayed in Figures 2.3-2.5.

The type of activity or travel data available from research participants can sometimes influence the choice of activity space construct. Note that the SDE, for example, only requires the coordinates of at least three destinations, since three 'anchor points' are necessary to draw an ellipse. Three destination points would also be required for constructing the MCP. These destinations could easily be gathered from participants using travel surveys, but travel destinations can also be derived from GPS tracking data (Du & Aultman-Hall 2007). Furthermore, using GPS tracking data to determine activity spaces is preferable because it demands less from participants than travel diaries, while yielding more complete data (Wolf 2000, Murakami et al. 1999). A study described by Zenk et al. (2011) is very pertinent because it was published as the research described here was ongoing. They tested both SDEs constructed from several days of GPS tracking points, and DPAs derived from the same point data buffered by ½ mile. Their results using SDEs were null, whereas those using DPAs showed a significant relationship between whole grain intake and fast food density. Apart from the research reported here, to date this is the only other study published exploring the use of activity-based food environment measures to investigate food environments and their relationship to dietary intake and overweight/obesity. But there is another reason the DPA might be preferable to the SDE, MCP, or similar constructs. The SDE and MCP are abstract Euclidean constructs that are a step removed from the context within which individuals travel to activity locations. In contrast, the DPA is based upon the actual, recorded movements of individuals within the context of the built environment. In this sense, it more precisely incorporates the influence of the transportation system and the locations of major employment centers (e.g., Downtown, UK campus), as well as differences in mobility that could be related to income or type of employment.

Table 2.1. Retail food types by NAICS codes

NAICS code & index listing
Supermarkets & Other Grocery Stores
445110 Supermarkets
445110 Grocery stores
445110 Food stores
Convenience stores
445120 Convenience stores
447110 Gasoline stations with convenience
Limited-service restaurants
722211 Delicatessen restaurants
722211 Fast food restaurants
722211 Pizza parlor, limited service
722211 Pizza delivery shops
722211 Sandwich shops, limited-service
Full-service restaurants
722110 Restaurants, full-service
722110 Steak houses
722110 Pizzerias, full-service
722110 Fine dining restaurants
722110 Family restaurants
722110 Diners, full-service
722112 Cafeterias

Table 2.2. Examples of previous studies of retail food environments

Authors	Year	Location	Measurements	Results
Accessibility & overweight/obesity				
Jilcott et al.	2010	NC	RFEI, supermarkets per capita, fast food restaurants per capita	RFEI was positively associated with BMI, fast food restaurants per capita were negatively associated with BMI
Morland & Evenson	2009	NC, MS	Frequency of 11 types of food stores in each census tract; also network distance to nearest supermarket, fast food locations	Conflicting. Obesity prevalence was lower in census tracts with at least one supermarket, and higher in those with at least one fast food restaurant. However, distance to supermarket was negatively associated with obesity risk, and distance to fast food was positively associated with risk.
Spence et al.	2009	Edmonton, Canada	RFEI within 800m, 1600m distances from participants' homes	Low RFEI was associated with obesity compared to highest RFEI group
Wang et al.	2007	California	Small groceries, convenience stores, supermarkets, fast food, ethnic markets per square mile in census tracts/block groups	Higher density of small grocery stores associated with higher BMI among women. Closer proximity to chain supermarkets also associated with higher BMI among women.
Morland et al.	2006	MS, NC, MD, MN	Presence or lack of supermarkets groceries, or convenience stores, and combinations thereof, within census tract	Presence of supermarkets was associated with lower prevalence of obesity and overweight. Convenience store presence associated with higher prevalence of the same.
Sturm & Datar	2005	59 U.S. metropolitan areas	Groceries, convenience stores, full-service restaurants, and fast food restaurants per capita by zip code; ratios of full-service to fast food and groceries to convenience stores	No effects noted for any food outlets per capita or ratios at the neighborhood level.
Burdette & Whitaker	2004	Cincinnati, OH	Distance from child's residence to the nearest fast food restaurant	No association observed between proximity to fast food restaurants and overweight.

Table 2.2. Examples of previous studies of retail food environments, cont.

Authors	Year	Location	Measurements	Results
Accessibility & SES, race/ethnicity				
Sharkey & Horel	2008	Rural counties in TX	Street network distance from population-weighted centroid of census block groups to nearest supermarket and other food stores	Distance to nearest supermarket decreased with increasing deprivation, minority composition, population density
Moore & Diez-Roux	2006	NC, MD, NY	Groceries, supermarkets, convenience stores, other food stores per 10,000 population in census tracts	Minority and racially mixed neighborhoods had significantly fewer supermarkets, more small groceries.
Cummins et al.	2005	England & Scotland	McDonald's restaurants per 1000 residents of 'small areas' ("data zones" in Scotland, "super output areas" in England)	Neighborhood deprivation was positively associated with McDonald's restaurants per 1000 residents
Macintyre et al.	2005	Glasgow, Scotland	Fast food, other restaurants, cafes, and 'takeaways' per 1000 population in postcode areas	Density of food outlets was not associated with postcode area deprivation quintiles.
Zenk et al.	2005	Detroit, Michigan	Distance from census tract centroid of residence to nearest supermarket	The most impoverished African-American neighborhoods were significantly farther from the nearest supermarket compared to White neighborhoods.
Block et al.	2004	New Orleans, LA	Fast food restaurant density (restaurants per sq. mile) within buffered Census tracts	Fast food density was significantly associated with median household income and percent Black residents.
Morland et al.	2002	MS, NC, MD, MN	Number of supermarkets, grocery stores, convenience stores, others in census tracts	Wealthier neighborhoods had more supermarkets, convenience stores with gas stations; many more supermarkets are located in White neighborhoods.
Reidpath et al.	2002	Melbourne, Australia	Population per fast food restaurant within postal districts	Postal districts with higher socioeconomic statuses had larger populations per fast food outlet.

Figure 2.1. Space-time prisms for (a) 2.5- and (b) 1-hour travel times (from Kim & Kwan 2003)

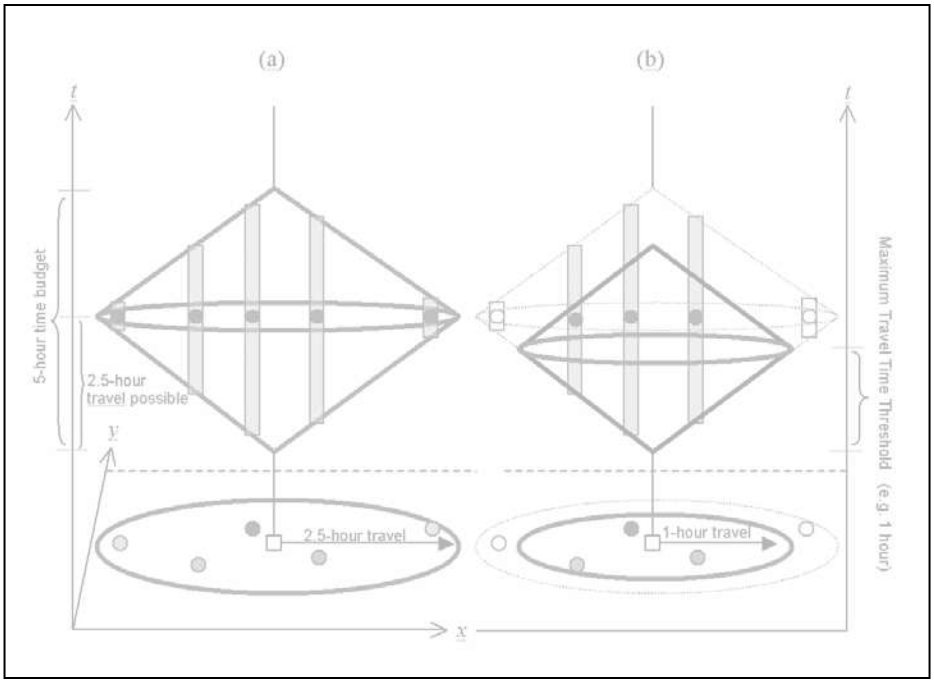


Figure 2.2. Example of a potential path area (from Weber 2003)

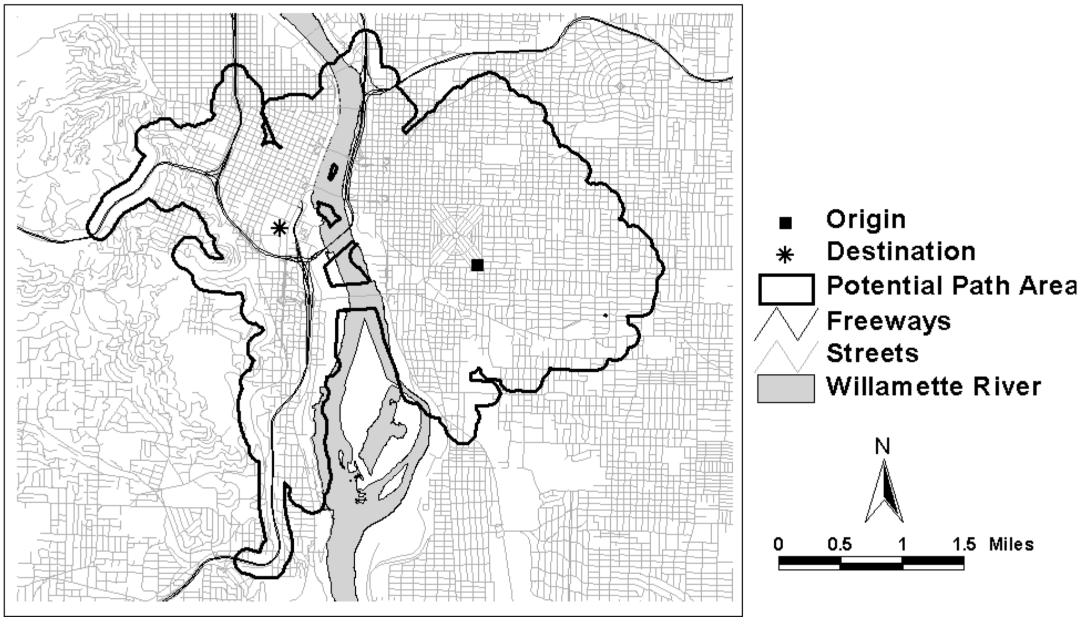
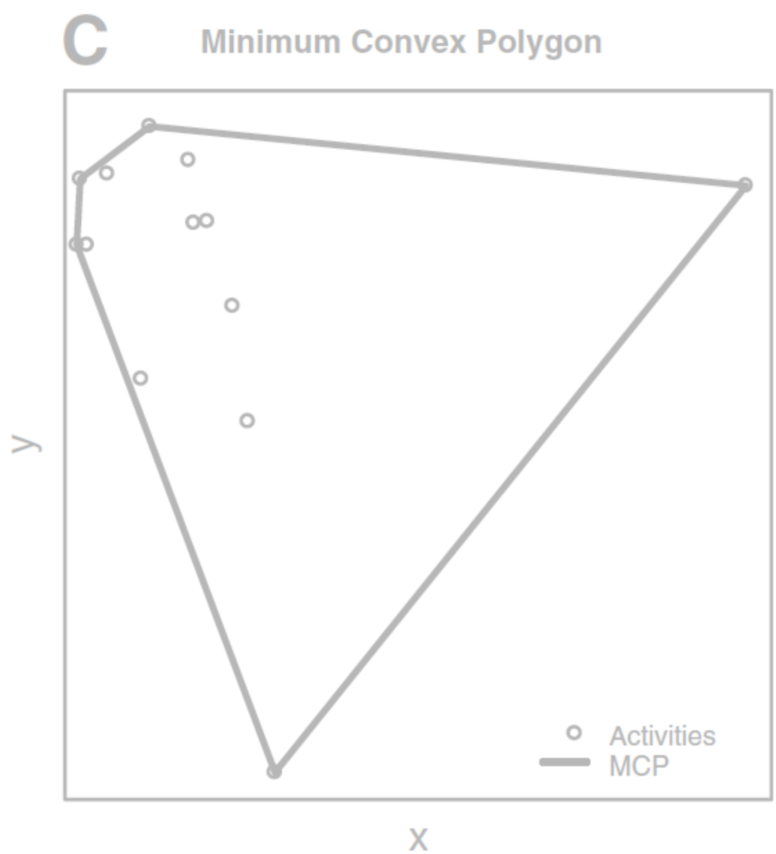


Figure 2.3. Standard deviation ellipse (SDE)

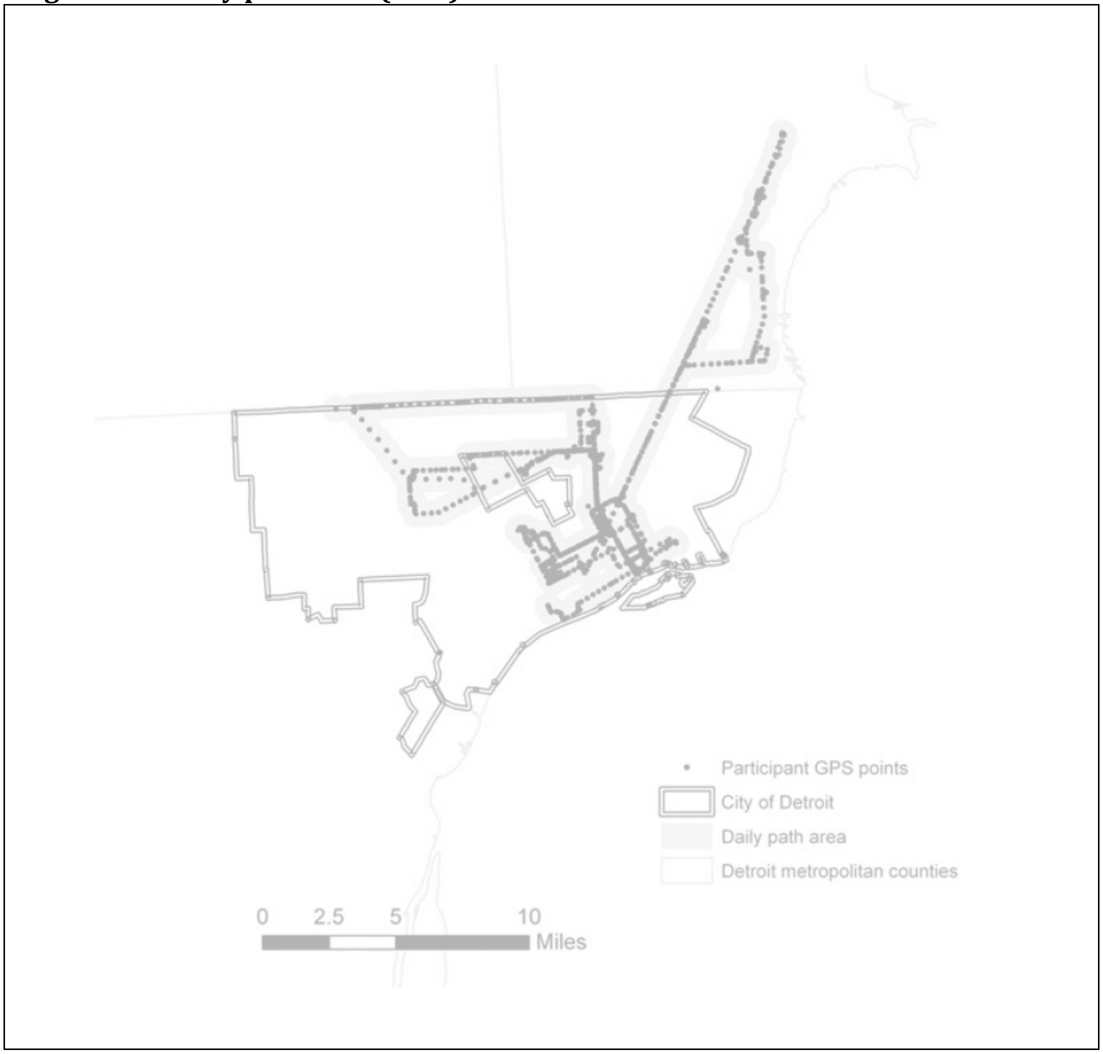
The SDEs of two households are depicted with solid lines in this figure from Buliung & Kanaroglou (2006). The standard distance circles for these households are shown in dashed lines. The red lines in this figure represent local highways, but the SDE is a strictly Euclidean construct, which is determined by the destination locations of each household (squares for the larger ellipse, circles for the smaller one).

Figure 2.4. Minimum convex polygon (MCP)



Buliung & Remmel (2008) used this figure to show an activity space as described by a MCP. A MCP is the smallest convex polygon containing a set of point events. Like the SDE, the MCP is Euclidean, and does not account for routes or street networks used to access locations.

Figure 2.5. Daily path area (DPA)



This figure from Zenk et al. (2011) shows a point-based DPA. The GPS points, recorded at 30-second intervals, were buffered by a ½-mile distance to create the activity space. The DPA is not an abstract, Euclidean construct, but is instead based upon actual movement of the participant within the context of the built environment.

Chapter 3: Research Design

Research questions

To explore the potential of activity-based measures of accessibility for spatial epidemiologic studies of the food environment, the study presented below employed techniques to identify participants' activity spaces and describe the food environments therein. In so doing, it addressed the following three questions: (1) How do individuals' activity-based measures of food accessibility compare to neighborhood-based measures? (2) How do these activity-based measures relate to individual characteristics, including weight? And, (3) Are activity-based measures associated with dietary behaviors and/or purchasing of certain types of foods?

Overview

Characterizing the activity-based food environments of participants required identification of their unique activity spaces, as well as the food locations within them. All research participants resided in the same census tract, which is the most common proxy for 'neighborhood' in food environment studies, to highlight the great variation in activity-based food environments expected. This comparison of the variety of activity-based food environments of participants to their shared neighborhood-level food environment thus addressed Research Question 1 (How do individuals' activity-based measures of food accessibility compare to neighborhood-based measures?). Data on individuals' personal characteristics and their dietary and food purchasing behaviors were used to address Research Question 2 (How do these activity-based measures relate to individual characteristics, including weight?) and Research Question 3 (Are activity-based measures associated with dietary behaviors and/or purchasing of certain types of foods?). This information, gathered via person-to-person questionnaires, was then analyzed in relation to participants' activity-based food environments. Streets and roads GIS data for the study area, as well as the locations of all retail food outlets, were required to facilitate this analysis. Thus, to address the research questions, the study described here collected data pertaining to: (1) the activity spaces of recruited participants; (2) their personal characteristics and behaviors, including weight status and dietary and food purchasing habits; and (3) the local built environment, including streets with address ranges and retail food locations.

The research protocol for this study was reviewed and approved by the University of Kentucky Institutional Review Board. Briefly, it required participants, who replied via telephone to mailed notices describing the research, to answer two brief person-to-person questionnaires and carry a GPS tracking device with them for about four days between questionnaires. (Participants were compensated with $30 for their time and attention to study activities.) The first questionnaire (Q1) collected information about personal characteristics, such as height, weight, age, gender, occupation, household income, educational attainment, and travel behaviors. These Q1 interviews were always conducted on a Sunday or Monday so that participants recorded at least three full weekdays of travel, Monday-Wednesday or Tuesday-Thursday. Participants were instructed to activate the GPS device the morning after Q1, and then carry it with them until the second questionnaire (Q2) on Thursday or Friday. After Q2, which gathered information regarding diet and food purchases, the GPS data were reviewed to assess completeness and quality. In a GIS, layering with food locations data enabled assessment of the retail food environments within participants' activity spaces.

This chapter addresses the rationale for the overall design of the study, including details pertaining to participant recruitment, data collection, and analysis. The next section describes the choices of setting and participant recruitment strategy. The following sections describe the food locations data obtained for research, as well as the GPS and questionnaire data collection protocols, including information about the specific GPS device deployed in this study, and the food consumption and purchasing surveys. Lastly, the final section describes the spatial, statistical, and other analyses conducted to address the research questions.

Research setting and participant recruitment

This research was conducted in Census Tract 5, in the merged city-county municipality of Lexington-Fayette County (Lexington), Kentucky (Figure 3.1). Lexington's population was approximately 300,000 in 2011, and it anchors a metropolitan area of about 480,000 (U.S. Census 2012). Located adjacent to Lexington's Downtown area, Census Tract 5 (Figure 3.2) encompasses about 1500 households and three neighborhood associations. The bulk of housing in the area was constructed from the 1910's through the 1940's. From west to east, the three neighborhoods comprising this census tract are Bell Court, the oldest and most affluent area, with many large Victorian and Craftsman homes; Mentelle, of a similar character, but with a wider range of home values and sizes; and Kenwick, where older bungalows built in the 1920's populate the first blocks off Richmond Road, but fade to brick Cape Cods and small white clapboard houses built in the following decades on the second and third blocks. The first blocks of the Kenwick avenues perpendicular to arterial Richmond Road—Richmond, Victory, Owsley, Lincoln, Preston, Bassett, and Sherman—are generally regarded as more desirable and affluent, due in part to somewhat larger homes, but especially to the bungalow architectural style that is actively maintained as a point of neighborhood pride (Boulton 2011). Because of its adjacency to the Downtown and University of Kentucky campus, this general area is increasingly popular with staff, faculty, and to a lesser degree university students.

While the great majority of residents (>90%) were white, this census tract was otherwise relatively diverse with regard to age, education, and income in 2000. Census data from that year, the most recent available when the study was being designed, show this area was similar to Lexington with regard to the rate of poverty (11.5% in CT5 versus 12.9% in Lexington), and the percentage of residents with a high school diploma (86.5% in CT5, 85.9% in Lexington) (U.S. Census 2012). The percentages of people who drive alone to work was similar (79.9% in CT5, 81.1% in Lexington), while a slightly larger percentage in CT5 walk, bike, or ride the bus to work (8.9% in CT5, 6.4% in Lexington). While primary data collection for this project was ongoing, the American Communities Survey (ACS) released 2005-2010 estimates showing some changes in the demographic and socioeconomic makeup of the census tract. In brief, the ACS estimates suggested the number of residents below poverty (5.6%) and without a high school diploma (7.8%) were substantially fewer than during the 2000 U.S. Census.

Participants were limited to adults 18-65 years old to increase the likelihood that most of them would travel to multiple destinations during the study period. Furthermore, participants were asked to select a week when they did not expect to travel outside Lexington to participate, since food locations were ultimately only available for Lexington (see below). Participant recruitment consisted primarily of mailed flyers that briefly described the research and encouraged interested parties to call a dedicated telephone number (this flyer is available in Appendix A). Approximately 1400 households received over 3100 flyers inviting participation, beginning in May 2011. Each household received at least two flyers on separate occasions about four weeks apart. Households in a low-response area (the eastern corner of Kenwick neighborhood) received a third flyer four more weeks later. Kenwick Neighborhood Association meetings provided an additional opportunity to speak briefly about the research and encourage participation among those living in the low-response area. This area was, notably, comprised of the second and third blocks of the main streets in Kenwick.

Upon calling the study telephone number, participants' eligibility was confirmed and the dates and times of both interviews, Q1 and Q2, were scheduled. These meetings could be scheduled for any week between May 1 and October 31, 2011, ensuring to some degree that participants' daily travel and activities would be minimally impacted by cold or inclement weather, and the widest range of transportation options (i.e., driving, cycling, walking) would be available.

Built environment data: food locations and streets

Before further addressing primary data collection methods, this section describes data pertaining to the local built environment—food locations and streets data.

Many food environment studies have purchased commercially available data sets from Dun & Bradstreet, InfoUSA, or similar firms to identify retail food locations in areas under study. Others have obtained data from local health departments. The Lexington-Fayette County Health Department provided data on every retail food location regularly inspected for health code compliance. These data included the names, addresses, and latitude/longitude coordinates of all establishments. These food locations were not, however, coded with Standard Industrial Classification (SIC) or NAICS codes. It was therefore necessary to categorize each location. Table 3.1 displays the full list of retail food location categories considered in this research and a short definition of each. Determinations as to which category each location belonged were made based upon the following information, where available: personal knowledge of the location, name of the establishments, information from store and restaurant websites (including menus, interior photos, and other information. In some cases, telephone calls or site visits were also necessary to confirm the kinds of foods sold, or the manner in which they were sold. A few locations were added to the database in early May 2011 to reflect a few new establishments that had recently opened.

Although most locations in the Health Department data had latitude and longitude coordinates, many were still missing, and a review showed coordinates for several other locations were incorrect. Streets data with address ranges were purchased from the

Lexington-Fayette Urban-County Government (LFUCG) to properly geocode these locations. Additional small corrections were made by a GIS technician to place these food locations as close to their true position as possible with respect to parking lots and other businesses and services, as determined by publicly available aerial imagery, primarily using Google Maps and Bing Maps.

Participant data collection

GPS data

Many GPS devices were considered for this research, and their capabilities varied dramatically. Portability, battery life, and ease of use were highly desirable features. The device chosen was the Qstarz BT-1000XT GPS Travel Recorder (Figure 3.3), which measures 2.84 x 1.83 x 0.79 in. (72.2 x 46.5 x 20.0 mm). This and similar devices are sometimes marketed to photographers for the purpose of geo-referencing photographs. (The time stamp in the GPS data is matched to that of the photo to accomplish this.) The device is configurable with regard to frequency of logging GPS points, and was set to log at three-second intervals to accommodate all modes of travel (i.e., walking, cycling, driving, public transit). Data logged included latitude, longitude, speed, heading, altitude, and local time.

This device features a vibration sensor that initiates a sleep mode when it does not sense motion for ten minutes. Turning this feature on substantially boosts the battery life, from about 40 hours to almost four days. This reduces burden on participants and simplifies the research protocol considerably, since more than three days of GPS points can be recorded without charging the device or operating it in any manner, other than to turn it on. Participants were required to activate the device the morning after Q1, but the device was not switched off until it was returned at Q2. (In a very few cases the battery was already drained at Q2, but still provided at least three full days.)

After each participant's Q2 meeting, their GPS data were reviewed to identify any spatial or temporal gaps that might indicate loss of signal or inadvertent deactivation. These checks were conducted using the QTravel software that accompanied the GPS devices, which can 'play back' the recorded travel. Participants with several large spatial and temporal gaps in their GPS tracks, and/or those with tracks showing travel outside Lexington, were excluded from most analyses. These large spatial and temporal gaps were limited to instances where the travel route of a participant could not be reasonably inferred from the recorded data. A single such occurrence by itself was not necessarily sufficient reason for invalidation, however. Participants whose tracks had less serious flaws such as this were contacted by telephone within a few days of Q2 to help 'fill the gap' based on their recollection. Only participants whose GPS tracks contained several large gaps were invalidated for this reason. The great majority of GPS tracks were assessed as valid for analysis (see Chapter 4 for specific results), and these were exported from QTravel as GPX files. These were then imported as GPS tracks into ArcGIS 10, which can read them as line files via the Data Interoperability extension. Several GPS tracks that were initially deemed unacceptable were nevertheless saved for further analysis if they provided at least two full, consecutive days of data points.

Questionnaire data

As noted previously, Q1 addressed socioeconomic, demographic, and other personal characteristics and behaviors. Most of these questions were the same or very similar to those used on the Behavioral Risk Factor Surveillance System (BRFSS) annual health survey, which is conducted by all states and territories under the authority of the Centers for Disease Control and Prevention (CDC). Topics on Q1 included age, gender, height, weight, marital status, race, Hispanic ethnicity, employment status, household income, automobile ownership, frequency of walking and biking, the Godin-Shephard Leisure Time Exercise questionnaire (Godin & Shephard 1985), and more.

Questionnaire 2 collected diet and food purchasing information. In medical and public health research, dietary information is often gathered using a food frequency questionnaire (FFQ). These can be quite lengthy, however, with questions for well over 100 specific food items. Examples include the NHANES FFQ, which totals 139 questions (many with multiple parts), and the Block FFQ, with 110 in its most recent iteration from 2005. While these types of surveys represent the 'gold standard' in self-reported dietary assessment, they also provide a level of detail not necessary for this research, and would require much longer interviews with research participants. For these reasons, this research used the NHANES dietary screener, a 26-question survey that assesses frequency of consuming a variety of food types (NCI 2012). Thus, instead of asking about how often the respondent eats individual fruits (e.g., grapes, strawberries), as on the FFQs, the dietary screener asks mostly about categories of foods, such as fresh fruits and fruit juices. Due to resource constraints and the exploratory nature of this research, this was considered sufficient detail for the research. Additionally, in those few instances where the NHANES dietary screener does ask about specific foods, knowing consumption of them could actually be helpful. There are fried potato and red meat questions, for example, so their consumption could potentially be analyzed with regard to the accessibility of limited-service restaurants.

The NHANES dietary screener asks how often (per day, per week, or per month) the respondent consumes each food or food type, without referring to portion or serving sizes. To assess food purchasing at Q2, questions following the same pattern were developed for each of the major food location types identified in Lexington (see above). Thus, for example, one question asks, "How often do you buy food at convenience stores?" A similar question was phrased, "How often does someone in your home cook food for supper?" in order to assess frequency of cooking at home. There are other questions included to assess how much of the household's food shopping the respondent does personally, food stores from which they most often buy groceries, and which food locations in particular were patronized during the GPS data logging period. The fast food restaurants category was created after the development of the research protocol, and participants therefore did not answer purchasing questions for this food location type.

Both questionnaires, for Q1 and Q2, are available in Appendix B.

Spatial and statistical analyses

<u>Defining activity spaces</u>

Once the GPS tracks were imported to the GIS, describing the activity-based retail food environment could be accomplished in many different ways, as noted in Chapter 2. Since this research explores new methodologies, it began with two retail food environment constructs that were relatively straightforward to produce based upon participants' GPS track lines. Given the recent success of Zenk et al. (2011) using DPAs created from ½-mile Euclidean buffers, a very similar analysis was conducted for here. The greatest difference is the use of GPS track lines to create the DPAs, rather than points as in Zenk et al. (2011), because the lines produce smooth polygons when applying a Euclidean buffer. Buffering points creates polygons with 'scalloped' edges, especially when based on automobile travel. This could potentially exclude food locations perpendicular to the direction of travel, especially if the GPS points are logged at intervals greater than a few seconds. Furthermore, this effect is influenced by speed of travel, with the scalloped edge effect becoming more apparent at higher speeds because tracking points are farther apart. This is somewhat apparent in Zenk et al. (2011) if one closely examines Figure 2.5.

In addition to the Euclidean-buffered DPAs, street network-based Daily Path Areas (nDPA) were constructed and used in an otherwise identical analysis. Using the Network Analyst extension in ArcGIS, the nDPAs were created as ½-mile 'service areas' for all vertices in the street network that were within 50 feet of a participant's GPS track line. The resulting service area polygons were generalized and trimmed using the default value of 100 meters (328 feet). In order to represent areas not traveled on city streets, the original GPS track lines were buffered by 100 meters and merged into the service area polygons to form the final nDPA. This amendment ensured the service area buffer included occasional travel off the street network, such as bicycle paths or large private parking areas.

Retail food environment measures

Several retail food environment measures were calculated and investigated with regard to diet, purchases, and weight status. Density and RFEI measures were easily adapted to activity spaces, rather than areal units. The number of food locations per population, however, would be difficult to accomplish for activity spaces, since they cut across census tracts and other administrative boundaries that have known populations. Instead, proportions of specific food location types were used to characterize their relative accessibility, since overall urban density necessarily influences the density of food stores and restaurants. Using a proportional measure, such as the proportion of restaurants that are limited-service, eliminates this influence. The RFEI is similar in this manner, since it is a ratio.

The original RFEI definition proposed by Babey et al. (2008) was adapted to calculate activity-based RFEI measures. Babey et al. (2008) included "grocery stores (including supermarkets)" based upon annual revenues of $1 million or more, and only included convenience stores without gasoline for sale. In this study, revenue data were not available, but it is possible some of the larger 'small groceries' had revenues beyond $1 million per year. Also, Babey et al. (2008) did not identify a rationale for excluding convenience stores with gasoline sales in their study, but they were included here precisely because no such rationale could be asserted. These differences would tend to decrease the RFEI ratio. For this study, small groceries were not included because, while they feature some fresh produce and low-fat food selections, they are generally smaller and of inferior quality compared to supermarkets. For this reason, these establishments were considered neutral with regard to healthy food selection, and thus excluded from the RFEI calculations. Babey et al. (2008) did not include full-service restaurants in their calculation of RFEI, and it was also excluded here because they were considered neutral with regard to healthy food selection—a variety of vegetable-based dishes can often be found at full-service restaurants, for example.

Table 3.2 shows the matrix of activity-based food environment measures calculated using the RFEI, and their specific definitions; these are referred to hereafter as 'activity-based food environment measures'. Neighborhood-based food environment measures corresponding to these were calculated for comparison. For these, the neighborhood was defined as CT5 plus a ½-mile Euclidean buffer for comparison with DPA-based food environment measures, and ½-mile street network buffers for comparison with nDPA-based food environment measures. These are also listed in Table 3.2.

Statistical notes and data coding

Unless otherwise noted, spatial analyses, including the creation of activity space constructs, were conducted using ArcGIS 10.1 (ESRI; Redlands, CA). Specific tools from ArcGIS that were used for these analyses are indicated in italics the first time they are mentioned. Statistical analyses were conducted using Stata/IC 12.1 (StataCorp.; College Station, TX). When referring to a particular statistical test, the corresponding Stata command is also indicated in italics at first mention. Due to the exploratory nature of this research, and the modest sample size, 'nearly' significant or 'marginally' significant ($p<0.10$) results were considered in addition to statistically significant ($p<0.05$) results. Many questionnaire and food environment variables were not normally distributed, as revealed by tests for skewness and kurtosis (*sktest*). Thus, this study relied primarily on non-parametric statistics.

For most statistical analyses, binary variables denoted gender (male, female), weight status (overweight for BMI>=25, obese for BMI>=30), marital status (ever married or currently living with a partner, never married), and race/ethnicity (white, non-Hispanic; non-white or Hispanic). Categorical variables included income (<$50,000/yr, $50,000-$100,000/yr, >$100,000/yr), education (high school diploma or less, Bachelor's degree, Graduate degree), age (18-34, 35-54, 55+), and employment (full-time, part-time, and not employed [homemaker, retired, unemployed, or disabled]). The categories selected for these variables represent a balance between concerns for (1) sufficient numbers in statistical analysis, and (2) potential differences in activity locations. Those age 35-54, for example, are most likely to have children or adolescents in the home, which undoubtedly influences the types of activity locations one might visit. Similarly, those with college degrees are more likely to work in office settings, and those who are not employed do not share the same constraints on the timing of their activities (although they likely experience others).

Dietary consumption and food purchasing variables were analyzed continuously and categorically. For the latter, weekly consumption and purchasing frequencies were dichotomized as 'high' if they were at or above the 75th percentile, and 'low/normal' if below. The 75th percentile was chosen to limit the number of positive outcomes (e.g., high weekly intake of added sugar, or high frequency of convenience store purchases), because of statistical concerns related to the multivariate logistic regression analysis (see below).

Preliminary analyses

Before analyses that addressed the three major research questions, several others were conducted to examine the food environment of Lexington as a whole, the representativeness of the sample of participants, the normality of questionnaire and food environment variables, and expected relationships between diet/food purchases and weight.

Using the *Kernel Density* tool in ArcGIS, maps for all retail food location types listed in Table 3.1 were produced to examine their distributions throughout the study area, using the default settings. For RFEI, maps were produced showing values within a 2-mile radius of each cell in a 300-foot raster grid using the *Raster Calculator* tool. The two-mile radius was chosen to create a continuous surface large enough to cover most of the city, since a zero denominator (i.e., an area with no supermarkets or fruit/vegetable markets) would create a null value, and a zero numerator divided by any denominator would equal zero. Proportions were similarly mapped using the same tool and settings. In this manner, maps were created showing continuous surfaces for all density-, proportion-, and RFEI-base food environment measures. Beyond presenting an overall view of the retail food environment in Lexington, these maps were useful for comparing the retail food environment of CT5 to other areas of the city. A somewhat related analysis examined correlations between all of the activity-based food environment measures to determine whether certain types of food stores and/or restaurants tend to cluster together within participants' activity spaces. Spearman's rank correlation coefficients (*spearman*) and p-values were used for this analysis.

Kernel density maps were also used to visualize the spatial representativeness of the study participants' residences. If the pattern of spatial density of all residences appears similar to that of study participants, it follows that participants are representative of the spatial distribution of residences. To supplement this visualization, a case-control spatial scan statistic (Kulldorff 1997) was employed to provide an inferential statistic that addressed the spatial representativeness of participants. While not 'cases' and 'controls' in the usual sense, participants and non-participants can similarly be analyzed to determine whether participants clustered together more than expected in any area, given the spatial distribution of non-participants. This analysis was completed with SaTScan 9.1.1 (Kulldorff & Information Management Services, Inc. 2011), using a Bernoulli (i.e., binomial) probability model, and scanning for both high and low rates. The presence of a statistically significant cluster in this analysis would suggest the spatial representativeness of the sample was biased in some manner. Because the number of potential participants in each household of the census tract was unknown, this analysis was limited to the household level. That is, multiple participants per household could not be considered, so only the spatial representativeness of households with at least one participant could be assessed in this analysis.

The characteristics of (1) all participants, (2) those with valid GPS and questionnaire data, and (3) the residents of CT5 (using data from Census 2010 and the American Communities Survey [ACS] 2006-2010) were tabulated to investigate the representativeness of the participants. A lack of matching U.S. Census data made comparisons impossible for some characteristics.

Non-parametric tests for trend (*nptrend;* Cuzick 1985) were used to examine the relationship between participants' responses to dietary/purchasing questions and their weight status. This analysis was conducted to confirm that consumption and/or purchasing of particular foods was associated with weight status, as expected. Weekly consumption of the following foods were expected to be associated with weight status:

- Fried potatoes—from a single question from NHANES that included french fries, tater tots, hashbrowns, or similar items

- Red meats—from a single question that included beef, lamb, pork, sausage, or similar meats
- Added sugar—a combined total for the following questionnaire items: sweetened beverages; sweetened soda; candy, including chocolate; ice cream or similar frozen dairy desserts; cookies, cake, pie, or brownies
- Non-potato vegetables and fruits—a combined total for the following questionnaire items: fruit juices; fresh, frozen, or canned fruit; green salads; all other vegetables except potatoes
- Whole grains—a combined total for the following questionnaire items: whole grain cereals; cooked whole grains; whole grain breads

The inclusion of these food items reflects previous research demonstrating that eating whole grains and non-potato fruits and vegetables tend to decrease risk of weight gain or related negative health outcomes (e.g., diabetes, metabolic syndrome), while added sugar, red meats, and fried potatoes tend to increase risk (Rosenheck et al., 2008; Halton et al., 2006; Malik et al., 2006; Fung et al., 2004; He et al., 2004; Newby et al., 2003; Liu et al., 2003).

Primary analyses

All primary analyses described here were conducted for both DPA- and nDPA-based food environment measures. Research Question 1 ("How do individuals' activity-based measures of food accessibility compare to neighborhood-based measures?") was addressed by comparing participants' activity-based food environment measures to their shared neighborhood food environment. The neighborhood was defined as CT5 plus adjacent areas within a half-mile buffer (Euclidean or network, as appropriate). Comparisons were accomplished using Wilcoxon sign-rank tests (*signrank*), and results were tabulated with means, medians, and ranges for each of the activity-based food environment measures listed in Table 3.2.

To answer Research Question 2 ("How do these activity-based measures relate to individual characteristics, including weight?"), Kruskal-Wallis tests and non-parametric tests for trend were used to explore differences in participants' activity-based food environment measures, based on age, gender, race/ethnicity, household income, educational attainment, marital status, employment status, and weight status. Kruskal-Wallis tests were used for non-ordinal, categorical variables (gender, race/ethnicity, marital status, employment status), while non-parametric tests for trend were used for the remaining ordinal variables.

For Research Question 3 ("Are activity-based measures associated with dietary behaviors and/or purchasing of certain types of foods?"), Spearman rank correlation coefficients (*spearman)* were used to examine potential bivariate associations between the activity-based food environment measures and diet and purchasing outcomes. Only the 99 participants with complete data were included in this analysis. Continuous weekly dietary intake outcomes included:

- Fried potatoes
- Red meats
- Added sugar
- Non-potato vegetables and fruits
- Whole grains

The following weekly purchasing frequency outcomes were chosen because they corresponded with specific questions from Q2, and were the most commonly visited food location types (all were visited at least once every two weeks, on average):

- Limited-service restaurants
- Full-service restaurants
- Convenience stores
- Small groceries
- Supermarkets

To further address Research Questions 2 and 3, multivariate logistic regression was employed to determine whether there were any significant associations between food environment measures and diet, purchasing, and weight variables, after adjustment for the demographic and socioeconomic variables (age, gender, race/ethnicity, marital status, employment status, education, and income). Again, only the 99 participants with complete data were included in this analysis. Each binary variable that denoted high dietary intake or purchasing of a food type was an outcome in a regression model with each of the food environment measures as the independent variable of interest. Thus, each outcome was examined in relation to each activity-based food environment measure separately. The 75th percentile was chosen as the cut-off point for 'high' dietary intake or purchasing because the odds ratios obtained through multivariate logistic regression are better estimates of relative risk with a small proportion of these in the sample. Too small of a proportion, however, would mean too few positive outcomes in absolute terms for a sufficiently robust analysis. Similar analyses were conducted for overweight and obese binary outcomes, including all of the same covariates, again with each model featuring a different food environment measure.

Analysis of three-day and seven-day GPS tracking

As mentioned previously, GPS tracking was generally limited to three weekdays. There were, however, several participants who agreed to carry the GPS again, but for seven days. Having both sets of tracking data for several participants thus allowed a comparison of three-day and seven-day activity spaces and food environment measures. These participants did not answer any more questions; they only provided a full seven days of GPS tracking. Their three-day and seven-day DPAs were compared visually by mapping their corresponding activity spaces, and by tabulation of their activity-based food environment measures with the results of Kruskal-Wallis tests.

Table 3.1. Retail food location categories

Supermarkets	Large food stores that feature a wide variety of produce, frozen foods, and low-fat foods (e.g., Kroger, Meijer, Whole Foods)
Small grocery stores	Smaller food stores with limited produce selections (e.g., Aldi, small independent grocers), including some ethnic grocers
Convenience stores	Stores that sell snacks, beverages, and packaged foods (e.g., gas stations, news stands)
Fruit/vegetable markets*	Small stores or markets that primarily sell fruits and vegetables (e.g., farmers markets, fruit and vegetable stands)
Limited-service restaurants	Restaurants where payment is presented *before* consumption (e.g., McDonald's, Starbucks, Chipotle, or similar independent cafés, fast food, and 'fast casual' restaurants)
Full-service restaurants	Restaurants where payment is presented *after* consumption (e.g., Outback Steakhouse, Applebee's, or similar independent restaurants)
Fast food restaurants†	Includes only limited-service restaurants that primarily serve sandwiches, hamburgers, hot dogs, fried chicken and/or fish, fried potatoes, pizza, tacos, or similar items

*Used only for RFEI and proportional calculations for food stores
†Used only for RFEI calculations

Table 3.2. Matrix of activity-based food environment measures

Food environment measures	Definition	Activity-based		Neighborhood-based	
		Half-mile Euclidean DPA	Half-mile street network DPA*	Half-mile Euclidean buffer	Half-mile street network buffer*
Supermarket density	Supermarkets per square mile	SD^{DPA}	SD^{nDPA}	SD^{N}	SD^{nN}
Small grocery density	Small groceries per square mile	GD^{DPA}	GD^{nDPA}	GD^{N}	GD^{nN}
Convenience store density	Convenience stores per square mile	CD^{DPA}	CD^{nDPA}	CD^{N}	CD^{nN}
Limited-service density	Limited-service restaurants per square mile	LD^{DPA}	LD^{nDPA}	LD^{N}	LD^{nN}
Full-service density	Full-service restaurants per square mile	FD^{DPA}	FD^{nDPA}	FD^{N}	FD^{nN}
Retail food environment index (RFEI)	Sum of fast food restaurants plus convenience stores, divided by sum of supermarkets and fruit/vegetable markets	$RFEI^{DPA}$	$RFEI^{nDPA}$	$RFEI^{N}$	$RFEI^{nN}$
Supermarket proportion	Number of supermarkets divided by sum of supermarkets, small groceries, convenience stores, and fruit/vegetable markets	SP^{DPA}	SP^{nDPA}	SP^{N}	SP^{nN}
Small grocery proportion	Number of small groceries divided by sum of supermarkets, small groceries, convenience stores, and fruit/vegetable markets	GP^{DPA}	GP^{nDPA}	GP^{N}	GP^{nN}
Convenience store proportion	Number of convenience stores divided by sum of supermarkets, small groceries, convenience stores, and fruit/vegetable markets	CP^{DPA}	CP^{nDPA}	CP^{N}	CP^{nN}
Limited-service proportion	Limited-service restaurants divided by sum of all restaurants	LP^{DPA}	LP^{nDPA}	LP^{N}	LP^{nN}
Full-service proportion	Full-service restaurants divided by sum of all restaurants	FP^{DPA}	FP^{nDPA}	FP^{N}	FP^{nN}

*Densities within 328 feet (100 meters—the default value in ArcGIS 10) of ½-mile street network buffer

Figure 3.1. Census tracts in Lexington-Fayette County, Kentucky

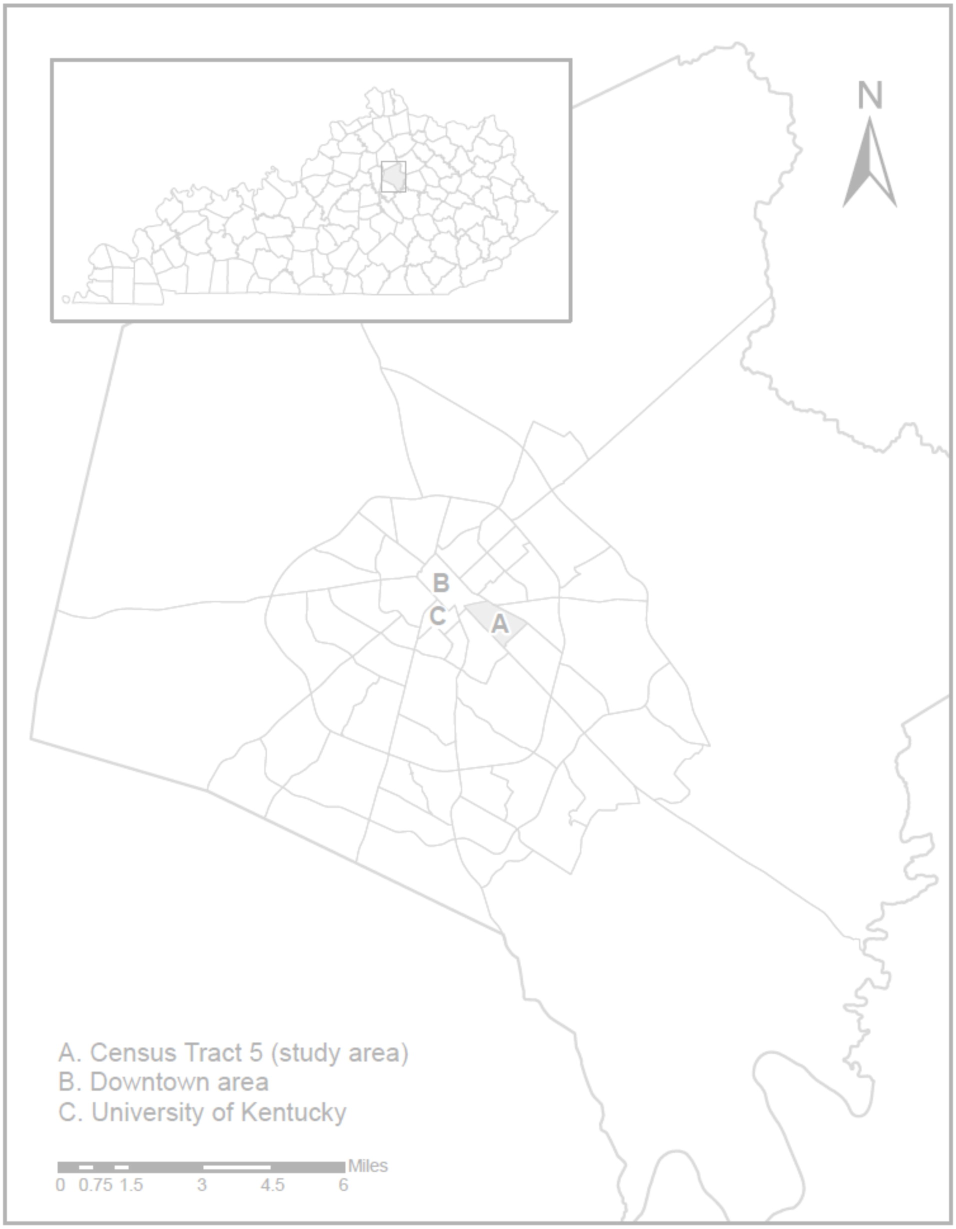


Figure 3.2. Census Tract 5 and environs in Lexington, KY

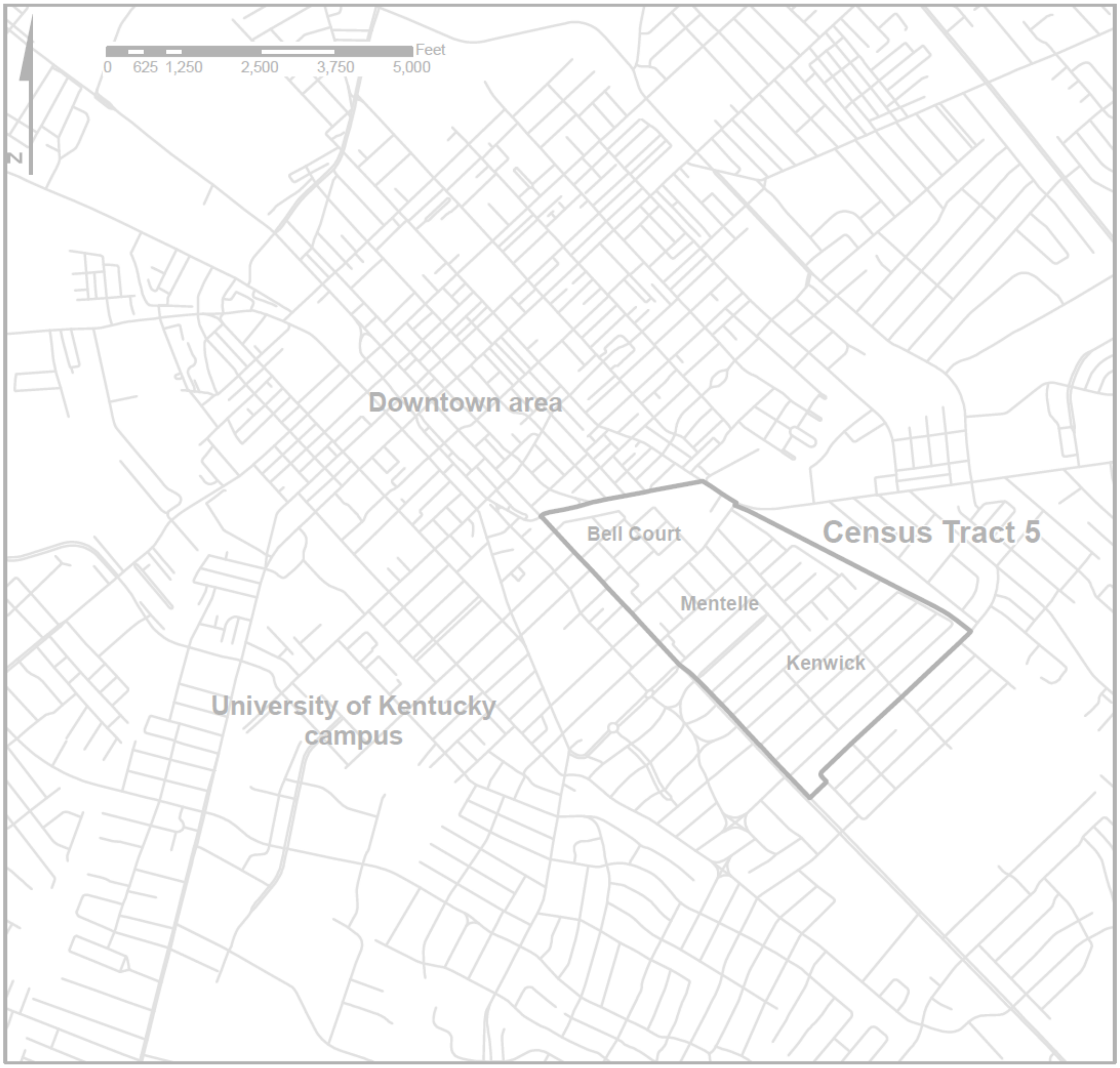


Figure 3.3. Qstarz BT-1000XT GPS Travel Recorder

Chapter 4: Research findings

Participant response

A total of 121 participants enrolled in the study. After reviewing and repairing their GPS tracks as described in Chapter 3, and discarding one individual who did not complete the protocol, 101 were deemed to have complete GPS data. Of these, two individuals refused to answer the household income question, which resulted in their exclusion from some analyses. Thus, complete questionnaire and GPS data were ultimately available for 99 individuals. The great majority of these participants were non-Hispanic and white, as expected based upon the census data. Participants with incomes below $50,000 per year and over $100,000 per year were fewer than expected given the household income distribution in the area. Also, participants generally had more education than residents. Employment, full- or part-time, was also higher among participants. Compared to the residents of the state of Kentucky, participants were more likely to be underweight or normal (59.2% vs. 35.5%) (CDC 2012).

Several individuals (n=30) in the sample represent married couples or unmarried couples living together. Multiple participants per household were allowed because individual activity spaces, rather than household activity spaces, were the focus of research. Furthermore, comparing the activity spaces of couples could yield insight into diet and purchasing behaviors. There were also eight individuals who comprised the roommates of three households.

There were 18 participants who also enrolled in the seven-day GPS tracking sub-study. The data for one of these was discarded because a change in employment had greatly altered the participant's activity space. Others failed to remain within Fayette County for seven days or forgot the GPS for one or more days (n=3), and another had to leave town for a family emergency. Thus, thirteen seven-day GPS tracks were available to compare to participants' corresponding three-day tracks.

GPS data collection

Participants' GPS tracking data, for the 101 individuals with complete data, yielded an average of 12,880 points, or about 10.7 hours of recorded points, with a range of 2273-36,587 points, or 1.9-30.5 hours. Participants at the low end of this range rarely left their residence during the three-day tracking period, or they worked very close to home and the GPS was often in sleep mode at both locations. The GPS tracks of those at the high end of the range suggested a lot of time spent driving or walking, often for work, with fewer daily opportunities for the GPS to enter sleep mode.

Preliminary analyses

Figures 4.1a-e display continuous surfaces for retail food location density, proportion, and RFEI measures. With the exception of supermarkets, all retail food location types were most dense in the downtown area, with high convenience store density extending farther from that area than other types. Supermarket density was highest in two areas, including a large swath of the city in the south, and a smaller region in the north. Because of the study area's location near the downtown area, its northwestern tip was in the highest density area for all types, except supermarkets. This portion of the study area was the neighborhood with the highest incomes and home values, Bell Court.

The RFEI continuous surface map is displayed in Figure 4.1f. The highest, and therefore least healthful, RFEI values were found on the northern and eastern edges of the city, with high RFEI areas just to the southwest of Main Street and also east of downtown between the intersections of Winchester Road and Richmond Road with New Circle Road. The study area was mostly within the middle category, but adjacent to a lower RFEI area extending into wealthier neighborhoods to the south. This area probably could be considered the most healthful in the city, at least with regard to retail food environment.

Like the RFEI map, the food store proportion continuous surfaces, in Figures 4.1g-4.1k, also reveal a more complex pattern than that presented by the density maps. The convenience store proportion was highest along the eastern edge of the city, likely due to the proliferation of gas stations with convenience stores at highway exits. Closer to the city there were two areas of moderately high convenience store density to the southwest of downtown. The study area was in a moderately low area for convenience store proportion. For most of the other proportional measures, the study area was in the middle category, but was split between moderately low and low areas for supermarket proportion. Note that the limited-service and full-service restaurant proportions are opposites. Small grocery proportions were highest in the rural parts of the county where isolated stores overwhelm the denominator, but within the city the highest proportion of small groceries matched pretty closely with the moderately low convenience store density area just northeast of the downtown. Census Tract 5 was located almost wholly within this area.

Kernel density maps of residences and participants are displayed in Figure 4.2. The blue map (residences) shows a high density of housing in the central portion of the census tract, near Hanover Drive, Mentelle Park, Richmond Avenue, and Victory Avenue. There is also a higher density near Memory Lane and further along Richmond Avenue. There are high-density apartments and condominiums near Forest & Sayre Avenues that are evident on this map. There are also areas of slightly higher density between Bassett and Sherman Avenues, and on Hambrick Avenue. The orange map (participants with good GPS data, n=101) demonstrates that most of these areas have a higher density of participants as well. Those areas with a high density of residences but not participants include the Forest Avenue area and along Hanover. Many of the flyers mailed to the apartments and condominiums in these areas were returned, however, suggesting several were unoccupied. Otherwise, the spatial trends in the two maps are very similar—areas of high density around Richmond and Victory Avenues in both maps, and also peaks along Hambrick Avenue, between Russell and Boonesboro Avenues, between Memory Lane and Richmond Avenue, and between Sherman and Bassett Avenues.

The results of the spatial scan statistic, conducted to determine whether the spatial distribution of participants was different than that of residences, showed a single statistically significant high-rate cluster of participants. This cluster was located along Richmond Avenue between Cramer Avenue and Richmond Road, and included several participating residences where only 1.05 would be expected. The precise location of this cluster, including the center coordinates and radius of the circular scan window that captures it, is not presented here due to concerns over participant confidentiality. There were no significant or nearly significant low rate clusters identified, but this high rate cluster suggests participation was spatially biased to some degree. The consequences and extent of this bias are difficult to assess, however, given that only the spatial representativeness of participating households could be determined. It is also interesting to note that none of the households located within the cluster had multiple participants, while 18 residences outside the cluster did. This could have biased the results of the spatial scan statistic somewhat in favor of identifying a spurious cluster.

Table 4.1 displays the characteristics of all participants, those with complete three-day GPS tracks, and the corresponding U.S. Census data for residents of CT5 in the same approximate age range as participants. There were very few participants who were not non-Hispanic and White, as expected based on the Census numbers. There was a slightly larger proportion of women among study participants with complete data (56.4%), compared to residents age 18-64 in CT5 (51.9%). Participants with complete data were also a bit older, as only 28.7% of participants were age 18-34, compared to 41.2% of those in CT5. Participants with incomes below $50,000 per year and over $100,000 per year were fewer than expected, with middle-income participants making up 44.6% of those with complete data, compared to 30.3% in CT5. Graduate degrees were much more common among study participants with complete data (44.6% vs. 27.7%), and Bachelor's degree attainment was similar (35.6% vs. 31.2%), but the proportion without a Bachelor's degree was about half that for CT5 (19.8% vs. 41.1%). Employment, full- or part-time, was higher than in CT5 (92.1% vs. 80.0%). Unlike the Census, unmarried cohabitating couples (about 9% of participants) were coded as "married", and included in the 'ever married' group (78.3% all participants with complete GPS tracks). Thus, the proportion of legally married or previously married participants is likely similar to the 67.5% figure from the ACS. Weight status among participants could not be compared to that among residents of CT5, as these data do not exist. Compared to the residents of the state of Kentucky, however, participants with complete data were more likely to be underweight or normal (57.4% vs. 35.5%) (CDC 2012).

Table 4.2 shows some significant relationships between weight status and some of the dietary intake and purchasing variables. Overweight and obese individuals consumed red meat well over three times per week, compared to less than twice per week among underweight/normal participants (p=0.001). Fried potato consumption was higher with each increase in weight status (p=0.06), as were limited-service restaurant visits (p=0.02), and small grocery visits (p=0.01). As expected, non-potato fruit and vegetable consumption was highest among the underweight/normal, and lowest among the obese (p=0.18), and added sugar consumption was equally higher among overweight and obese participants (p=0.51), but these differences were not significant or nearly significant. The remaining consumption and purchasing variables were not much different among weight groups, but these results nevertheless demonstrate that some dietary and purchasing measures are associated with weight status.

Primary analyses

<u>DPA-based analysis</u>

Table 4.3 displays the means, medians, standard deviations (SD), and ranges for DPA area in square miles, counts of retail food locations, and all DPA-based food environment measures, as well as corresponding values for the neighborhood. These results thus address Research Question 1. Participants' DPAs were about four and a half times larger than the buffered square mile area of CT5. Most participants thus encountered a much greater number of food locations in their DPAs than are present in or near (within 0.5 miles) CT5. Convenience stores were three times more numerous, for example, and full-service restaurants were over ten times more numerous. Furthermore, Wilcoxon sign-rank tests revealed highly significant differences ($p<0.01$) in all comparisons of neighborhood- and DPA-based food environment measures. The DPA-based measures generally seemed to indicate healthier food environments than the neighborhood-based, with the notable exceptions of limited-service density and convenience store proportion.

Table 4.4 displays many significant correlations among DPA-based food environment measures. The DPA size was significantly correlated with most of the food environment measures, with the exceptions being supermarket density, RFEI, limited-service and full-service restaurant proportions. This demonstrates that the physical extent of participants' activity spaces, which provides a measure of their overall mobility, is associated with the densities and proportions of several food locations. The densities of most food locations were negatively correlated with DPA size, suggesting that the study area generally had a higher density of food locations than the areas where participants traveled. This is not unexpected, as the census tract is adjacent to the downtown area, the University of Kentucky, and mixed-use development to the northwest, but is also convenient by automobile to more suburban areas and a limited-access beltway (New Circle Road) to the southeast.

With the exception of supermarket density, the other density-based measures were all significantly and positively correlated with each other. Only small grocery density was significantly (and negatively) associated with supermarket density, perhaps confirming that small groceries serve a need where supermarkets are less accessible. The densities of limited- and full-service restaurant types were very highly correlated ($\rho=0.91$, $p<0.01$), demonstrating that they are clustered together in commercial districts.

RFEI was significantly correlated with convenience store density and supermarket density, since the frequencies of these food locations were used in its calculation. A weak, non-significant correlation (ρ=0.16, p=0.11) was also observed between RFEI and limited-service density, probably reflecting that a subset of limited-service restaurants, fast food restaurants, were used in calculating RFEI. This is also why RFEI was significantly correlated with the proportion of limited-service restaurants (and, necessarily, the proportion of full-service), convenience store proportion, and supermarket proportion.

Several relationships among food store and restaurant proportions were significant, mostly reflecting the fact that they are all relative to one another. But there were also several interesting associations between proportions and densities, as well as activity space size. DPA size was significantly correlated with proportions of the three food store types, indicating that the extent of participants' daily mobility was related to the relative accessibility of food stores. Those with larger activity spaces, and thus participants who drove their cars the most, had retail food environments with relatively more convenience stores and supermarkets, but relatively fewer small groceries. Supermarket proportion was negatively correlated with all of the density-based measures, while small grocery (positively) and convenience store (negatively) proportions were significantly correlated with most. These relationships appear to reveal a spectrum of accessibility related to mobility within urban space, with small groceries being relatively more plentiful in the activity spaces of those who stick to the older, more densely developed areas near the neighborhood, and supermarkets and convenience stores dominating in the activity spaces of those who more often travel to newer, suburban parts of the city.

Limited-service and full-service proportions were, naturally, perfectly correlated since they are essentially the same measure. Neither of the restaurant proportions was correlated with DPA size. Limited-service density was positively correlated with convenience store density, perhaps reflecting the tendency of gas stations with convenience stores and fast food restaurants to cluster around each other at major intersections. This is also evident in the positive correlation between limited-service proportion and convenience store proportion.

Table 4.5 shows several statistically significant or nearly significant relationships between participants' characteristics and DPA-based food environment measures, as well as DPA size. These trends demonstrate how participants' activity-based retail food environments varied significantly by age, income, education, marital status, and weight status, addressing Research Question 2. Note first, however, that there were no significant differences observed based on gender, or race/ethnic group, although there were admittedly few non-white, non-Hispanic participants.

One of the clearest trends recognizable in this table is the relationship between education and DPA size. There was a clear trend toward smaller DPAs for those with more education, likely reflecting the adjacency of downtown and university areas where professionals and academics were often employed. Another notable trend was that older age groups had DPAs with lower density of several food store and restaurant types. There was a similar pattern among participants from the higher income groups. Greater educational attainment, however, was associated with higher limited- and full-service restaurant density, rather than lower. Four density-based measures differed significantly, or nearly significantly, by marital status; the densities of convenience stores, limited-service restaurants, full-service restaurants, and small groceries were all higher among the never married.

Among proportional measures, there were no significant differences by age or household income. Educational attainment, however, showed significant associations with limited- and full-service proportions, which are essentially the same measure since they always add up to 100. Marital status was significantly, or nearly significantly, associated with RFEI, limited-/full-service proportion, and small grocery proportion. Married or previously married participants generally had lower densities of most measures, and slightly lower RFEI, limited-service proportion, and small grocery proportion. Lastly, obese participants had the highest RFEI scores, and overweight and underweight/normal participants had progressively lower scores. This trend was nearly significant.

Table 4.6 shows the Spearman rank correlation coefficients and p-values for the dietary and purchasing outcomes and the DPA-based food environment measures. There were few relationships that appeared to be nearly significant or significant. Added sugar intake was positively associated with limited-service proportion, but weekly red meat and fried potato intake were not associated with any of the DPA-based food environment variables. Non-potato fruit and vegetable intake was positively associated with full-service density and proportion. Whole grain intake was positively associated with supermarket density, and negatively associated with RFEI and convenience store proportion. Surprisingly, convenience store purchases were inversely related to both convenience store density and proportion. Small grocery purchases were positively correlated with limited-service density, perhaps suggesting that these establishments' densities vary similarly. Also, small grocery purchases were nearly significantly associated with both small grocery density and proportion. Limited-service purchases, full-service purchases, and supermarket purchases were not associated with any of the DPA-based food environment measures. It is notable that there were only 12 correlations out of 120 that were significant or nearly significant. This number is no more than would be expected under the null hypothesis, given the p<0.10 threshold for consideration as 'nearly significant'. Given that several of the correlations calculated might not necessarily make sense (e.g., convenience store purchases correlated with full-service restaurant density), however, this is not necessarily unexpected. Such correlations are reported only in the interest of showing all possible combinations, and the gray boxes in Table 4.6 indicate direct correlations (e.g., limited-service purchases correlated with limited-service density).

Table 4.7 displays several interesting relationships between dietary intake outcomes and food environment measures after adjustment for social, economic, and demographic factors (i.e., age, gender, race/ethnicity, household income, education, employment status, marital status). High weekly added sugar intake (13.375+ times per week) was significantly less likely as DPA-based limited-service and full-service densities increased, and as small grocery proportion increased. It was more likely, however, as convenience store proportion increased. High weekly red meat intake (3+ times per week) was not associated with any of the food environment measures. Fried potato intake was only associated with limited-service proportion, but not in the expected direction—high intake was actually less likely as limited-service proportion increased. High intake of non-potato vegetables and fruits was more likely as full-service density and proportion increased, and was less likely as RFEI and limited-service proportion increased. These findings support the notion that better access to healthful foods positively influences individuals' diets. Results regarding whole grain would also support this hypothesis, as high intake was less likely with increasing RFEI and convenience store proportion. High whole grain intake was also associated with higher limited-service density, however, which would suggest the opposite.

Table 4.8 similarly shows adjusted ORs for weekly purchasing frequency in relation to the DPA-based food environment measures, adjusting for the same factors. Here, the gray squares again highlight the direct relationships between each food location type and its corresponding food environment measures. There were fewer significant associations between the food environment measures and high food purchasing frequency than were found for the high dietary intake outcomes. Surprisingly, a high frequency of convenience store purchases was less likely with increasing convenience store density. Small grocery purchasing was strongly associated with small grocery density, as well as limited-service and full-service densities (likely because these are significantly correlated with small grocery density). High frequency of small grocery purchases was more likely with increasing small grocery proportion, but less likely with increasing convenience store proportion, suggesting perhaps that these food location types serve similar needs or functions.

Table 4.9 shows the results of multivariate analyses of weight status outcomes. Obesity was significantly more likely among participants with higher RFEI scores (indicating poorer food environments), and less likely among those with higher supermarket densities. Overweight was not associated with any of the DPA-based food environment measures examined.

Taken together, the results presented in these last few tables address Research Question 3, and thus provide preliminary evidence that at least some activity-based measures of the retail food environment are associated with self-reported dietary and food purchasing behaviors, as well as obesity. Several of the proportional measures in particular, as well as RFEI, seemed to yield intuitive findings with regard to several outcomes. Most notably, high intake of whole grains and non-potato fruits and vegetables was less likely as participants' activity-based RFEI increased. The density measures, however, more often produced counterintuitive findings in analysis, suggesting they might be less useful. Indeed, there were several puzzling results that command some attention. Those regarding added sugar intake in Table 4.7, for example, show lower risk of high intake with each increase in limited-service restaurant density. This might seem surprising, given that limited-service menus often feature sugary beverages and, depending on the type of establishment, desserts or pastries. One might further speculate that participants most likely to consume food from such places would also be more likely to consume a lot of added sugar elsewhere. And indeed, limited-service purchases per week were significantly correlated with added sugar intake per week among research participants ($\rho=0.29$, $p=0.001$, analysis not shown). But also consider that there was a similar relationship between added sugar intake and full-service restaurant density, perhaps only because the latter is highly correlated with limited-service density. These restaurant densities were, in turn, both significantly and negatively correlated with DPA size. These observations, therefore, could suggest participants whose activity spaces were limited to nearby high density areas, such as the downtown and University of Kentucky campus areas, were less likely to consume added sugar with high frequency. Adjusting for household income and education cannot fully account for this bias, since those with high income and advanced education are not the only participants who worked at the university or in the downtown area.

Network-based DPA analysis

The results of identical analyses using nDPAs, the street network-based activity space measures, were very similar to those from the DPA-based analyses. About the same number of significant or nearly significant results were observed, and those associations were mostly between the same outcomes and food environment measures. It is also important to note that creating the nDPAs was considerably more laborious and computationally intensive. Regardless, because these results were so similar, those tables are not presented with the text, but are available in Appendix C.

Comparing three-day and seven-day DPAs

Figures 4.3a-m show the three-day and seven-day DPAs of the 13 participants who had acceptable GPS data for both time periods. One of the individuals (see Figure 4.3a) traveled beyond the border of Fayette County, but these data were not discarded because the area visited in the neighboring county was very rural, with no food locations within ½-mile of the participant's GPS track (using Google Maps and Google Search to identify potential food stores or restaurants in the area). Each map shows how many of each type of food location was within each DPA, the difference between three-day and seven-day DPA sizes, and the ratio of three-day to seven-day area. All of these indicators generally agreed that seven-day DPAs were substantially larger and contained more food locations. The RFEI was often very similar, however, despite large differences in DPA size and the number of food locations. There were some exceptions, however; two of the three-day DPAs were actually smaller than their corresponding seven-day DPAs, and two three-day/seven-day pairs were almost exactly the same size.

Table 4.10 displays the results of Kruskal-Wallis tests employed to detect any significant differences between participants' three-day and seven-day food environment measures. The seven-day food location counts were significantly greater than the three-day counts, with the exception of small groceries. The opposite was true for seven-day food location densities, which were significantly higher in the three-day DPAs. The exception was supermarket density, which was similar for both. This is notable because supermarket density was the only density measure associated with obesity, albeit at an only marginally significant level. The values for DPA-based RFEI, which was associated with obesity, weekly whole grain intake, and weekly fruit and vegetable intake, were also similar for three-day and seven-day DPAs. None of the proportion-based measures were significantly different. Supermarket proportions were somewhat higher for three-day DPAs, and small grocery proportions were somewhat lower for three-day DPAs; these relationships were nearly significant.

While most participants had more food locations within their seven-day activity spaces, and the density of food locations was usually higher, the relative accessibility of food locations (as measured by RFEI, other proportion-based measure) was still similar. Even the differences in small grocery and supermarket proportions, which were both nearly significant, were still fairly similar. Since some proportional measures and RFEI were already associated with the dietary and food purchasing outcomes, the marginal utility of seven day GPS tracking should be examined further. It is possible that three days of tracking are sufficient to derive activity spaces that include food locations individuals rely upon most heavily.

Table 4.1. Participant characteristics

	All participants (N=121)		Participants w/complete data (N=101)		Census Tract 5 (N=2474*)	
	n	%	n	%	n	%
Gender*						
Female	70	57.8	57	56.4	1284	51.9
Male	51	42.2	44	43.6	1190	48.1
Age, median (range)*	41	19-65	41	19-65	36	18-64
18-34	40	33.1	29	28.7	1020	41.2
35-54	58	47.9	52	51.5	1180	47.7
55+	23	19.0	20	19.8	274	11.1
Race/ethnicity†						
White, non-Hispanic	112	94.1	96	95.0	2507	93.2
All others	7	5.9	5	5.0	182	6.8
Household income‡§						
<$50k/yr	46	38.7	35	34.7		44.2
$50k-100k/yr	52	43.7	45	44.6		30.3
$100k+/yr	21	17.6	19	18.8		25.4
Education§						
Less than Bachelor's degree	26	21.5	20	19.8		41.1
Bachelor's degree	43	35.5	36	35.6		31.2
Graduate degree	52	43.0	45	44.6		27.7
Employment**						
Full-time	85	70.2	73	72.3		80.0
Part-time	25	20.7	20	19.8		
Homemaker/retired/ disabled/unemployed	11	9.1	8	7.9		20.0
Marital status††						
Married, co-habiting, or	94	78.3	79	78.2		67.5
Never married	26	21.7	22	21.8		32.5
Weight status						
Underweight/Normal (BMI<25.0)	71	59.2	58	57.4		
Overweight (BMI 25.0-29.9)	33	27.5	29	28.7		
Obese (BMI 30.0+)	16	13.3	14	13.9		

*CT5 figures are for ages 18-64 only, from Census 2010
†CT5 race/ethnicity figures are for ages 18+, from Census 2010
‡Two participants with complete data refused to answer the household income question
§CT5 education estimates for population 25 and older, American Communities Survey
**Employment estimates for Ages 20-64 only, ACS 2006-2010

††Marital status estimates for ages 15+, do not include cohabitation, ACS 2006-2010

Table 4.2. Selected weekly dietary intake and weekly purchasing frequency measures, by weight status (n=120)

	Under/Normal (BMI<25)			Overweight (25<=BMI<30)			Obese (BMI>=30)			Test for trend
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD	p-value
Added sugar	8.82	6	8.01	10.49	7.25	8.62	10.50	11	8.91	0.32
Red meat	**1.69**	**1**	**1.73**	**3.25**	**3**	**2.57**	**3.56**	**3**	**3.43**	**<0.01**
Fried potato	**0.88**	**0.5**	**1.17**	**1.08**	**1**	**0.92**	**1.44**	**1**	**1.60**	**0.03**
Fruits & vegetables (non-pot.)	28.33	25.75	11.74	25.28	22.5	10.89	23.24	24.5	12.14	0.30
Whole grains	8.44	7.5	5.82	6.50	4.5	5.33	7.56	7	5.73	0.41
Limited-service restaurant	**1.14**	**1**	**1.04**	**1.47**	**1**	**1.15**	**2.12**	**2**	**2.04**	**0.01**
Full-service restaurant	1.25	1	1.07	1.45	1	1.01	1.21	1	0.96	0.29
Convenience store	0.55	0	1.45	0.86	0	1.67	0.44	0	0.75	0.41
Small grocery	**0.54**	**0.25**	**0.93**	**1.02**	**0.5**	**1.67**	**1.06**	**0.625**	**1.41**	**<0.01**
Supermarket	2.12	2	1.39	2.20	1.5	2.12	2.76	2.5	1.82	0.21

Table 4.3. Comparison of neighborhood- and DPA-based food environment measures (n=101)

	Neighborhood-based	Activity-based			
		Mean	Median	SD	Range
Area (sq. mi.)	2.79	12.75	11.85	7.56	1.53 – 34.20
Convenience stores	7	24.51	23	12.35	6 – 57
Limited-service restaurants	20	117.87	109	53.44	11 – 256
Full-service restaurants	8	84.99	85	35.98	1 – 183
Small groceries	7	12.50	13	5.54	2 – 29
Supermarkets	0	5.19	5	3.53	0 – 14
Convenience store density	2.51	2.11	2.03	0.54	1.14 – 4.57
Limited-service density	7.17	10.62	9.97	3.95	3.55 – 23.05
Full-service density	2.87	7.78	7.25	3.16	0.65 – 18.75
Small grocery density	2.51	1.22	1.01	0.71	0.31 – 4.54
Supermarket density	0.00	3.95	4.07	1.53	0.00 – 7.14
RFEI	18.00	13.81	13.22	3.90	6.83 – 29.00
Convenience store proportion	41.17	53.74	53.52	7.95	33.33 – 71.43
Limited-service proportion	71.43	58.04	57.85	5.02	47.80 – 91.67
Full-service proportion	28.57	41.96	42.15	5.02	8.33 – 52.20
Small grocery proportion	41.17	28.89	27.88	8.63	12.90 – 57.69
Supermarket proportion	0.00	10.61	11.11	2.87	0.00 – 12.50

Note: All differences between neighborhood- and DPA-based food environment measures were highly significant ($p<0.01$) using the Wilcoxon signed-rank test

Table 4.4. Spearman rank correlation coefficients for DPA-based food environment measures (n=101)

	DPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.
Conv. store density	**-0.59**	1.00									
p-value	**<0.01**										
Lim.-serv. density	**-0.59**	**0.58**	1.00								
p-value	**<0.01**	**<0.01**									
Full-serv. density	**-0.60**	**0.40**	**0.91**	1.00							
p-value	**<0.01**	**<0.01**	**<0.01**								
Small groc. density	**-0.58**	**0.49**	**0.61**	**0.63**	1.00						
p-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**							
Supermkt. density	0.13	0.07	-0.06	-0.14	**-0.21**	1.00					
p-value	0.19	0.46	0.56	0.16	**0.03**						
RFEI	-0.09	**0.34**	0.16	0.03	0.02	**-0.54**	1.00				
p-value	0.35	**<0.01**	0.11	0.73	0.86	**<0.01**					
Conv. store prop.	**0.37**	0.08	**-0.40**	**-0.53**	**-0.74**	0.05	**0.42**	1.00			
p-value	**<0.01**	0.43	**<0.01**	**<0.01**	**<0.01**	0.61	**<0.01**				
Lim.-serv. prop.	0.06	**0.43**	0.00	**-0.38**	-0.11	**0.20**	**0.25**	**0.38**	1.00		
p-value	0.55	**<0.01**	0.97	**<0.01**	0.27	**0.05**	**0.01**	**<0.01**			
Full-serv. prop.	-0.06	**-0.43**	0.00	**0.38**	0.11	-0.20	**-0.25**	**-0.38**	**-1.00**	1.00	
p-value	0.55	**<0.01**	0.97	**<0.01**	0.27	0.05	**0.01**	**<0.01**	**<0.01**		
Small groc. prop.	**-0.42**	0.15	**0.37**	**0.44**	**0.87**	**-0.36**	-0.03	**-0.86**	**-0.22**	**0.22**	1.00
p-value	**<0.01**	0.14	**<0.01**	**<0.01**	**<0.01**	**<0.01**	0.80	**<0.01**	**0.02**	**0.02**	
Supermarket prop.	**0.55**	**-0.45**	**-0.46**	**-0.47**	**-0.64**	**0.77**	**-0.53**	**0.29**	0.04	-0.04	**-0.64**
p-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	0.67	0.67	**<0.01**

Table 4.5. Personal characteristics by median DPA-based food environment measures (n=101)

	DPA size	Conv. store density	Limited -service density	Full-service density	Small grocery density	Super-market density
Gender						
Female	11.88	2.02	9.42	6.66	1.01	3.74
Male	11.48	2.15	10.89	8.08	1.00	4.09
Age group						
18-34	11.13	**2.26†**	**12.09†**	**8.50†**	**1.18***	4.09
35-54	10.23	**1.96**	**9.82**	**7.32**	**1.03**	3.84
55+	13.55	**1.87**	**8.30**	**6.17**	**0.88**	4.34
Race/ethnicity						
White, non-Hispanic	11.9	2.03	12.08	7.24	1.01	3.74
All others	8.03	2.12	9.92	9.09	1.01	4.08
Household income[a]						
<$50k/yr	11.85	**2.13†**	**11.13***	7.98	**1.07†**	4.14
$50k-100k/yr	11.13	**2.08**	**9.86**	6.66	**1.08**	4.05
$100k+/yr	15.78	**1.64**	**8.57**	6.83	**0.82**	4.09
Education						
No Bachelor's degree	**14.18†**	1.89	**8.21†**	**6.16†**	0.98	4.09
Bachelor's degree	**12.65**	2.14	**9.48**	**7.25**	0.97	3.83
Graduate degree	**9.61**	2.03	**10.70**	**8.51**	1.07	4.16
Employment						
Full-time	11.85	2.00	9.77	7.11	1.05	4.04
Part-time	11.88	2.10	11.40	8.43	0.95	4.15
Not employed	12.58	1.94	10.73	7.45	1.38	4.55
Marital status						
Now or previously married	12.74	**1.96†**	**9.26†**	**6.81†**	**0.96**	4.05
Never married	9.62	**2.46**	**12.56**	**8.49**	**1.41**	4.17
Weight status						
Underweight/Normal (BMI<25.0)	12.81	1.96	9.82	7.47	1.01	4.11
Overweight (25<=BMI<30)	10.27	2.23	11.28	8.08	1.00	4.37
Obese (BMI>=30.0)	10.74	2.08	9.00	6.33	1.09	3.32

[a]Two participants did not answer the household income question

* p<0.10

† p<0.05

Table 4.5, Personal characteristics by median DPA-based food environment measures (n=101), cont.

	RFEI	Conv. store prop.	Limited -service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Gender						
Female	13.14	53.85	57.33	42.67	27.88	10.26
Male	13.41	53.23	58.32	41.68	27.32	11.11
Age group						
18-34	13.18	53.85	57.94	42.06	28.17	11.29
35-54	13.07	52.97	57.36	42.64	29.15	10.21
55+	13.63	54.68	58.13	41.87	24.31	12.37
Race/ethnicity						
White, non-Hispanic	12.63	53.85	58.44	41.56	25.81	9.68
All others	13.24	53.50	57.78	42.22	28.03	11.11
Household income[a]						
<$50k/yr	13.22	52.46	57.97	42.03	28.17	10.42
$50k-100k/yr	13.75	55.56	57.98	42.02	29.41	10.71
$100k+/yr	11.29	53.85	57.09	42.91	25.71	12.86
Education						
No Bachelor's degree	13.38	55.83	**59.09†**	**40.91†**	26.70	12.18
Bachelor's degree	13.24	54.09	**57.66**	**42.34**	28.39	10.85
Graduate degree	13.14	52.63	**57.09**	**42.91**	28.95	11.11
Employment						
Full-time	13.27	53.49	57.85	42.15	**29.41†**	10.94
Part-time	13.16	55.54	57.22	42.78	**25.62**	11.58
Not employed	12.61	49.58	57.35	42.65	**33.43**	10.85
Marital status						
Now or previously married	**13.14***	53.85	**57.10†**	**42.90†**	**27.08***	11.11
Never married	**13.46**	51.76	**58.65**	**41.35**	**29.66**	10.55
Weight status						
Underweight/Normal (BMI<25.0)	**12.95***	57.21	57.21	42.79	27.68	11.31
Overweight (25<=BMI<30)	**13.67**	57.98	57.98	42.02	25.93	10.94
Obese (BMI>=30.0)	**14.60**	58.28	58.28	41.72	31.14	7.87

[a]Two participants did not answer the household income question
* p<0.10
† p<0.05

Table 4.6. Spearman rank correlation coefficients: DPA-based food environment measures, diet, purchasing outcomes (n=99)

	DPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Added sugar	0.14	0.03	-0.05	-0.12	-0.05	0.14	-0.03	0.10	**0.22**	**-0.22**	-0.10	0.13
p-value	0.16	0.79	0.62	0.23	0.61	0.17	0.79	0.32	**0.03**	**0.03**	0.32	0.20
Red meat	-0.07	0.12	-0.03	-0.09	0.03	0.03	0.02	0.05	0.09	-0.09	0.02	0.01
p-value	0.48	0.22	0.79	0.38	0.75	0.78	0.82	0.65	0.38	0.38	0.86	0.92
Fried potatoes	-0.08	0.08	0.06	0.00	0.06	-0.09	0.06	0.02	0.10	-0.10	0.01	-0.13
p-value	0.44	0.43	0.55	0.99	0.55	0.35	0.56	0.85	0.34	0.34	0.89	0.22
Fruits & vegs.	0.04	0.03	0.12	**0.21**	0.06	0.01	-0.03	-0.09	**-0.19**	**0.19**	0.05	-0.02
p-value	0.72	0.78	0.25	**0.04**	0.57	0.91	0.77	0.37	**0.06**	**0.06**	0.63	0.84
Whole grains	-0.02	0.01	0.15	0.16	0.11	**0.18**	**-0.25**	**-0.22**	0.02	-0.02	0.06	0.02
p-value	0.87	0.92	0.13	0.11	0.27	**0.07**	**0.01**	**0.03**	0.83	0.83	0.56	0.81
Conv. stores	0.13	**-0.17**	-0.08	-0.10	-0.03	0.02	**-0.18**	-0.07	0.01	-0.01	0.01	0.12
p-value	0.20	**0.08**	0.43	0.31	0.76	0.85	**0.07**	0.47	0.90	0.90	0.90	0.24
Limited-service	0.06	0.04	0.01	0.00	-0.05	-0.01	-0.02	0.07	0.03	-0.03	-0.07	-0.01
p-value	0.57	0.72	0.93	0.97	0.62	0.92	0.85	0.49	0.76	0.76	0.51	0.92
Full-service	0.11	-0.03	0.03	0.00	0.00	-0.02	-0.03	-0.01	0.08	-0.08	0.04	0.01
p-value	0.27	0.73	0.79	1.00	0.97	0.86	0.79	0.94	0.42	0.42	0.72	0.95
Small groceries	-0.04	0.10	**0.18**	0.14	**0.19**	-0.03	0.03	-0.15	0.09	-0.09	**0.19**	-0.07
p-value	0.71	0.33	**0.07**	0.17	**0.06**	0.79	0.77	0.14	0.37	0.37	**0.06**	0.49
Supermarkets	0.07	-0.08	-0.01	-0.04	-0.02	-0.10	0.12	0.00	0.07	-0.07	0.07	-0.05
p-value	0.47	0.44	0.89	0.68	0.85	0.31	0.24	1.00	0.48	0.48	0.49	0.63

Table 4.7. Adjusted odds ratios and confidence intervals for weekly dietary intake, by DPA-based food environment measures (n=99)[a]

Odds ratios for high (4Q) dietary intake of:	DPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density
Added sugar (13.375+/wk)	2.66	0.83	**0.84**	**0.78**	0.43	1.04
Conf. Int.	0.85 – 8.35	0.32 – 2.16	**0.71 – 1.00**	**0.63 – 0.98**	0.15 – 1.18	0.73 – 1.48
Red meat (3+/wk)	0.86	1.26	0.90	0.87	0.70	1.03
Conf. Int.	0.32 – 2.34	0.49 – 3.29	0.78 – 1.04	0.73 – 1.05	0.34 – 1.46	0.75 – 1.42
Fried potatoes (1+/wk)	1.85	0.38	0.93	1.00	0.76	0.91
Conf. Int.	0.58 – 5.97	0.12 – 1.20	0.79 – 1.08	0.83 – 1.21	0.34 – 1.71	0.62 – 1.32
Fruits & vegetables (32.625+/wk)	0.73	0.89	1.09	**1.19**	1.15	1.05
Conf. Int.	0.23 – 2.31	0.30 – 2.66	0.94 – 1.26	**0.99 – 1.45**	0.53 – 2.51	0.74 – 1.49
Whole grains (12.75+/wk)	0.61	0.99	**1.14**	1.12	1.62	1.24
Conf. Int.	0.21 – 1.81	0.35 – 2.79	**0.98 – 1.33**	0.93 – 1.35	0.76 – 3.44	0.86 – 1.78

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table 4.7. Adjusted odds ratios and confidence intervals for weekly dietary intake, by DPA-based food environment measures (n=99)[a], cont.

Odds ratios for high (4Q) dietary intake of:	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Added sugar (13.375+/wk)	0.93	**1.07**	1.06	0.94	**0.93**	1.09
Conf. Int.	0.80 – 1.08	**0.99 – 1.14**	0.94 – 1.19	0.84 – 1.06	**0.87 – 1.00**	0.96 – 1.24
Red meat (3+/wk)	1.05	1.04	1.03	0.97	0.98	1.02
Conf. Int.	0.94 – 1.18	0.98 – 1.10	0.93 – 1.14	0.87 – 1.08	0.92 – 1.03	0.91 – 1.14
Fried potatoes (1+/wk)	0.98	1.00	**0.86**	**1.17**	0.99	1.01
Conf. Int.	0.86 – 1.11	0.94 – 1.07	**0.76 – 0.96**	**1.04 – 1.31**	0.93 – 1.06	0.89 – 1.14
Fruits & vegetables (32.625+/wk)	**0.86**	0.95	**0.83**	**1.20**	1.02	0.97
Conf. Int.	**0.72 – 1.02**	0.89 – 1.02	**0.70 – 0.99**	**1.01 – 1.43**	0.96 – 1.09	0.86 – 1.10
Whole grains (12.75+/wk)	**0.83**	**0.92**	1.02	0.98	1.04	1.00
Conf. Int.	**0.70 – 1.00**	**0.86 – 0.99**	0.92 – 1.12	0.89 – 1.09	0.98 – 1.11	0.89 – 1.12

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table 4.8. Adjusted odds ratios and confidence intervals for weekly food purchases, by DPA-based food environment measures (n=99)[a]

Odds ratios for high (4Q) dietary intake of:	DPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density
Convenience stores (0.5+/wk)	1.78	**0.36**	0.93	0.98	1.02	0.87
Conf. Int.	0.54 – 5.82	**0.12 – 1.09**	0.79 – 1.09	0.81 – 1.19	0.48 – 2.18	0.62 – 1.24
Limited-service restaurants (2+/wk)	0.89	0.97	1.02	1.00	0.84	1.00
Conf. Int.	0.30 – 2.64	0.38 – 2.45	0.88 – 1.18	0.83 – 1.20	0.39 – 1.82	0.72 – 1.39
Full-service restaurants (2+/wk)	1.36	1.75	0.98	0.96	0.68	0.93
Conf. Int.	0.44 – 4.14	0.56 – 5.48	0.84 – 1.15	0.79 – 1.16	0.28 – 1.66	0.65 – 1.33
Small groceries (1+/wk)	2.12	0.71	**1.14**	**1.22**	**2.23**	0.82
Conf. Int.	0.68 – 6.63	0.26 – 1.90	**0.98 – 1.31**	**1.01 – 1.48**	**1.03 – 4.83**	0.57 – 1.17
Supermarkets (3+/wk)	2.01	0.46	0.94	0.93	0.76	0.83
Conf. Int.	0.68 – 5.90	0.17 – 1.30	0.81 – 1.08	0.77 – 1.11	0.34 – 1.71	0.60 – 1.16

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table 4.8. Adjusted odds ratios and confidence intervals for weekly food purchases, by DPA-based food environment measures (n=99)[a], cont.

Odds ratios for high (4Q) dietary intake of:	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Convenience stores (0.5+/wk)	0.90	0.96	0.93	1.08	1.04	0.99
Conf. Int.	0.77 – 1.05	0.89 – 1.02	0.83 – 1.03	0.97 – 1.20	0.97 – 1.10	0.88 – 1.12
Limited-service restaurants (2+/wk)	1.04	1.03	0.97	1.03	0.98	1.02
Conf. Int.	0.92 – 1.17	0.96 – 1.09	0.88 – 1.07	0.94 – 1.13	0.92 – 1.04	0.91 – 1.15
Full-service restaurants (2+/wk)	1.10	1.06	1.06	0.94	0.97	0.98
Conf. Int.	0.97 – 1.26	0.98 – 1.14	0.95 – 1.18	0.84 – 1.06	0.90 – 1.03	0.86 – 1.11
Small groceries (1+/wk)	0.96	**0.90**	0.93	1.08	**1.09**	0.90
Conf. Int.	0.83 – 1.10	**0.84 – 0.97**	0.83 – 1.04	0.96 – 1.21	**1.02 – 1.17**	0.79 – 1.03
Supermarkets (3+/wk)	0.96	0.99	0.96	1.04	1.02	0.98
Conf. Int.	0.84 – 1.11	0.93 – 1.06	0.87 – 1.06	0.94 – 1.15	0.96 – 1.08	0.88 – 1.10

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table 4.9. Adjusted odds ratios and confidence intervals for overweight and obesity, by DPA-based food environment measures (n=99)[a]

Odds ratios for high (4Q) dietary intake of:	DPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density
Overweight (BMI 25.0+)	0.59	1.97	0.98	1.00	1.55	0.88
Conf. Int.	0.21 – 1.62	0.71 – 5.46	0.86 – 1.12	0.85 – 1.18	0.74 – 3.23	0.64 – 1.20
Obese (BMI 30.0+)	1.03	0.84	0.86	0.93	1.55	**0.61**
Conf. Int.	0.24 – 4.36	0.26 – 2.67	0.67 – 1.11	0.71 – 1.22	0.56 – 4.31	**0.37 – 1.01**

Odds ratios for high (4Q) dietary intake of:	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Overweight (BMI 25.0+)	1.02	1.01	1.00	1.00	1.01	0.95
Conf. Int.	0.91 – 1.14	0.95 – 1.07	0.91 – 1.11	0.90 – 1.10	0.96 – 1.07	0.85 – 1.06
Obese (BMI 30.0+)	**1.18**	1.04	0.91	1.10	1.02	0.89
Conf. Int.	**1.00 – 1.38**	0.95 – 1.13	0.79 – 1.06	0.94 – 1.27	0.94 – 1.11	0.75 – 1.05

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table 4.10. Comparison of three-day and seven-day DPA-based food environment measures (n=13)

Measures	Three-day		Seven-day		
	Mean	Median	Mean	Median	P-value
Area (sq. mi.)	12.73	11.185	20.45	21.63	0.002
Convenience stores	24.42	23	35.15	37	0.003
Limited-service restaurants	118.01	109	169.85	170	0.002
Full-service restaurants	85.14	85	118.54	116	0.002
Small groceries	12.5	13	16	15	0.093
Supermarkets	5.19	5	7.92	8	0.007
Convenience store density	2.11	2.03	1.81	1.80	0.002
Limited-service density	10.63	9.97	9.25	9.09	0.007
Full-service density	7.79	7.25	6.42	6.51	0.019
Small grocery density	1.22	1.01	0.88	0.74	0.007
Supermarket density	3.95	4.08	3.89	3.70	0.807
RFEI	13.78	13.18	14.28	14.00	0.861
Convenience store proportion	37.09	36.51	38.52	38.80	0.311
Limited-service proportion	58.02	57.85	58.78	58.66	0.861
Full-service proportion	41.98	42.15	41.22	41.34	0.861
Small grocery proportion	20.34	20.00	18.16	20.00	0.055
Supermarket proportion	7.22	7.69	8.16	8.33	0.055

Figure 4.1a. Convenience store density

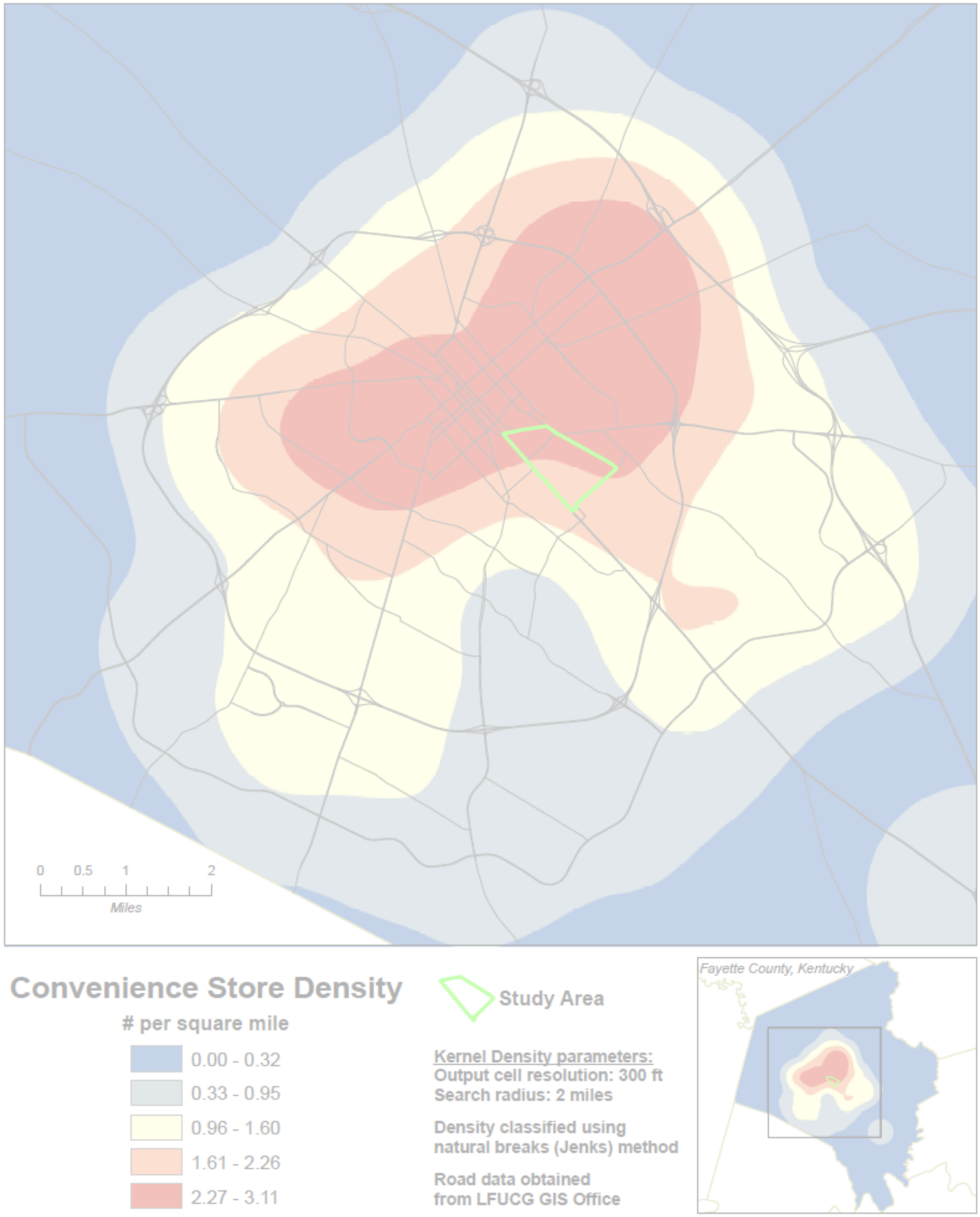


Figure 4.1b. Limited-service restaurant density

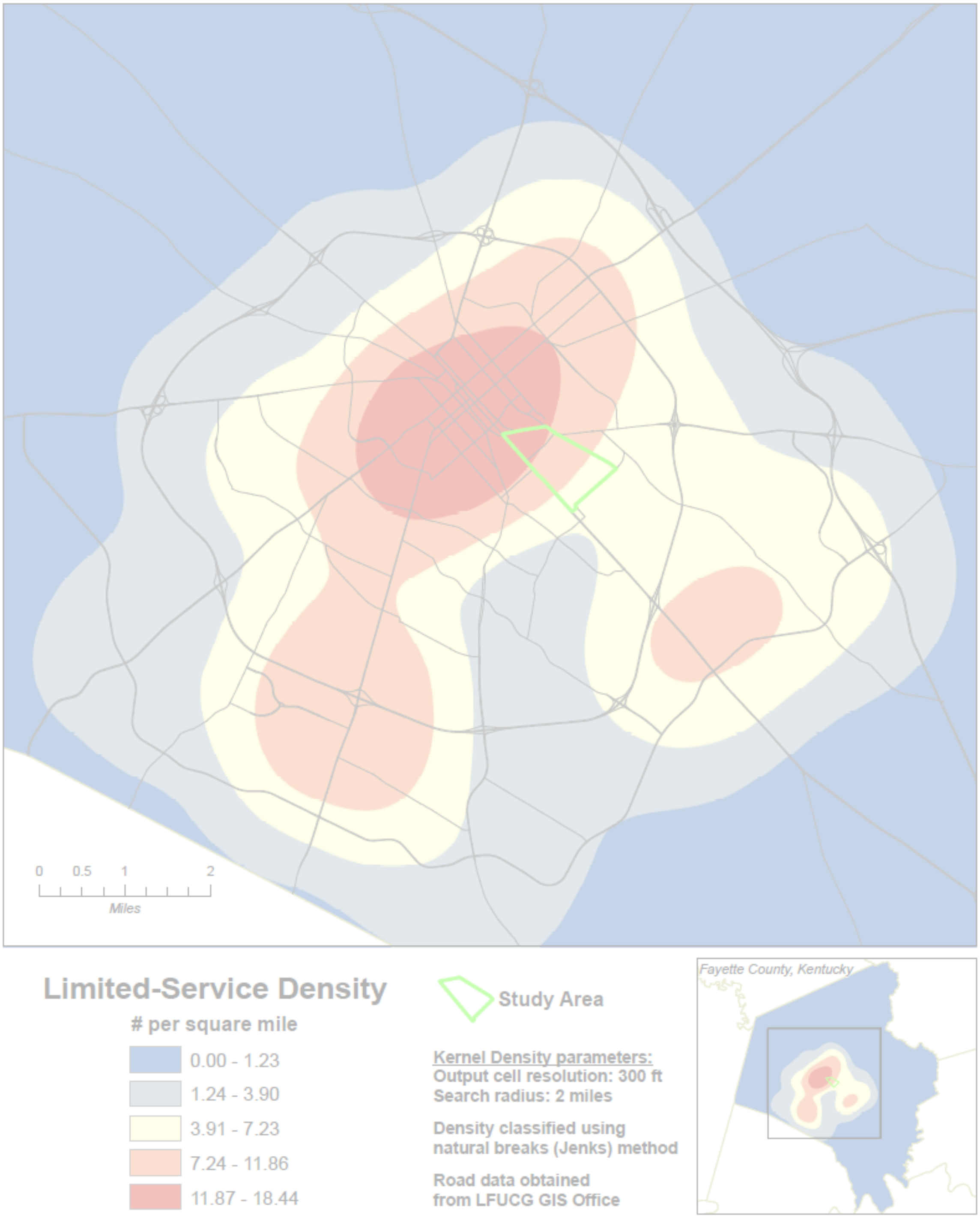


Figure 4.1c. Full-service restaurant density

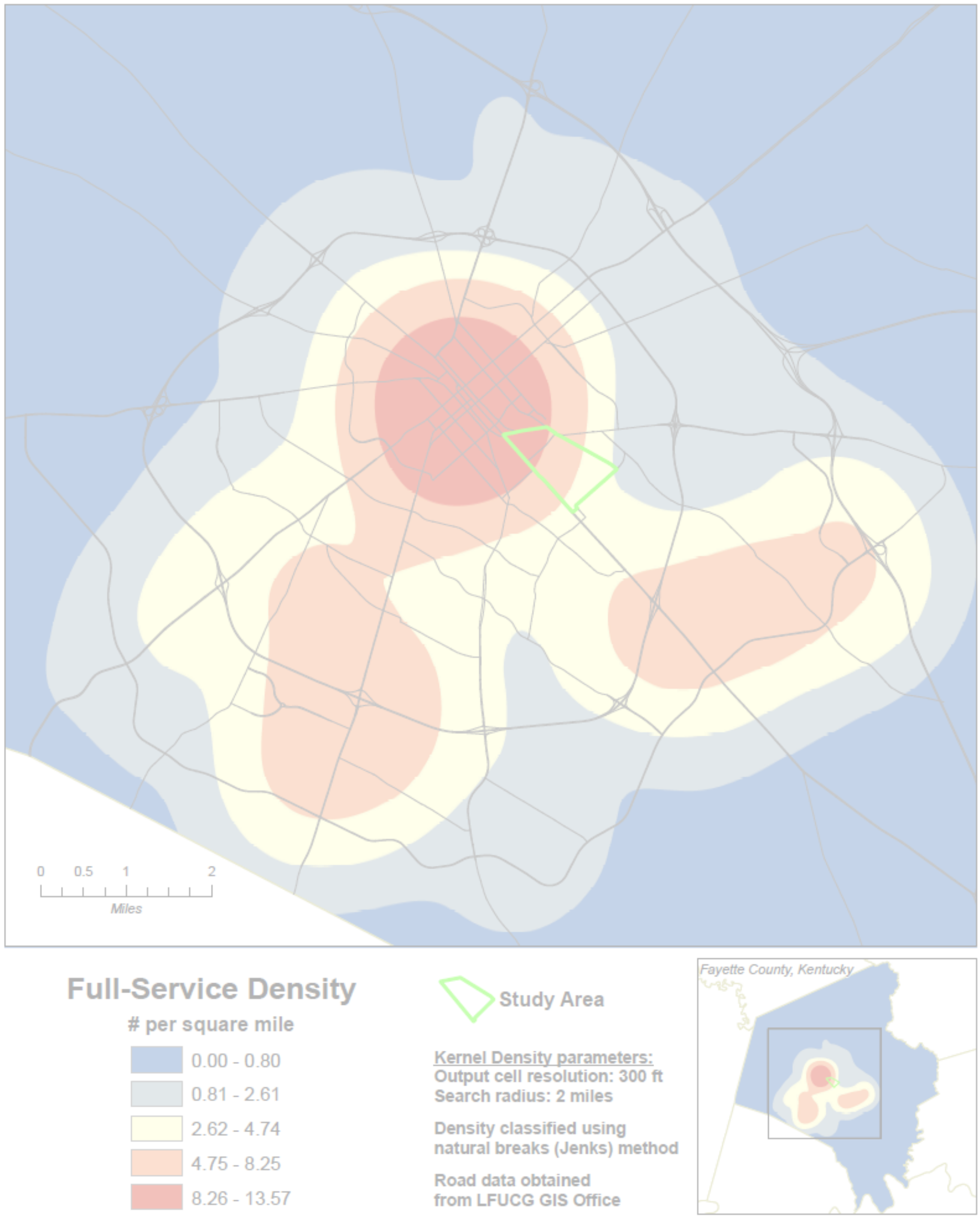


Figure 4.1d. Small grocery density

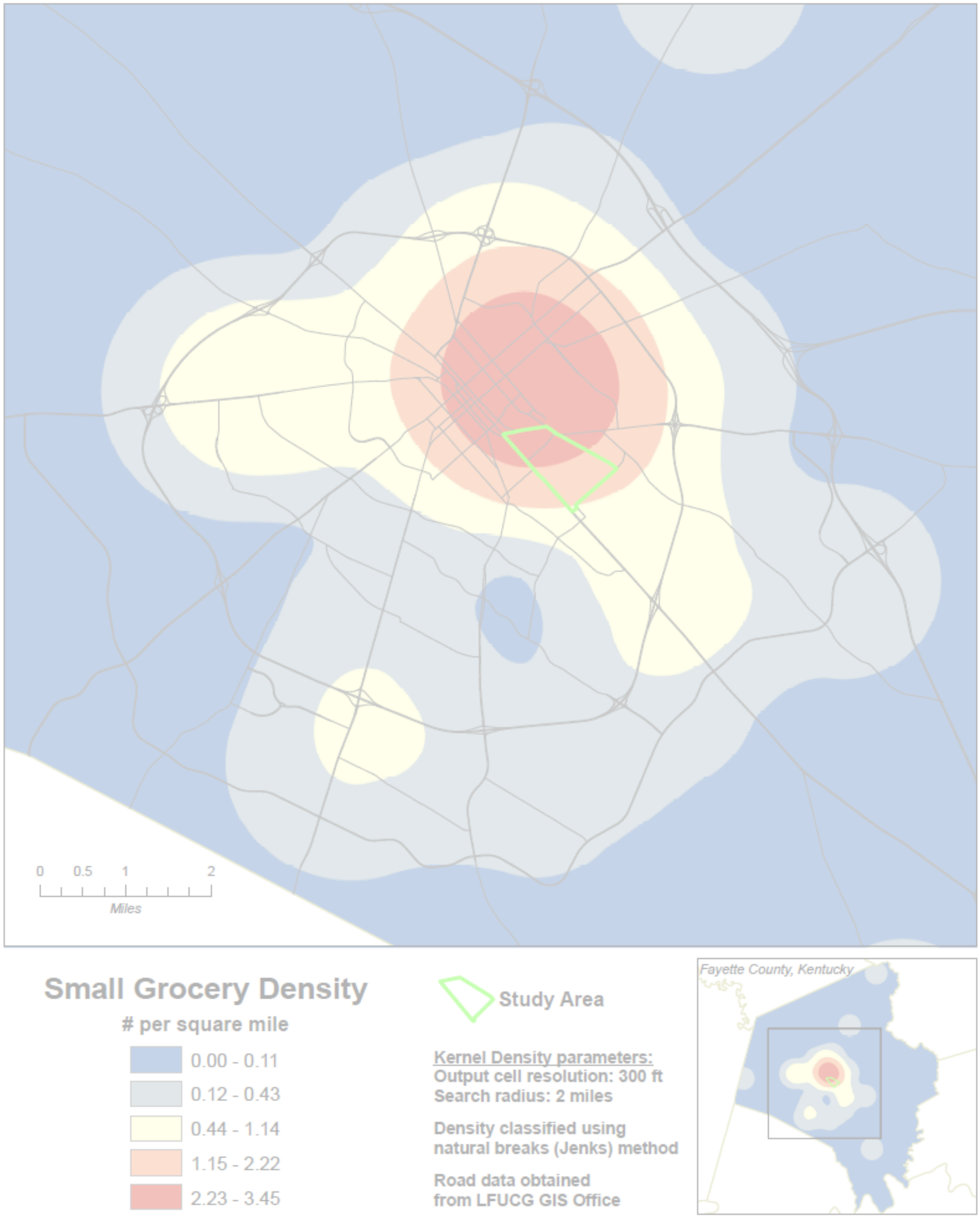


Figure 4.1e. Supermarket density

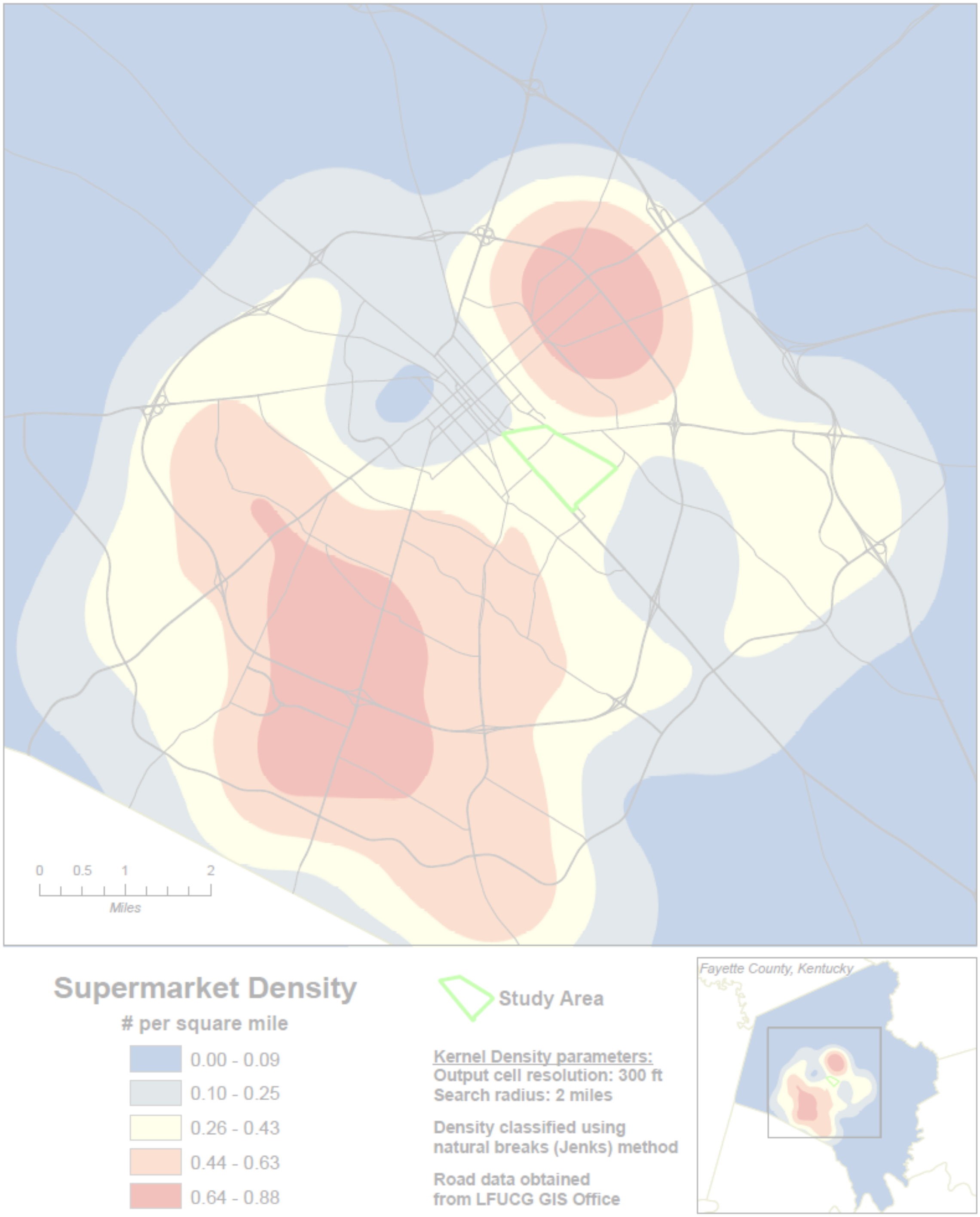


Figure 4.1f. Retail Food Environment Index surface

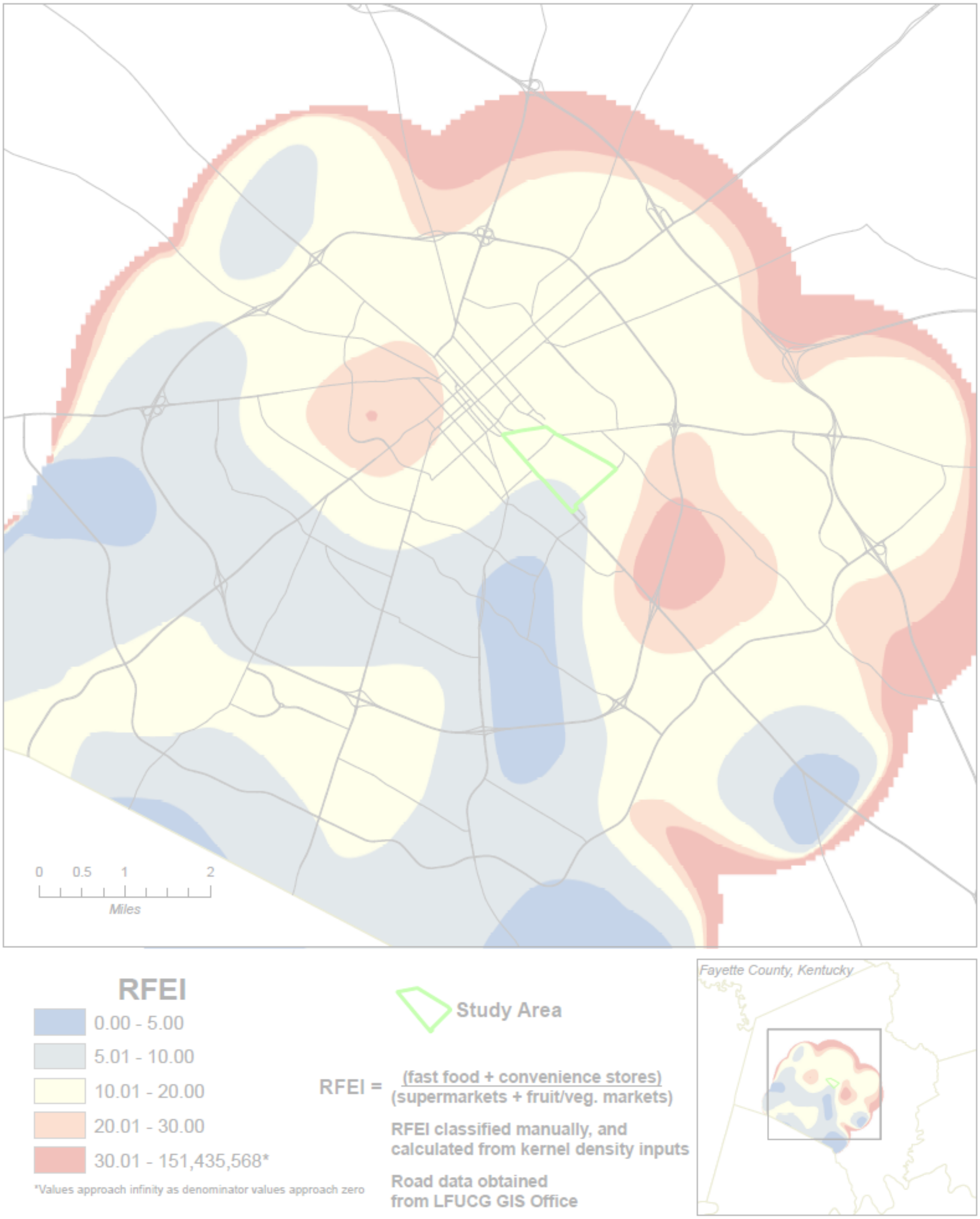


Figure 4.1g. Convenience store proportion surface

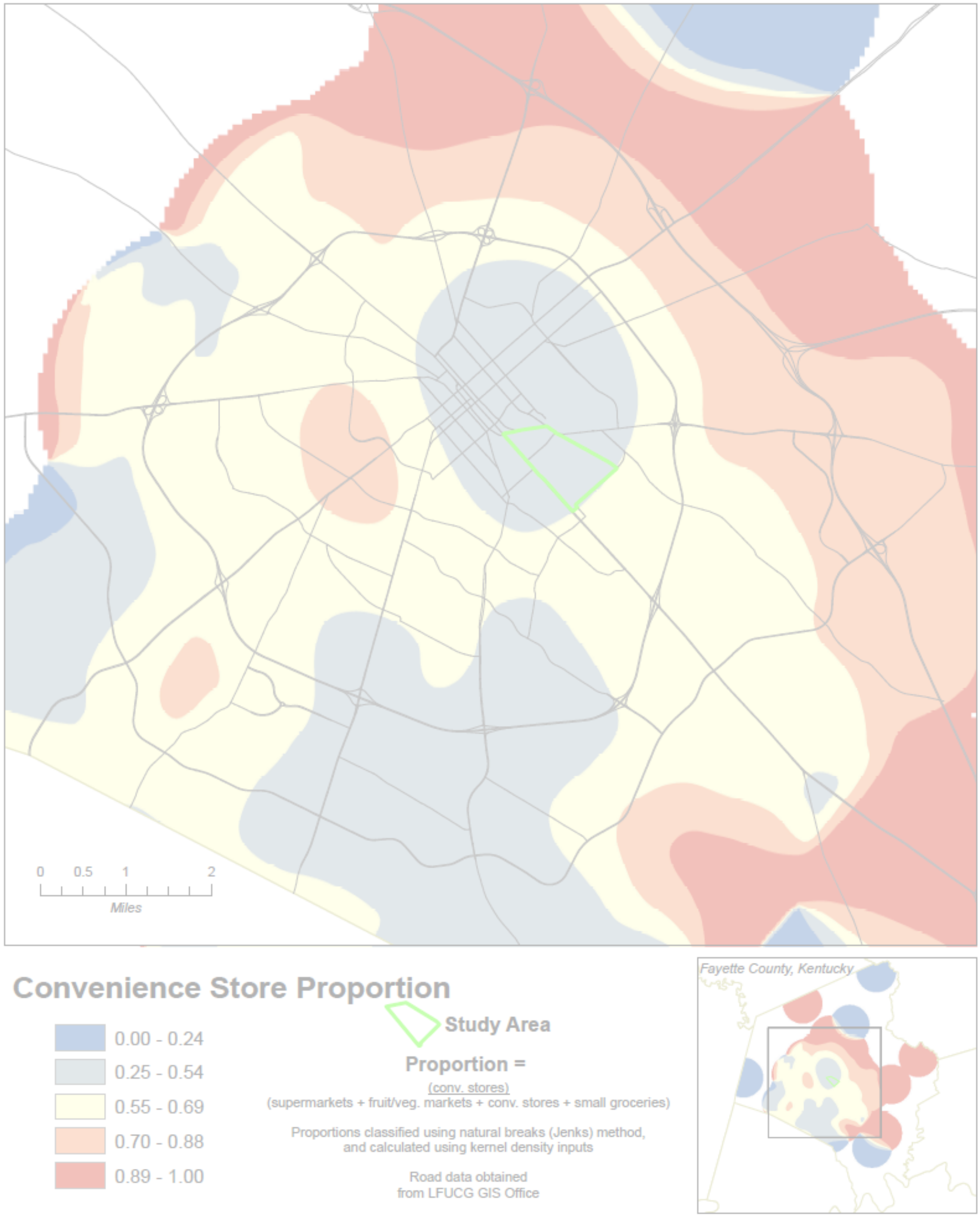


Figure 4.1h. Limited-service restaurant proportion surface

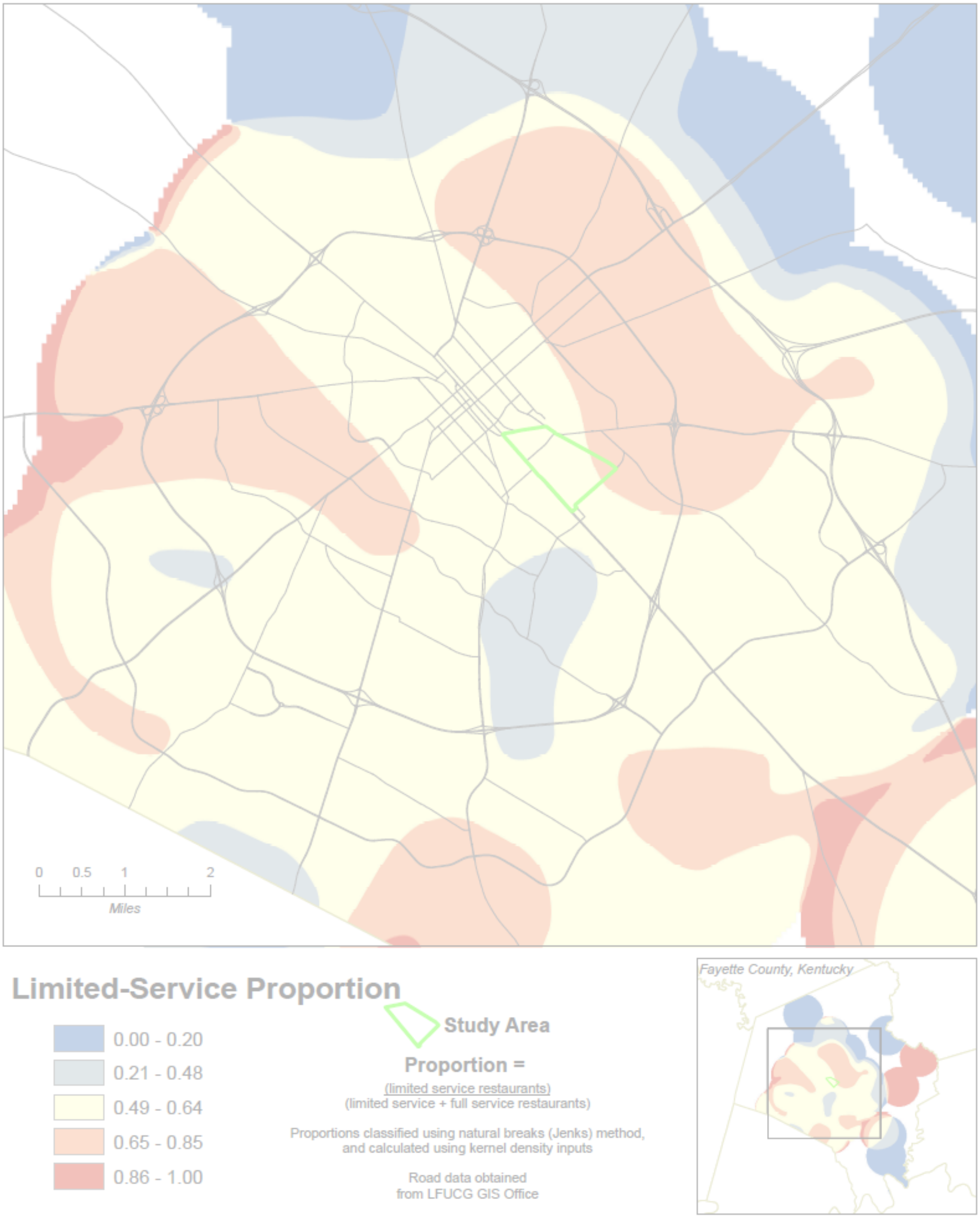


Figure 4.1i. Full-service restaurant proportion surface

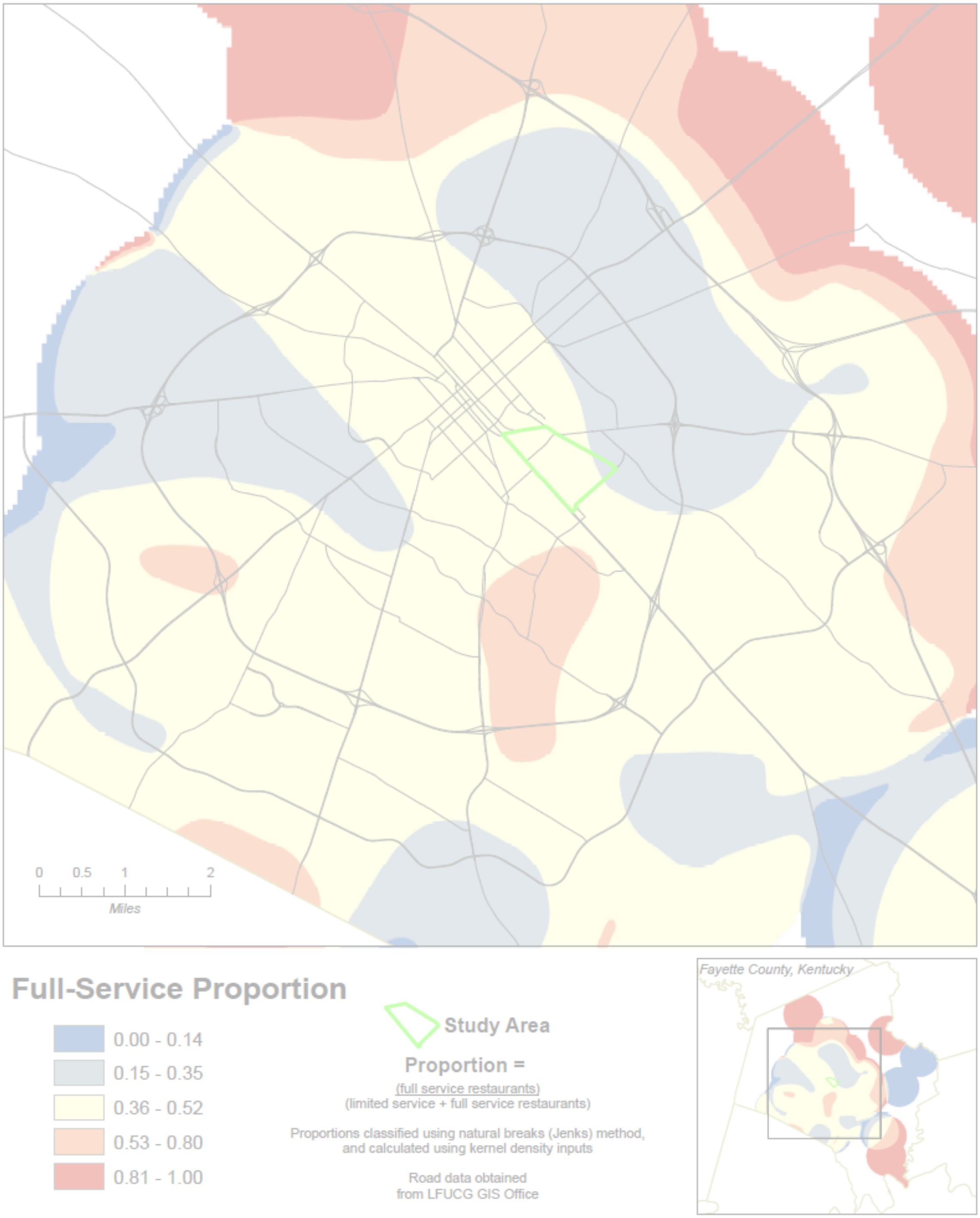


Figure 4.1j. Small grocery proportion surface

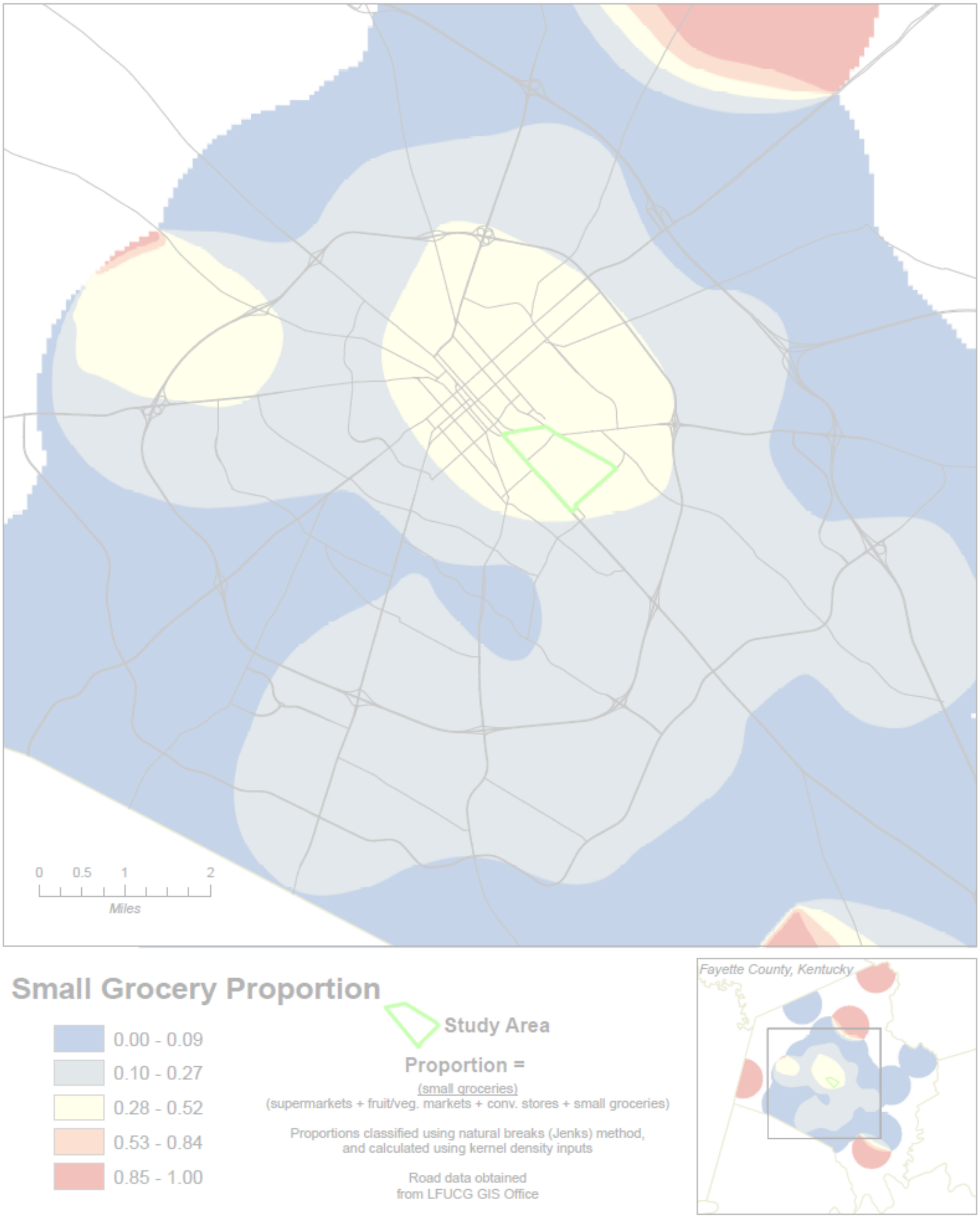


Figure 4.1k. Supermarket proportion surface

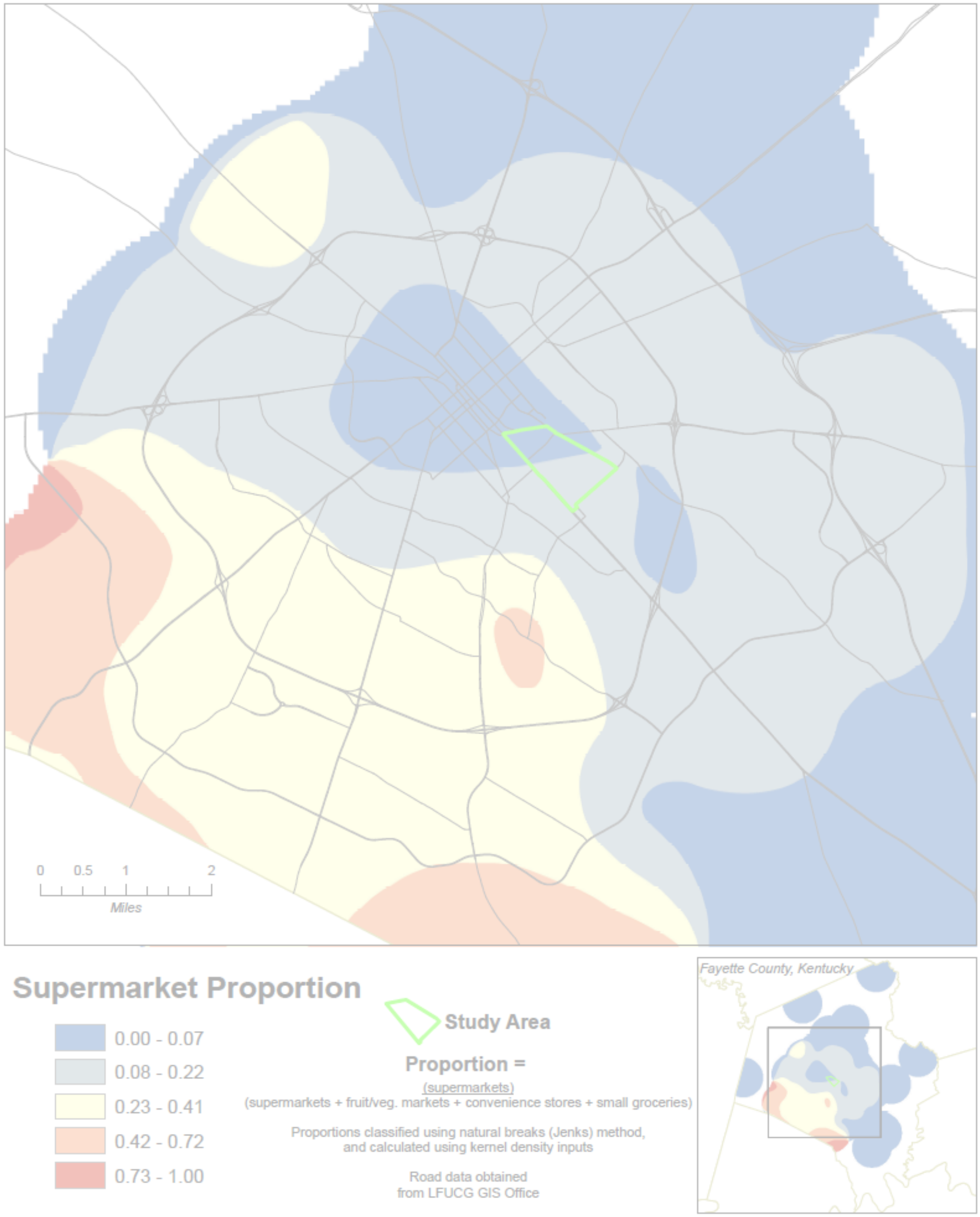


Figure 4.2. Kernel density maps of participants (orange) and all residential addresses (blue)

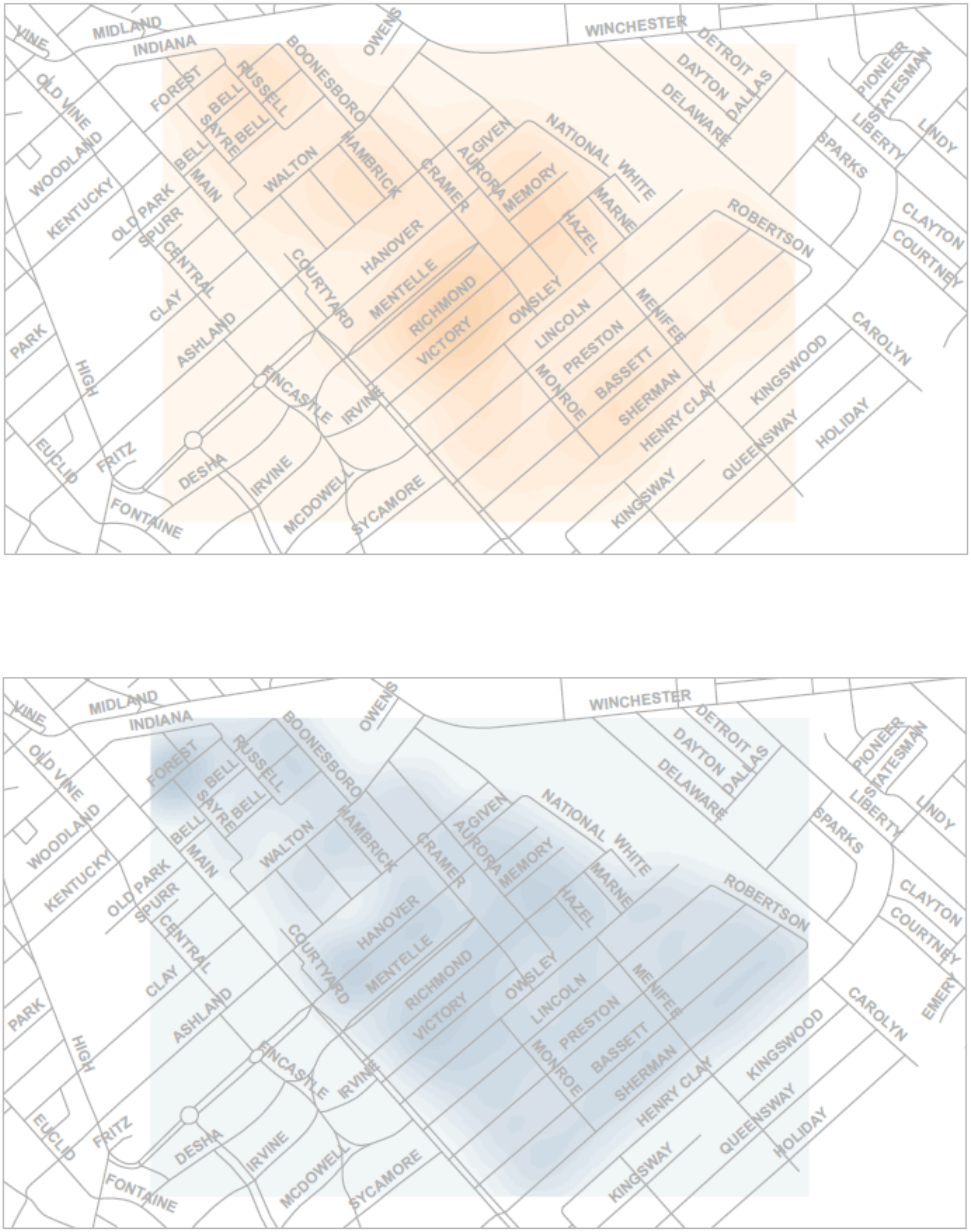


Figure 4.3a. Comparing three-day and seven-day DPAs

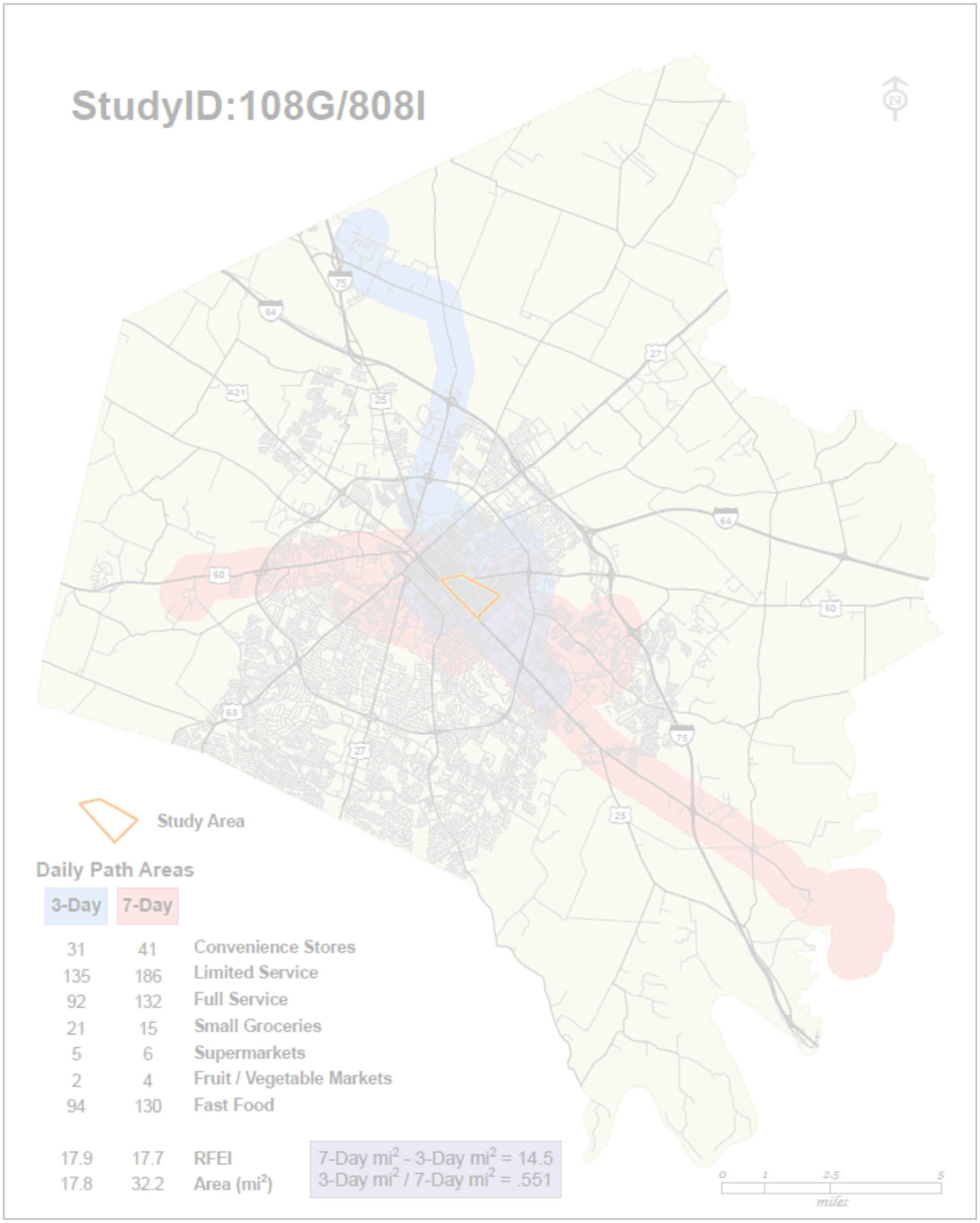


Figure 4.3b. Comparing three-day and seven-day DPAs

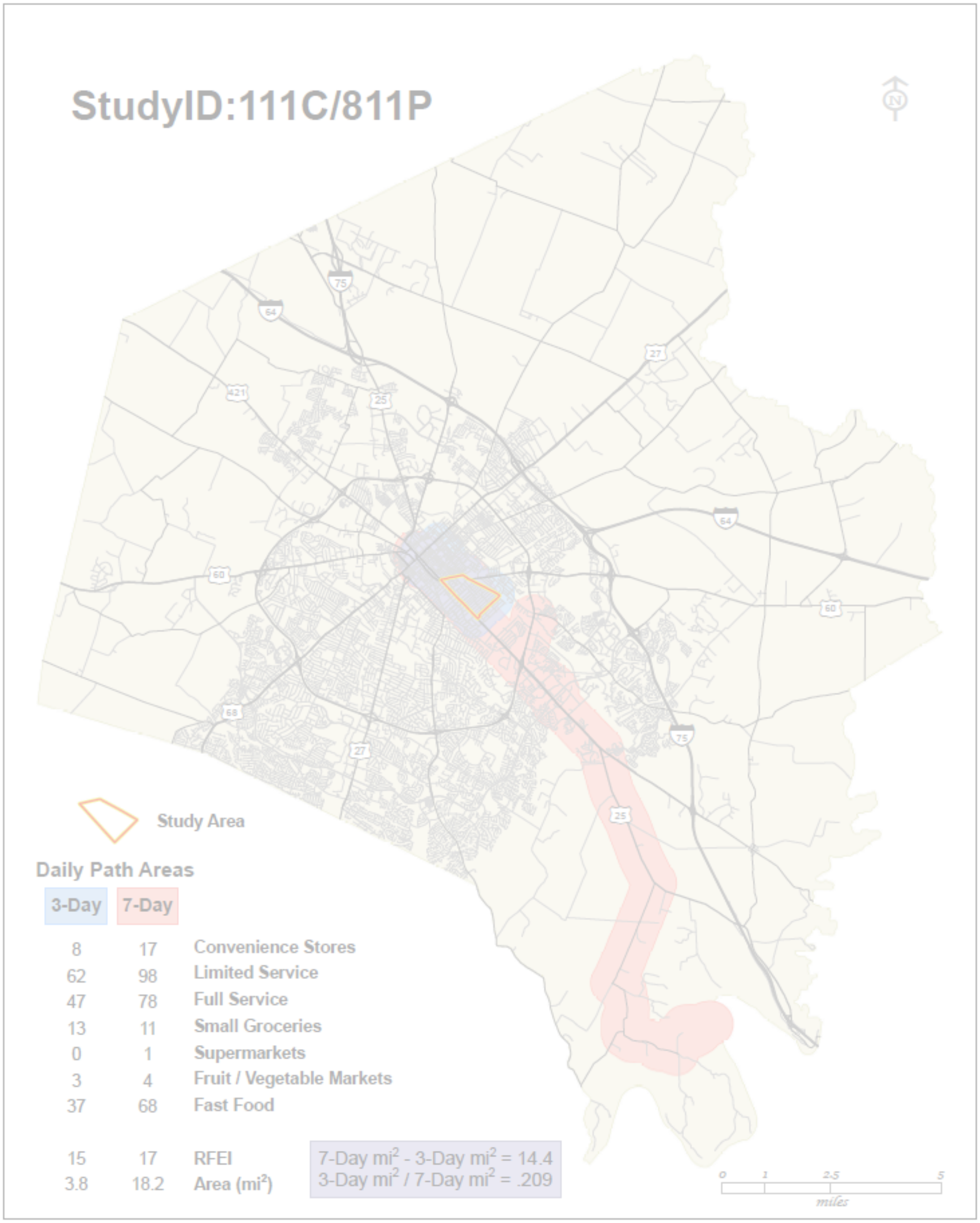


Figure 4.3c. Comparing three-day and seven-day DPAs

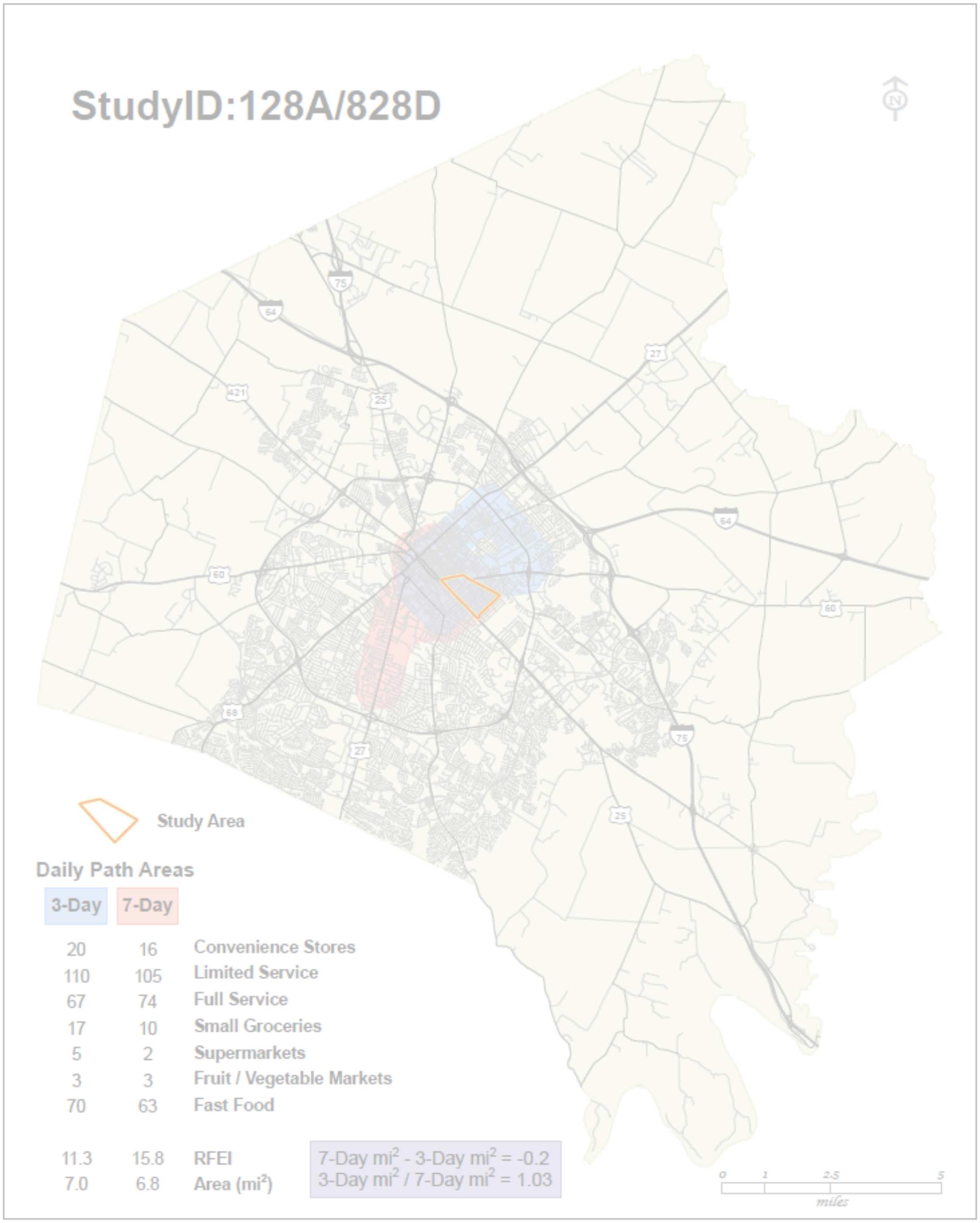


Figure 4.3d. Comparing three-day and seven-day DPAs

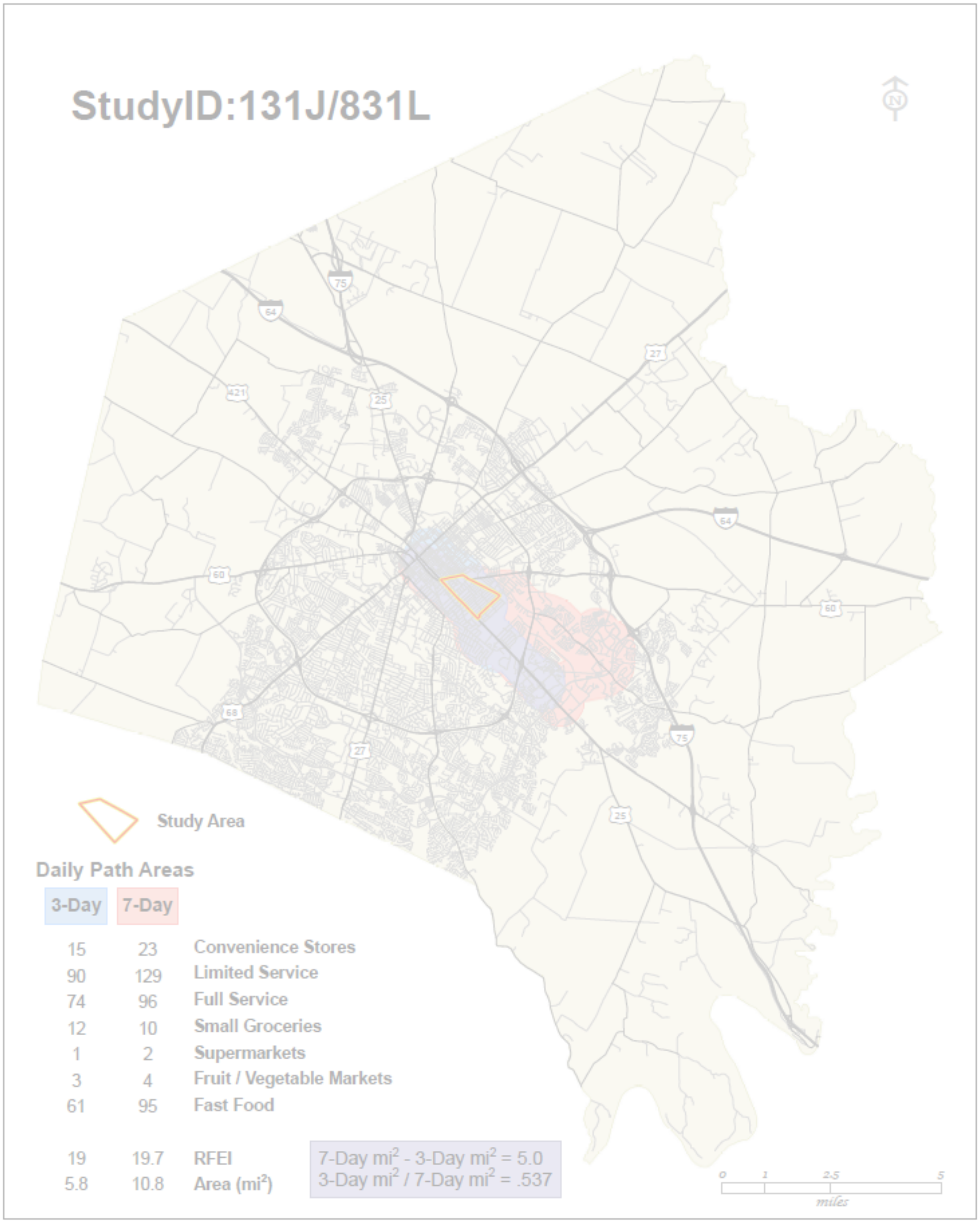


Figure 4.3e. Comparing three-day and seven-day DPAs

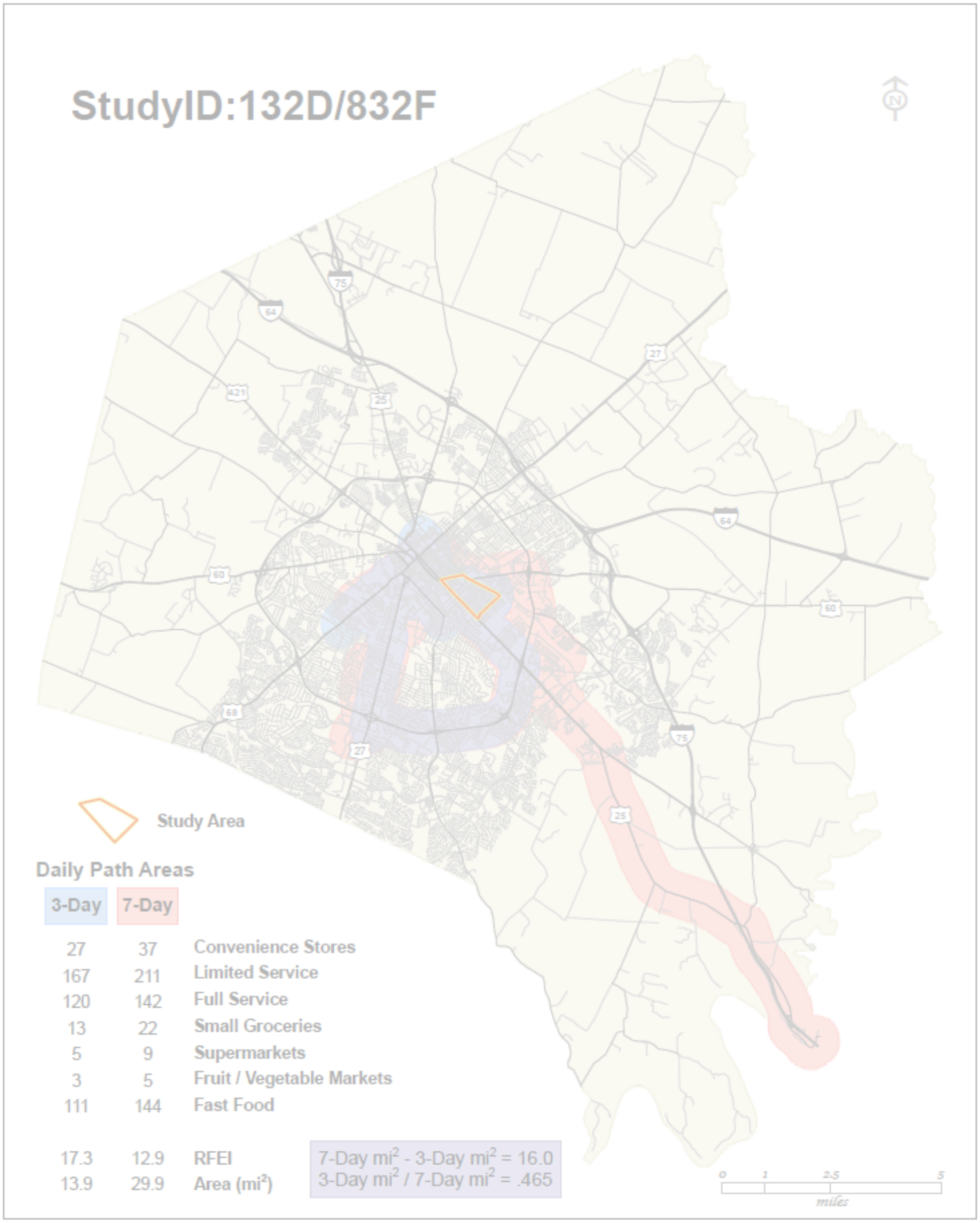


Figure 4.3f. Comparing three-day and seven-day DPAs

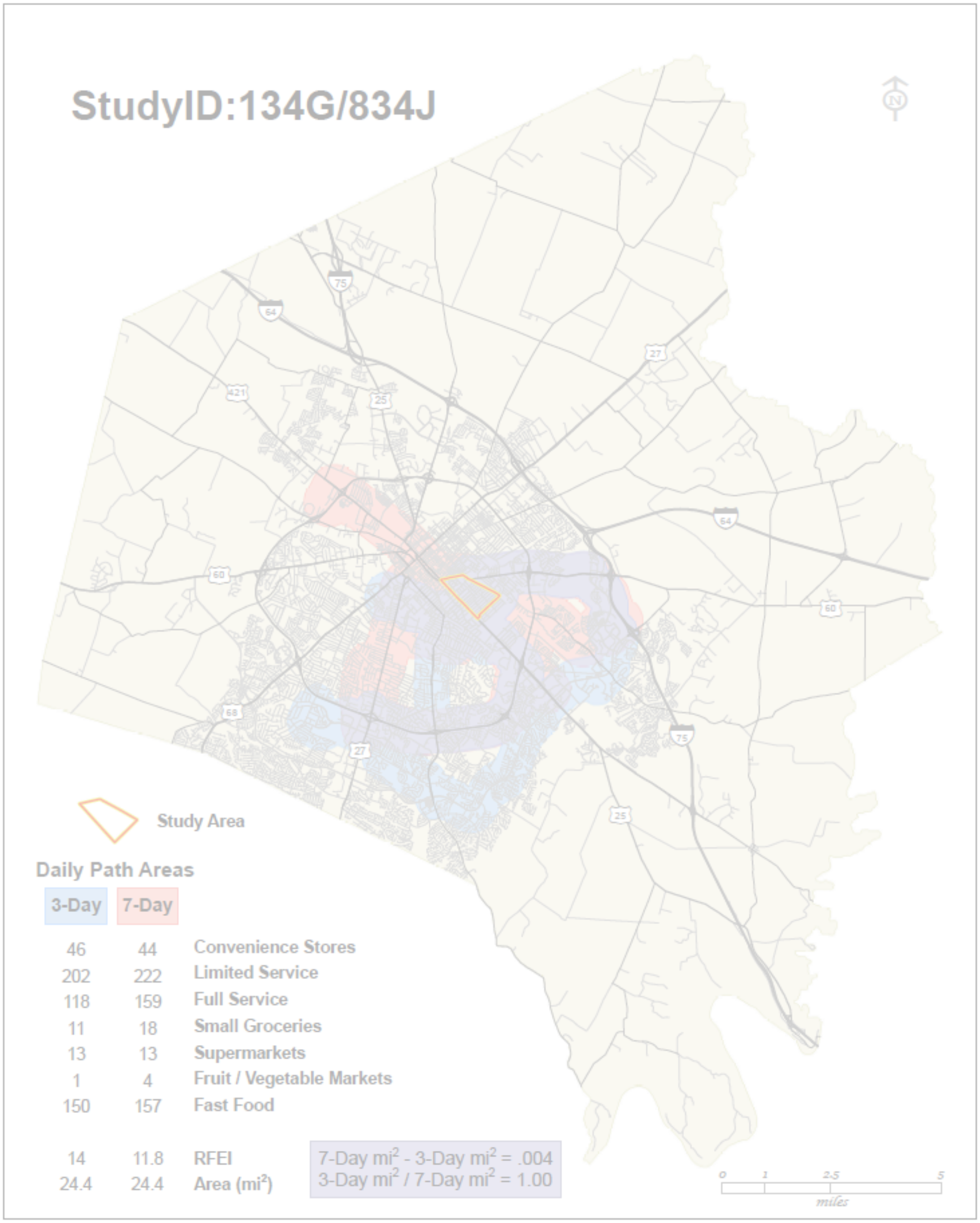


Figure 4.3g. Comparing three-day and seven-day DPAs

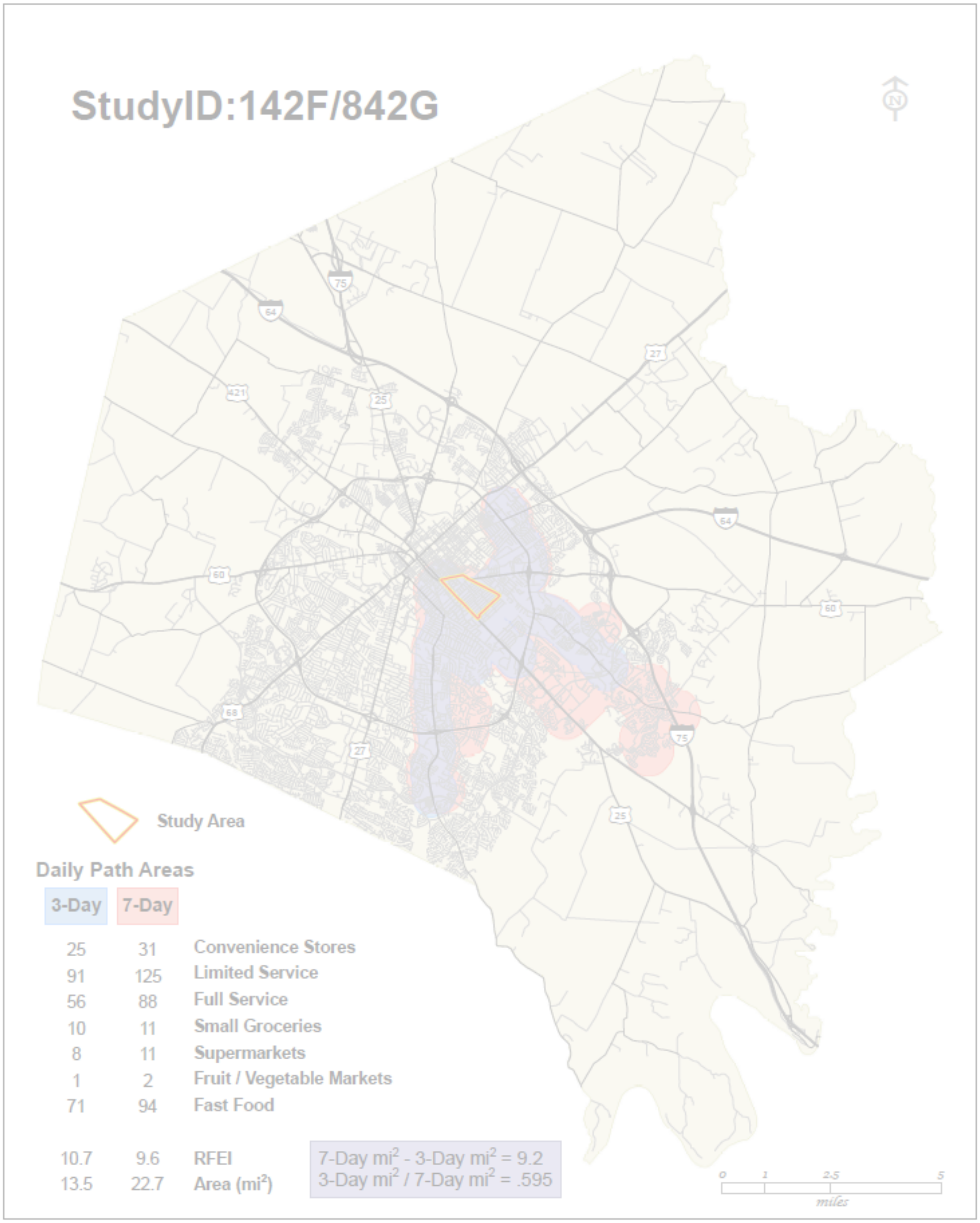


Figure 4.3h. Comparing three-day and seven-day DPAs

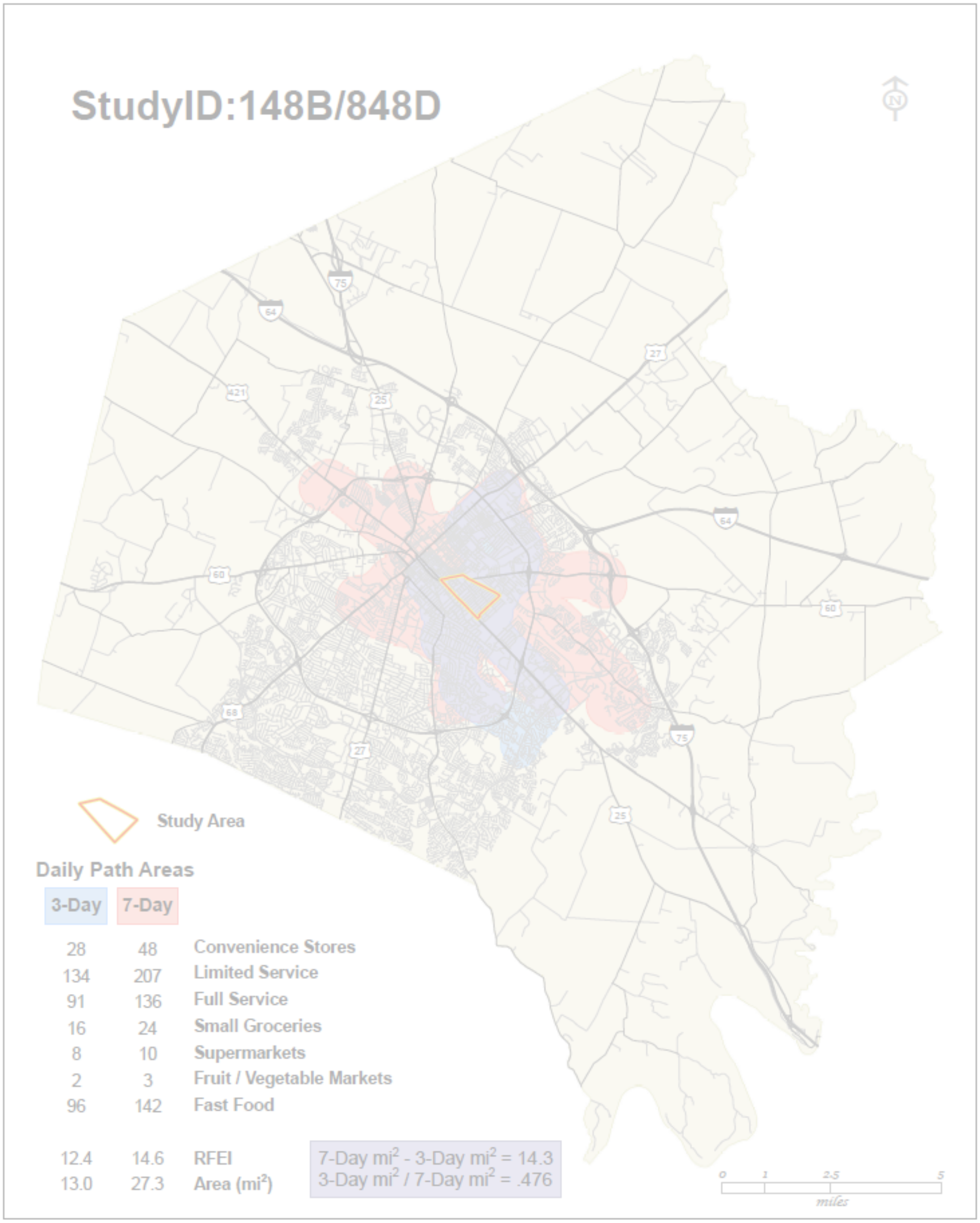


Figure 4.3i. Comparing three-day and seven-day DPAs

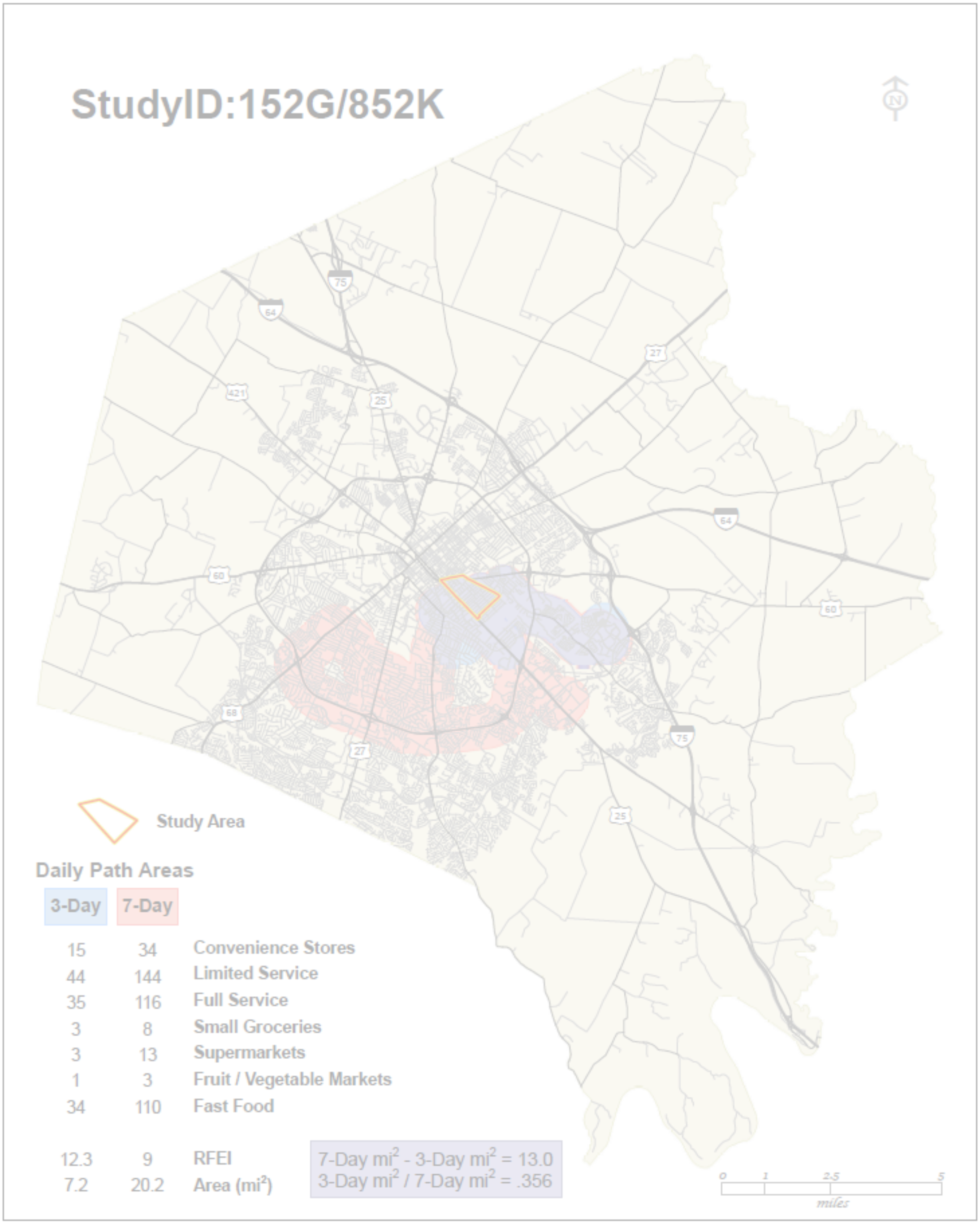


Figure 4.3j. Comparing three-day and seven-day DPAs

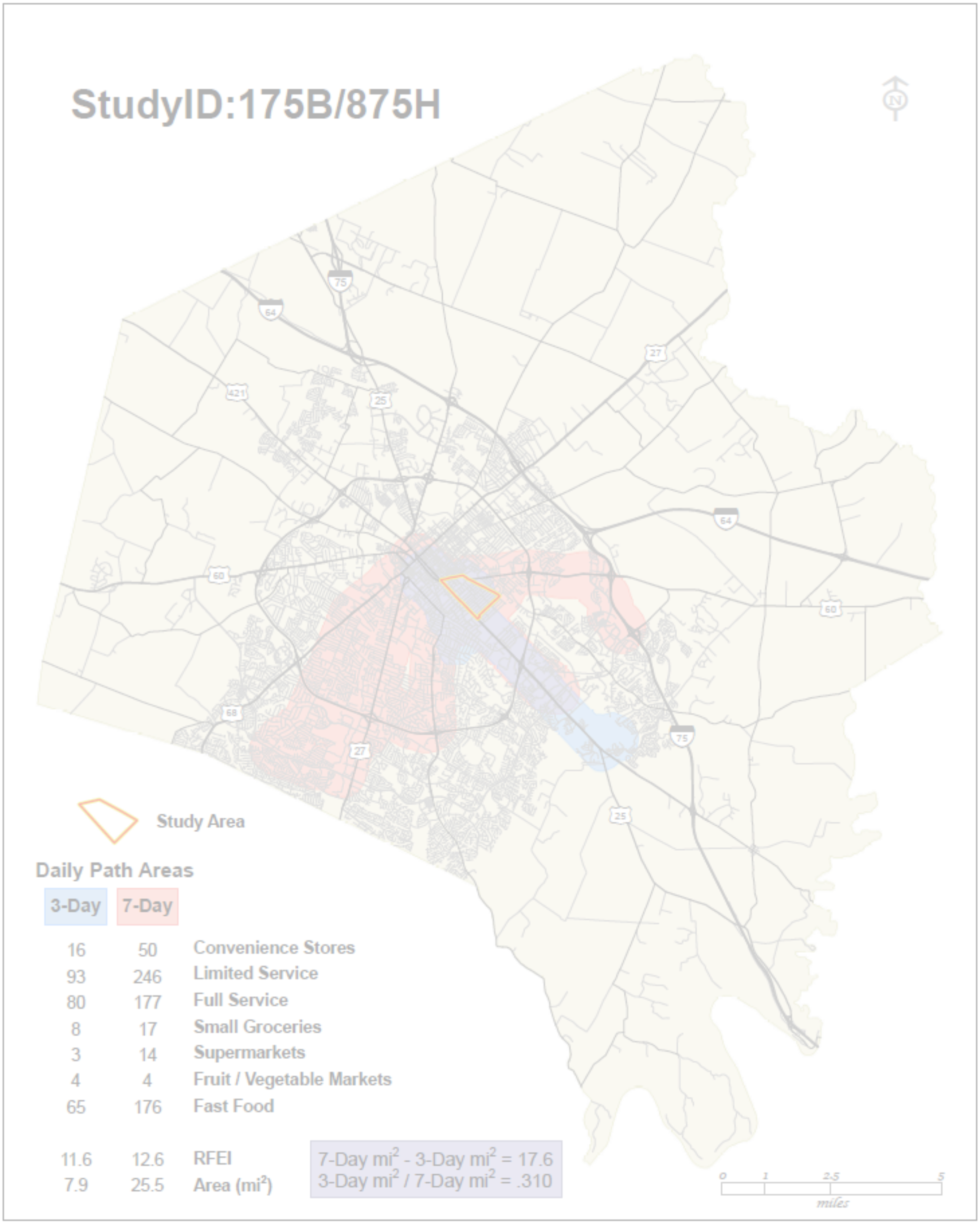


Figure 4.3k. Comparing three-day and seven-day DPAs

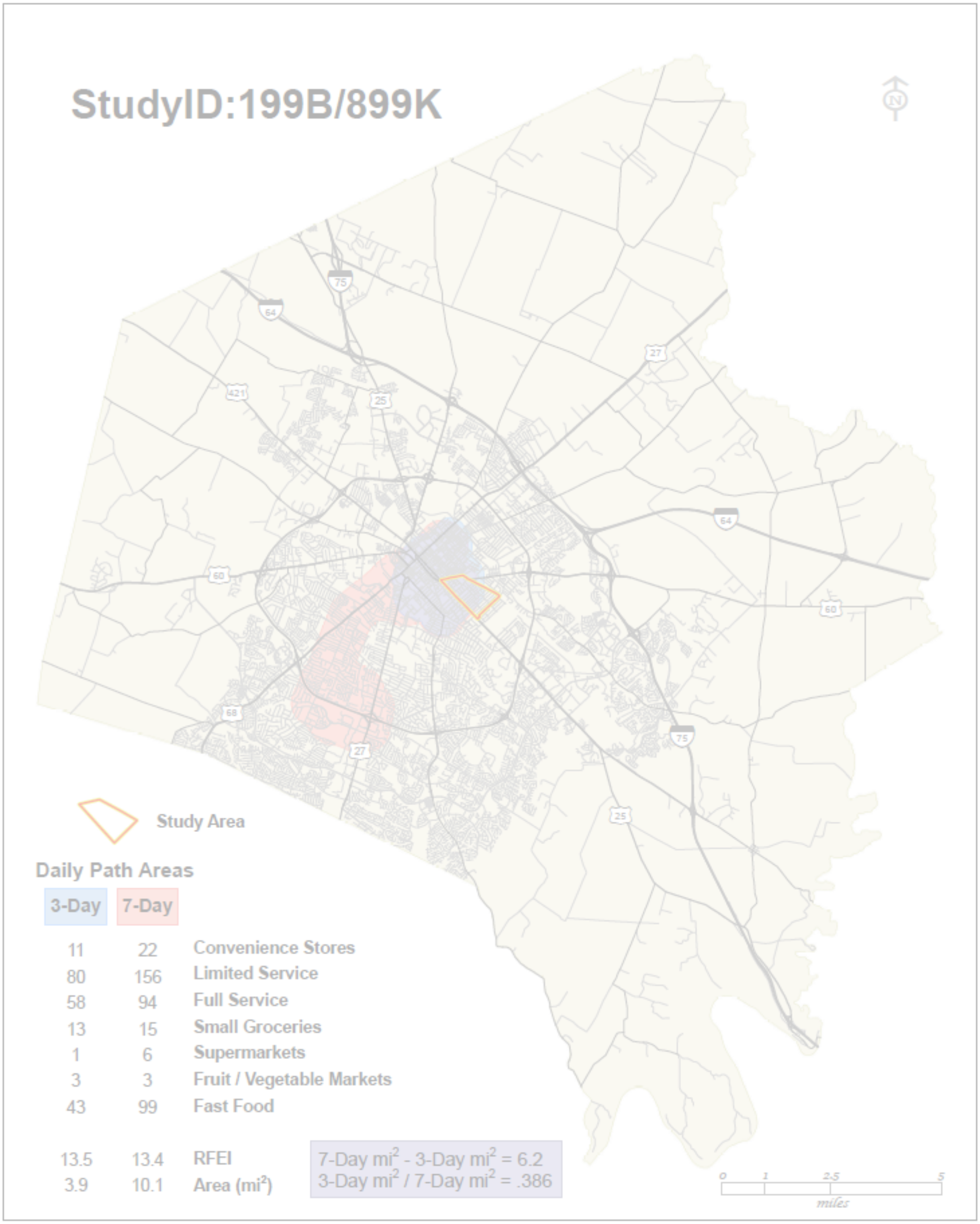


Figure 4.3l. Comparing three-day and seven-day DPAs

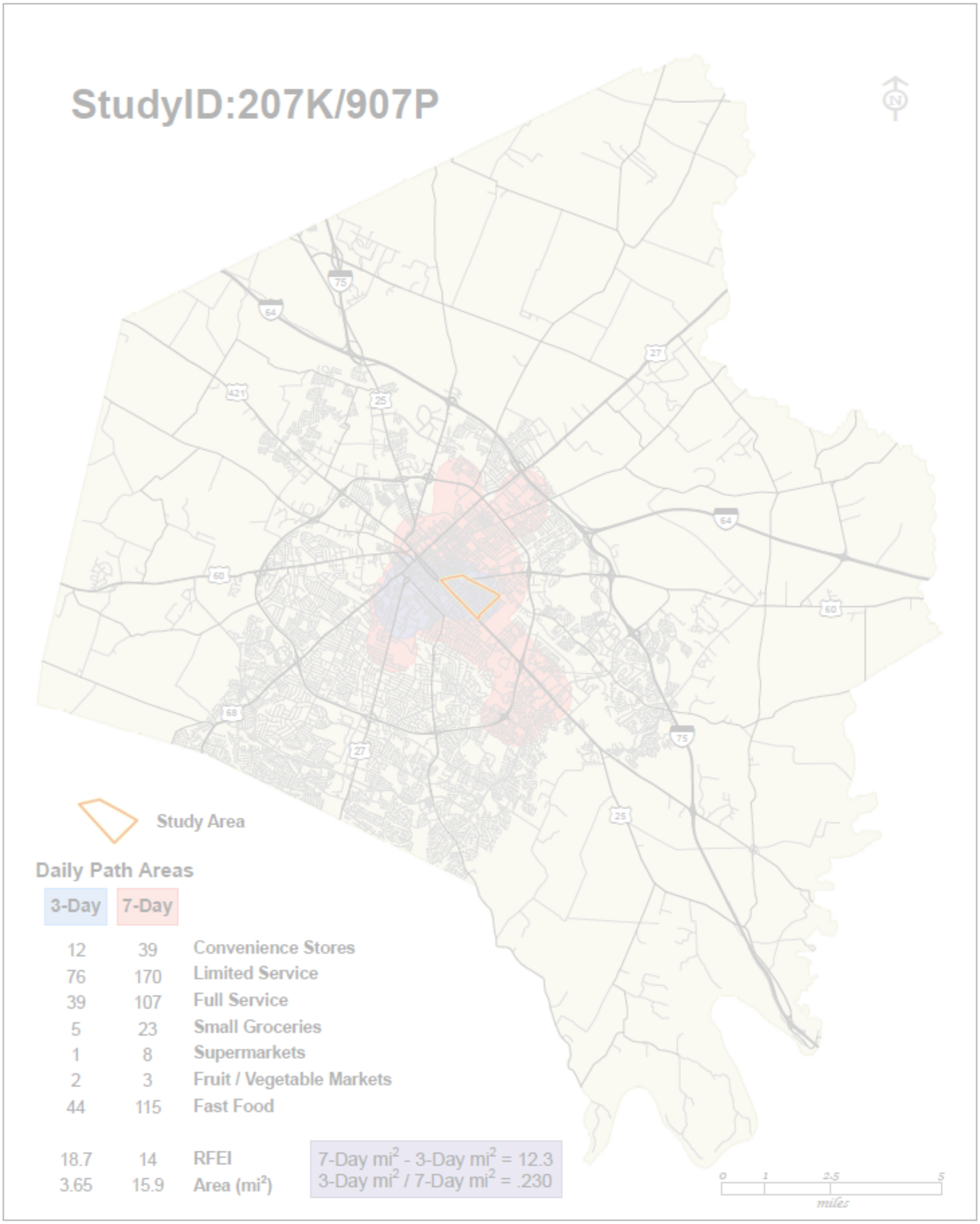
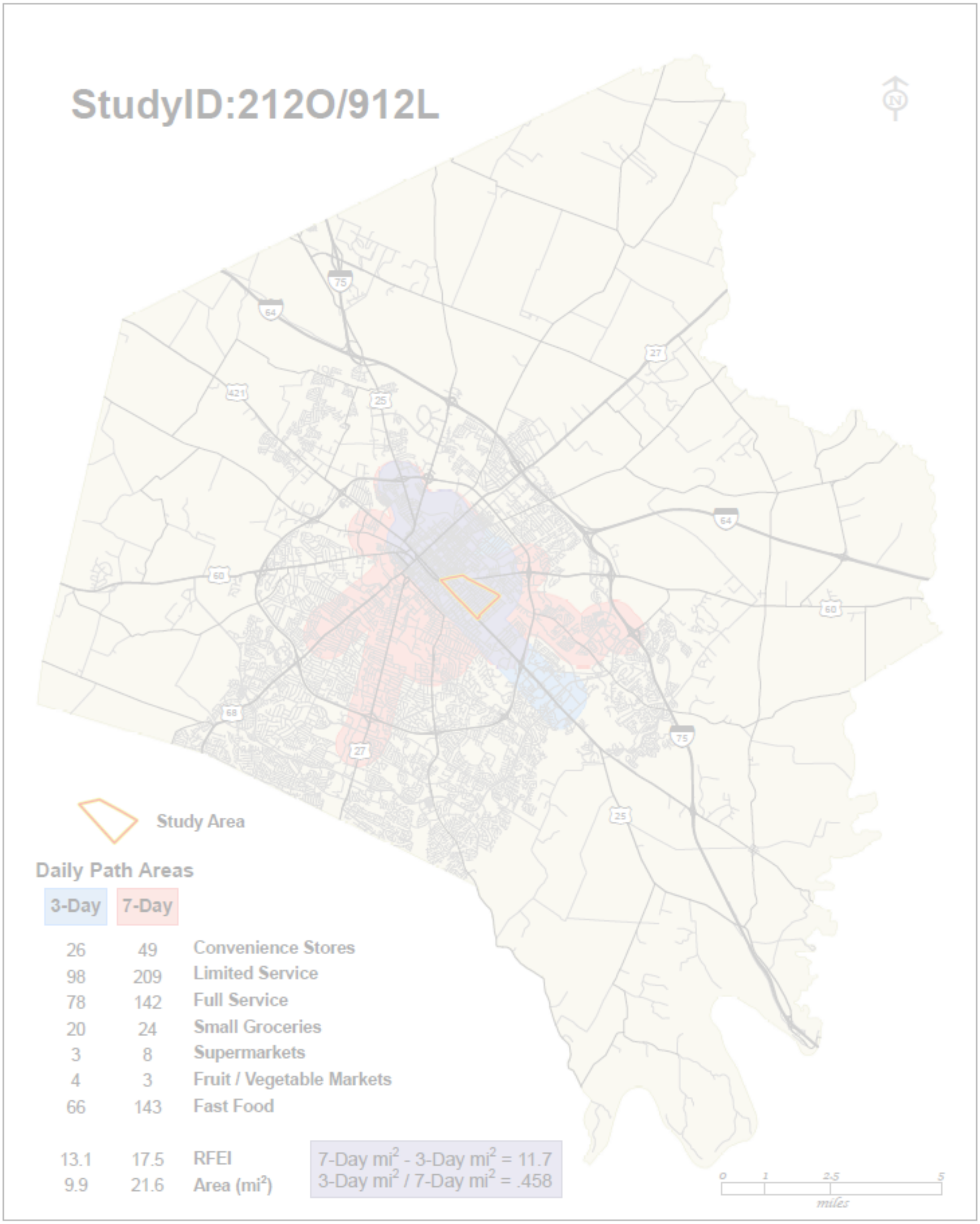


Figure 4.3m. Comparing three-day and seven-day DPAs



Chapter 5: Discussion

The techniques developed and demonstrated in this research have considerable potential for the analysis of retail food environments and their relationship to diets, food purchasing, and body weight. First, these techniques have demonstrated the potential for substantial misclassification bias in epidemiological assessments of retail food accessibility. This research has also revealed some intuitive relationships among new activity-based food accessibility measures, personal characteristics, and diet-related behaviors. Furthermore, this study has developed new techniques that respond to a recent call in the literature to conduct research that incorporates a relational understanding of interactions between human health and the environment. After further discussion of these conclusions, this chapter presents several limitations and challenges encountered in this research, as well as some notes on developing these techniques for further research.

Misclassification bias

The misclassification bias that results from using residence- or neighborhood-based measures of the retail food environment stems from inattention to the fact of daily mobility among urban residents. Analysis addressing Research Question 1 (How do individuals' activity-based measures of food accessibility compare to neighborhood-based measures?) demonstrated that participants' activity spaces contain many more food store and restaurant locations than are present in or near their neighborhood. Furthermore, the mean densities and relative proportions of locations were all significantly different than corresponding neighborhood values. (See Table 5.1, which shows selected results mentioned in this chapter.) These findings confirm that mobility is a key concept for accessibility assessment in epidemiologic studies of food environments, since they demonstrate everyday proximity to retail food locations far from the neighborhood among participants. Additionally, the misclassification is differential for many measures, since some participants would have higher activity-based values than the neighborhood, while others would have lower values. For most measures, the mean and median activity-based values were higher than the corresponding neighborhood-based values, yet the minimum for every activity-based measure was still lower than the neighborhood value (with the exception of supermarket measures, which were all zero for the neighborhood).

Other researchers have made similar observations regarding the need to look beyond neighborhoods and residences to better understand retail food accessibility (e.g., Zenk et al. 2011, Kestens et al. 2010, Papas et al. 2007, Jeffrey et al. 2006), but this research study was the first to directly compare the residence-based accessibility of several retail food types with the corresponding activity-based accessibility of individuals residing in a single neighborhood. The results demonstrate clearly that, at least with regard to spatial accessibility, individuals possess widely varying degrees of access to retail food types in both absolute and relative terms, despite sharing a neighborhood.

Activity-based measures and personal characteristics

This study is one of very few to have pursued alternatives based on the concept of activity space, along with Zenk et al. (2011) and Kestens et al. (2010), who also used density measures. Analyses that addressed Research Question 2 (How do these activity-based measures relate to individual characteristics, including weight?) produced results that were consistent with Kestens et al. (2010) with regard to food store types' densities, but there are no other activity-based studies that employed proportional measures or RFEI. Still, comparison with residence- or neighborhood-based studies using RFEI is still possible.

Density measures

Both this study and Kestens et al. (2010) show many of these activity-based density measures are correlated with each other, most likely because such establishments tend to cluster together. Frequent travel to full-service restaurants could thus result in high DPA-based limited-service density. Furthermore, both studies have noted that food location densities are highest among the youngest age groups. This trend was very clear for limited-service restaurants, for example. Taken together, the trends observed in these studies might reflect a tendency for younger age groups to live in high-density housing in or near commercial districts, and/or to travel to these areas for work, social gatherings, and other activities. Lexington's downtown has no supermarkets, but restaurants of all kinds proliferate, and both upscale and more modest small groceries offer some packaged foods and produce (see Figures 4.1b-d). It's likely that the younger participants in this study spent more time in this and/or similar areas, or were simply less likely to leave this area during the three-day GPS tracking period.

Since younger participants generally had lower incomes, this might also explain the similar trend observed in densities vis-à-vis income. Educational attainment, however, showed the opposite trend. Considering those with more education had smaller DPAs, it seems clear that participants with professional and doctoral degrees were likely to work downtown, or at one of the adjacent universities, and remain nearby for other activities.

Zenk et al. (2011) did not observe similar differences in food location density between age or income categories in their study, perhaps because their population from Detroit was very different than that investigated here. For example, in Zenk et al.'s (2011) study, 75% of participants were women, 55% were African-American, 55% did not have any education past high school, and 65% were unemployed. Most participants in this study were college graduates, the great majority was white, and about 70% were employed full-time. While Kestens et al. (2010) do not provide much detail on the social, economic, or ethnic composition of their participants, their study area (Montreal and Quebec City, Canada) and methods (online survey) suggest they could be more similar to those investigated here.

Overall, the findings of this study with regard to activity-based density measures and personal characteristics seem to indicate that the density of food environments tends to differ by demographic and socioeconomic factors. Further exploration of these issues could have important implications for those planning public health interventions that aim to improve access to nutritious foods, especially if specific groups are to be targeted.

Retail Food Environment Index

The RFEI scores in this research, especially the neighborhood-based RFEI, were somewhat higher than those reported in the research of Babey et al. (2008), who first employed this measure. They reported that the average California adult lived in an area with RFEI of 4.5; the mean DPA-based RFEI in this study was 13.8, and the neighborhood-based RFEI was 18.0. These differences are largely due to the types of stores included in the calculations. As mentioned in Chapter 3, Babey et al. (2008) excluded convenience stores at gasoline stations from the numerator, and possibly included a few stores considered "small groceries" here in the denominator, particularly if their annual revenue was greater than $1 million. These differences resulted in lower RFEI scores than those observed here. In another RFEI-based study, Jilcott et al. (2010) calculated the measure in two different ways: (1) as the sum of convenience stores, fast food restaurants, and small groceries, divided by supermarkets and produce stores; and (2) as fast food restaurants divided by supermarkets and produce stores. For the former, RFEI varied between 3.5 and 20.0 among 30 North Carolina counties; the latter RFEI definition yielded a range of 0.75 to 6.0. The RFEI for all of Lexington-Fayette County in this research was 12.16, which is more similar to the first RFEI results Jilcott et al. (2010) observed, despite their inclusion of small groceries in the numerator of the RFEI calculation.

The DPA-based RFEI measure used in this research did not vary significantly by any of the social, demographic, or economic characteristics of participants in bivariate analysis. Although it was not a significant difference, however, it is worth noting that the lowest median DPA-based RFEI score for any group was found among those with the highest household income. With a larger sample, some significant differences could likely be discerned, especially with regard to marital status and weight status. Differences by marital status were nearly significant, and there was a clear trend in RFEI among weight categories. Still, it is surprising that the RFEI should vary so little, given that it was more closely associated with obesity than any of the other measures.

Proportional measures

As with RFEI, it is clear that the proportional measures did not vary by participant characteristics as much as the density measures. Consider, for example, that none of the proportional measures were significantly or nearly significantly different among age, gender, or income groups. Furthermore, where statistically significant differences were noted, these were not substantial, and thus appeared unlikely to influence diet or food purchasing. The DPA-based limited-service restaurant proportion, for instance, was significantly different among educational groups, with the least educated (no college degree) having the lowest median proportion (57.09%), and the most educated (graduate or professional degree) having the highest (59.09%). But it is difficult to imagine such a small difference being perceptible to individuals or influencing their decision-making regarding diet and food purchasing. This is an intriguing finding, since it could suggest that there is actually very little difference in the retail food environments of various socioeconomic groups who reside in the same neighborhood, and individual differences are unlikely to be related to structural disparities in access. Few participants in this study, however, were black or Hispanic, living in poverty, or of low education, which are characteristics more commonly associated with poor access to food (e.g., Moore & Diez-Roux 2006, Zenk et al. 2005, Block et al. 2004). Like the RFEI, it is likely these proportional measures would vary more substantially given a more diverse sample of participants.

Activity-based measures and diet, food purchasing

Despite the differences with others' RFEI calculations, as well as the lack of significant relationships with social, demographic, or economic characteristics, the RFEI measure showed perhaps the greatest potential of any other activity-based measure in addressing Research Question 3 (Are activity-based measures associated with dietary behaviors and/or purchasing of certain types of foods?). After adjustment for covariates, DPA-based RFEI was significantly associated with high frequency of whole grain intake, and nearly significantly associated with high non-potato fruit and vegetable intake. Because DPA-based RFEI was found to be associated with these dietary intake outcomes, as well as obesity, it could be the best measure developed through this research with regard to dietary intake. Unfortunately, however, the RFEI cannot be directly compared to shopping habits at a single store or restaurant type, as with the density and proportional measures, since it is an index of several types. Thus, the RFEI cannot be used to directly examine all of the links between accessibility, purchasing, consumption, and weight status.

In examining the purchasing frequency outcomes, the small grocery accessibility measures also stand out for the relationships observed with high frequency of purchases. Both high density and high proportion of small groceries were significantly and positively associated with high purchasing frequency, suggesting that such establishments might indeed be ideal for interventions aiming to improve accessibility and consumption of healthful foods, as suggested by several previous studies recently reviewed by Gittelsohn et al. (2012). This was the only food location type for which purchasing was associated with both density- and proportion-based measures.

Although the proportional measures did not vary much by participant characteristics, there were several more associations observed between the dietary outcomes and proportional measures than between the dietary outcomes and the density measures. Some of these findings—for example, high fruit and vegetable intake was associated with full-service density and proportion; convenience store proportion was negatively associated with high whole grain intake, and positively associated with high added sugar intake—if confirmed through further research in a larger study, would support the notion that a more healthful retail food environment can positively influence the diets of some individuals. There are, however, some conflicting or unintuitive findings that also merit careful consideration. For instance, the relationship between convenience store density and purchasing, shown in Table 5.1, suggests that higher density is inversely associated with high purchasing frequency, but this makes little intuitive sense. Another unexpected finding suggests that high frequency of fried potato consumption was negatively associated with limited-service proportion, but positively associated with full-service proportion. It is possible that these are merely spurious associations that would disappear in a larger sample, but this could also be the case for some of the more intuitive findings.

Supermarket density was the only DPA-based density measure that was associated with obesity after adjustment for other factors, although not quite significantly. This was somewhat surprising, since supermarket density was not really associated with any of the dietary intake measures (whole grain intake was only weakly and marginally correlated). If an association between supermarket density and obesity is not mediated through dietary intake or food purchasing, it seems likely that it is a result of some factor(s) unaccounted for in the analysis.

Relational understanding of health and place

Cummins et al. (2007) have argued that a relational understanding of place in health research is important for formulating effective policy interventions. Since the techniques developed and tested in this research regard individuals as mobile, and describe contextual features (i.e., the food environment) in relation to this mobility, they facilitate a more relational understanding of place when examining the relationship between health and the environment. This means that individuals are not seen as discrete entities within a static context, as within neighborhood-based studies that rely on multilevel statistical modeling, but as constituent elements of a context that they interact with in a mutually reinforcing manner. Cummins et al. (2007) have suggested that such measures of the environment will "allow us not only to understand which environments are most salient for health in terms of location and duration but also how an individual's personal characteristics mediate the relationship." (p. 1835) In the study described here, personal characteristics (e.g., age, education, income) were undoubtedly related to activity-based food environments, and thus mediated the relationship between participants' health (i.e., diet, weight) and the accessibility of food within the local environment. Put another way: participants' unique activity-based food environments were constituted through the interaction between their personal characteristics and the local urban context. Characteristics such as age, education, and income influenced where, how, and why people traveled on a daily basis, and therefore what food locations were spatially accessible to them. This accessibility was in some cases related to diet and food purchasing, but not always, perhaps due to any of several limitations of this methodological exploration.

Limitations and notes for future food environment studies

There are several limitations to this research that should be carefully considered. First, while many of these findings could suggest that a more healthful retail food environment positively influences dietary habits, the direction of causation is not so clear. It is likely, for example, that participants with more healthful diets, perhaps for reasons not accounted for here, seek out stores and restaurants that sell healthful foods. This could tend to increase the proportion and density of such establishments within their activity spaces, thus biasing these activity-based measures toward the very behaviors being assessed as outcomes. This is an important consideration for study design, and underlies the rationale for collecting activity-travel data during the workweek, when participants were very likely to remain within their most habitual, and thus most convenient and well-known, spaces. At the second interview, several participants even expressed regret for not doing their regular weekly food shopping during their GPS tracking period, since they often accomplish this task on the weekend. These laments demonstrate that the data captured do not merely reflect behaviors associated with food shopping, but rather better approximate the spaces participants most frequently inhabit during daily life.

Several limitations of this research relate to the classification of retail food locations. Limited-service restaurants, for example, included a diverse collection of eateries with very different offerings. Additionally, there was no question at Q2 that asked about “fast food” restaurants specifically, but these were included under a single “limited-service” restaurant category that also included “snack and non-alcoholic beverage bars” and small delicatessens. Future research would thus benefit from incorporating a better-developed survey instrument to gather retail food purchasing data. In the survey for this study, participants only answered how often they purchased food at limited-service restaurants generally. Finer distinctions regarding the categorization of restaurant types, as with a food frequency questionnaire, would allow a more specific analysis of purchasing.

This study is also limited by its use of retail food types to describe the food environment, rather than in-depth examination of food store shelves and restaurant menus. Researchers have noted, for example, that supermarkets devote as much or more shelf space to unhealthy foods as healthy ones (Farley et al. 2009), and 'sit-down' restaurants do not consistently offer healthier choices than fast food restaurants (Saelens et al. 2007). For this study, however, it was considered more important to facilitate comparison with previous neighborhood- or residence-based research that also relied on retail food types, and resources were limited. In future research, combining activity space data with measures similar to the Nutritional Environment Measurement Surveys for restaurants (NEMS-R) and stores (NEMS-S), which examine the inventories and/or menus of food locations, could more precisely identify which foods are accessible regardless of retail food type (Glanz et al. 2007, Saelens et al. 2007).

In a related matter, the measures of the food environment developed in this research could also benefit from further refinement. For example, the RFEI measures used here omitted several retail food types considered neutral with regard to in-store availability of fresh produce, whole grains, and other low-fat items. Full-service restaurants, for example, often serve a variety of vegetable-based side dishes or meals. Small groceries often have a limited selection of fresh, canned, and frozen fruits and vegetables in addition to snack foods and candy, so they were also considered neutral in this respect and omitted from RFEI calculations. While these decisions were arguably well-reasoned, given the positive results noted with regard to RFEI, it is also notable that small grocery purchases were associated with both small grocery proportion and density, and this food store type was excluded from RFEI. The existence of these significant relationships questions the use of any measure that excludes small groceries.

The study area for this research was not chosen because it was considered to have poor access to food or to have a high proportion of low-income residents. Instead, it was chosen largely for convenience, as it is home to the author. This could have introduced some selection bias among the participants, but nevertheless provided some advantages for this exploratory research. First, it resulted in negligible costs associated with travel to, from, and between participants' homes for interviews. Also, existing acquaintances among the membership of the Kenwick Neighborhood Association helped to facilitate recruitment at that organization's general meetings. For the purpose of this exploratory research, these advantages outweighed the risk of bias. Future research, however, should endeavor to include participants who are considered food insecure or who perceive poor access to nutritious food.

Requesting that participants conduct research activities during a week when they planned to remain within Fayette County might have biased the sample of participants to a degree. This was not a concern, however, for the great majority of participants, as only a handful recorded GPS data showing they were ultimately required to leave the county. Still, several participants' may have altered their usual behavior slightly in order to participate in the study. In a related matter, this research collected only three days of GPS data to minimize participant responsibilities and concentrate on the most habitual activities. This decision could have influenced the results if some participants' food purchasing was heavily influenced by weekend travel. For this reason, logging GPS data for several more days (or even weeks) could provide a more accurate activity space assessment. This study's main findings, however, indicate that fewer days can still yield statistically significant results. Weekend activity and travel patterns might vary substantially from weekdays, as the analysis of three-day and seven-day DPAs demonstrates, but the implications for diet and purchasing habits could be relatively minor.

Another temporal concern points the way to future methodological development. The times and dates of participants' GPS tracking points, which formed the vertices of the lines used to create DPAs, were not considered. Thus, this study did not attempt to discern which food locations were accessible to participants during mealtimes, when they might have been most likely to purchase food, especially from restaurants. Limited-service restaurant purchases, for example, might be more highly correlated with the spatial accessibility of such establishments around mealtimes, rather than over three days generally. This type of analysis should be possible given the data collected, however, and could also provide insight into *when* people access food locations, and how this relates to their personal characteristics. It seems rather possible, for example, that those employed in food or retail services often eat at restaurants near their workplace, because these sources of food are so convenient during limited breaks for mealtimes. This could lead to a tendency to eat restaurant food more frequently than the general public. But this might not be discernible using the DPAs constructed in this research, since they do not incorporate the amount of time spent in each region within the DPA. Further research could thus provide insight by examining temporal accessibility, in addition to spatial accessibility, over several days.

The GPS tracking methods developed in this research are rather intrusive, as they entail close surveillance of individuals at home, at work, or wherever else they conduct the business of daily life. This is a serious consideration for bias related to selection of research participants—many people would never consider participating due to this degree of monitoring. Some individuals' daily habits might include a variety of potentially incriminating or embarrassing behaviors, including minor traffic violations, alcohol or illicit drug purchases, thefts, or other legal risks. This fact could have substantially influenced some individuals' willingness to participate in this research, potentially resulting in selection bias. Since confidentiality for participants is naturally vital to such an investigation, future work, especially if conducted in areas where poverty or crime is prevalent, might consider incorporating a National Institutes of Health (NIH) Certificate of Confidentiality into regulatory protocols. When NIH awards this certificate for research conducted in the U.S., which need not be federally funded, participants can be shielded from inquiries from law enforcement authorities. In effect, obtaining a Certificate of Confidentiality would mean that participants' locational data could not be used against them in a court of law.

Final thoughts

Despite the limitations mentioned above, the techniques developed in this research have provided evidence of a clear source of bias inherent in previous research, and have enabled an encouraging analysis of the relationship between the retail food environment and the health of individuals. These methods rely on rapidly developing GIS and GPS technologies that enable complex spatio-temporal analyses, and are firmly rooted in quantitative geography, but they have been used here in a manner that seeks to recognize the importance of developing relational approaches to representing 'place' in studies of health and the environment (Cummins et al. 2007).

There is a notable lack of methodological consistency in food environment studies published over the past decade or more, as noted by Feng et al. (2010). This makes comparisons of research findings from different places very difficult, and hinders progress in this field of research. Relying on the analysis of areal units makes comparisons even more difficult due to regional differences in administrative units—ZIP codes, census tracts, postal codes, and others have stood as proxies for neighborhoods—and these can vary greatly in size and shape depending on factors such as population density, physical geography, and transportation systems. Because the techniques described here are independent of areal units, they could greatly facilitate comparisons of the food environments of people who live in very different urban, suburban, and rural (or multiple) contexts.

Going forward, however, there are several issues that will require attention as the geospatial techniques developed in this research, or similar techniques developed by others, are deployed more widely for social science and public health. Many of these have already been described in the previous section, and some pose substantial challenges. Furthermore, there are undoubtedly other unknown difficulties that will arise as work progresses in different directions, addressing other disease outcomes or environmental exposures. Nevertheless, revealing and facing these future challenges will almost certainly yield further insight, and perhaps serve to enhance these methods further.

Table 5.1. Select results for Discussion

Select results addressing Research Question #1:

Food environment measures	Neighborhood-based	Activity-based			
		Mean	Median	SD	Range
Supermarket density	0.00	3.95	4.07	1.53	0.00 – 7.14
Limited-service prop.	71.43	58.04	57.85	5.02	47.80 – 91.67
RFEI	18.00	13.81	13.22	3.90	6.83 – 29.00

Note: All differences between neighborhood- and DPA-based food environment measures were highly significant (p<0.01) using the Wilcoxon signed-rank test

Select results addressing Research Question #2:

Median values by:	Small grocery density	Limited-service density	Limited-service prop.	RFEI
<u>Age</u>				
18-34	1.18*	12.09†	57.94	13.18
35-54	1.03	9.82	57.36	13.07
55+	0.88	8.30	58.13	13.63
<u>Income</u>				
<$50k/yr	1.07†	11.13*	57.97	13.22
$50k-100k/yr	1.08	9.86	57.98	13.75
$100k+/yr	0.82	8.57	57.09	11.29
<u>Education</u>				
No Bachelor's degree	0.98	8.21†	59.09†	13.38
Bachelor's degree	0.97	9.48	57.66	13.24
Graduate degree	1.07	10.70	57.09	13.14

* p<0.10
† p<0.05

Select results addressing Research Question #3:

Adjusted OR for high intake of:	RFEI	Conv. store density	Limited-service prop.	Small grocery density	Small grocery prop.	Super-market density
Whole grains	0.83†					
Fruits/vegetables	0.86*					
Fried potatoes			0.86†			
Small groc. purchases				2.23†	1.09†	
Conv. store purchases		0.36†				
Obesity	1.18†					0.61*

* p<0.10
† p<0.05

APPENDIX A: Recruitment flyer

UNIVERSITY OF KENTUCKY

INVITATION TO PARTICIPATE IN A RESEARCH STUDY

TO: Adult residents of Bell Court, Mentelle, and Kenwick neighborhoods in Lexington
FROM: Jay Christian, PhD candidate at the University of Kentucky, Dept. of Geography

I am conducting a research study to fulfill the requirements of my doctoral (PhD) degree in geography. If you have received this invitation at your home address, you could be eligible to participate. Only adult residents, ages 18-65, of these three neighborhoods can participate, and participation is strictly confidential.

Participants will be compensated for their time.

* * *

WHAT IS THE RESEARCH ABOUT?

This research study addresses the accessibility of different kinds of food stores and restaurants in Lexington.

WHAT WOULD I HAVE TO DO TO PARTICIPATE?

This research study requires you to do two things as a participant:
(1) Carry a global positioning system (GPS) device (about the size of a small mobile phone) with you for four days, and
(2) Answer some questions about yourself, your daily habits, and your activities on those few days, in two brief interviews.

WHEN DOES THE RESEARCH STUDY BEGIN/END?

You can participate in this research any time between May 1 and October 31, 2011. The dates of your participation can be scheduled in advance, if needed.

* * *

Please call **859-396-4323** if you think you might be interested in participating in this research study. When you call you will be asked a few questions to confirm your eligibility, then we can make an appointment to formally enroll you in the study if you are eligible.

APPENDIX B: Research questionnaires

DOCTORAL DISSERTATION RESEARCH: Using Geospatial Technologies to Characterize Relationships Between Travel Behavior, Food Availability and Health

NSF #1031430

Co-PI: W. Jay Christian, MPH (PhD Candidate)
PI: Gary Shannon, PhD (Faculty Advisor)
Department of Geography
University of Kentucky
Lexington, Kentucky

QUESTIONNAIRE #1

STUDY ID: ______________ INTERVIEWER: ______________ DATE: ______________

1. What is your **gender**?
    a. Male
    b. Female

2. What is your **age**?

    → Answer: ________________

    ☐ REFUSED

3. How **tall** are you, in feet and inches?

    → Answer: ________ft ________in

    ☐ REFUSED

4. How much do you **weigh**, in pounds?

    → Answer: ________ lbs

    ☐ REFUSED

5. How would you describe your **race**?
    a. White or Caucasian
    b. Black or African-American
    c. Asian
    d. Native Hawaiian or Pacific Islander
    e. Native American or Alaskan
    f. Multiracial
    g. Other: ________________
    h. REFUSED

6. Would you describe yourself as **Hispanic**?
    a. Yes
    b. No
    c. REFUSED

7. What is your current **marital status**?
    a. Single—never been married
    b. Married
    c. Living with boyfriend, girlfriend, or significant other
    d. Divorced, or separated
    e. Widowed
    f. REFUSED

8. In what **country** were you born?
    a. United States
    b. Other country → List here: ________________
    c. REFUSED

9. How many years have you lived in **Lexington**?

   → Answer: ________ years

   ☐ REFUSED

10. How many years have you lived in your **current neighborhood**?

    → Answer: ________ years

    ☐ REFUSED

11. Besides Lexington, **where else have you lived** for at least 6 months? *(List up to 5 cities/counties and their states/countries below.)*

    ☐ Always lived in Lexington

    ☐ REFUSED

12. What is your current address?

13. Which of the following people **live in your home**? *(Circle all that apply.)*
    a. Husband, wife, or partner
    b. Boyfriend, girlfriend, or significant other
    c. Children → Number: ________
    d. Other relatives → Number: ________
    e. Unrelated friends, acquaintances, or roommates → Number: ________
    f. REFUSED

14. What is the highest level of **education** you have completed?
    a. Did not finish high school
    b. High school diploma, including GED or equivalent
    c. Some college, no degree
    d. Associate degree
    e. Bachelor's degree
    f. Master's degree
    g. Professional or Doctoral degree (e.g., MD, PhD, DO, DVM, JD)
    h. REFUSED

15. Are you **currently taking classes** at a school, college, or university?
    a. Yes—Full-time student
    b. Yes—Part-time student
    c. No
    d. REFUSED

16. What is your **annual income**? Add the income of your spouse or significant other, if he/she lives with you.
    a. $15,000 per year or less
    b. $15,001-$25,000 per year
    c. $25,001-$50,000 per year
    d. $50,001-$75,000 per year
    e. $75,001-$100,000 per year
    f. More than $100,000 per year
    g. REFUSED

17. How would you describe your current **employment status**?
    a. Employed—Full-time (35+ hours per week)
    b. Employed—Part-time (<35 hours per week)
    c. Homemaker *(Skip to Question #20)*
    d. Disabled *(Skip to Question #20)*
    e. Retired *(Skip to Question #20)*
    f. Unemployed *(Skip to Question #20)*
    g. REFUSED *(Skip to Question #20)*

18. What is your **occupation**? Also, list the name and address (or location) of your **place of employment** in the space(s) provided below. If you work at more than one job or location, please list all of them.

    → **Occupation #1**, and name and address/location of **Employer #1**:

    → **Occupation #2**, and name and address/location of **Employer #2**:

    → **Occupation #3**, and name and address/location of **Employer #3**:

19. When you go to work, do you **always drive or ride in a car** (or van, or truck)? *(Include travel within Lexington to look for work and/or to access unemployment services.)*
    a. Yes
    b. No
    c. REFUSED

20. When you do not ride in a car (or van, or truck), **how else do you get to work**? *(Circle all that apply.)*
    a. Bus
    b. Walk
    c. Bicycle
    d. Motorcycle
    e. Scooter or moped
    f. Other: ________________
    g. REFUSED

21. How often do you **walk or ride a bike** to destinations near your home, office, or other location? Please answer in the number of times per week or per month.

    → Answer: ________ time(s) per week / per month
    ☐ Never *(Skip to Question #3)*
    ☐ REFUSED

22. To **which places do you walk or ride a bike**?

    → List specific destinations accessed via walking or biking:

23. **How many automobiles** are owned, leased, or available for daily use by the people who currently live in your home?

    → Answer: ________

    ☐ REFUSED

24. Do you currently own or lease your **own automobile**, or drive an automobile that someone else owns or leases for you? If so, what kind? *(Circle all that apply. Does not include two-wheeled vehicles. If individual has more than one, answer below for primary automobile.)*
    a. I do not have a car
    b. I have a sedan, wagon, or compact car
    c. I have a pickup truck or sport utility vehicle (SUV)
    d. I have a van or minivan
    e. I have another kind of automobile: → List here: ________________
    f. REFUSED

25. During a typical 7-day period (a week), how many times on average do you do the following kinds of exercise for more than 15 minutes during your free time (write on each line the appropriate number):

	Times Per Week
a. STRENUOUS EXERCISE (HEART BEATS RAPIDLY) (e.g., running, jogging, hockey, football, soccer, Squash, basketball, cross country skiing, judo, Roller skating, vigorous swimming, vigorous Long distance bicycling)	________
b. MODERATE EXERCISE (NOT EXHAUSTING) (e.g., fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)	________
c. MILD EXERCISE (MINIMAL EFFORT) (e.g., yoga, archery, fishing from river bank, Bowling, horseshoes, golf, snow-mobiling, easy walking)	________

26. During a typical 7-day period (a week), in your leisure time, how often do you engage in any regular activity long enough to work up a sweat (heart beats rapidly)?
    a. Often
    b. Sometimes
    c. Never/Rarely

END OF QUESTIONNAIRE 1
Thank you for your participation in this research!

DOCTORAL DISSERTATION RESEARCH: Using Geospatial Technologies to Characterize Relationships Between Travel Behavior, Food Availability and Health

NSF #1031430

Co-PI: W. Jay Christian, MPH (PhD Candidate)
PI: Gary Shannon, PhD (Faculty Advisor)
Department of Geography
University of Kentucky
Lexington, Kentucky

QUESTIONNAIRE #2

STUDY ID: ______________ INTERVIEWER: ______________ DATE: ______________

The first set of questions is about the different kinds of foods that you usually eat or drink. When answering, please include meals and snacks eaten at home, at work or school, in restaurants, and anyplace else. You may answer in the number of times per week or month that you eat each item.

1. How often do you eat **hot or cold cereals**?

   → Answer: ________ time(s) per week / per month
   ☐ Never *(Skip to Question #3)*
   ☐ REFUSED

2. What **kinds of cereal** do you usually eat?

3. How often do you have **milk**, either to drink or on cereal? Do not include soy milk or small amounts of milk in coffee or tea. INCLUDE: SKIM, NO-FAT, LOW-FAT, WHOLE MILK, BUTTERMILK, AND LACTOSE-FREE MILK. ALSO INCLUDE CHOCOLATE OR OTHER FLAVORED MILKS. DO NOT INCLUDE: CREAM.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

4. How often do you drink **regular soda or pop** that contains sugar during a typical week? Do not include diet soda. INCLUDE: MANZANITA AND PEÑAFIEL SODAS. DO NOT INCLUDE: DIET OR SUGAR-FREE FRUIT DRINKS. DO NOT INCLUDE JUICES OR TEA IN CANS.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

5. How often do you drink **100% pure fruit juice** such as orange, mango, apple, grape and pineapple juices? INCLUDE: ONLY 100% PURE JUICES. DO NOT INCLUDE: FRUIT-FLAVORED DRINKS WITH ADDED SUGAR, LIKE CRANBERRY COCKTAIL, HI-C, LEMONADE, KOOL-AID, GATORADE, TAMPICO, AND SUNNY DELIGHT.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

6. How often do you drink **coffee or tea that had sugar or honey added** to it? Include coffee and tea you sweetened yourself and presweetened tea and coffee drinks such as Arizona Iced Tea and Frappuccino. Do not include artificially sweetened coffee or diet tea.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

7. How often do you drink **sweetened fruit drinks, sports or energy drinks**, such as Kool-aid, lemonade, Hi-C, cranberry drink, Gatorade, Red Bull or Vitamin Water? Include fruit juices you made at home and added sugar to. Do not include diet drinks or artificially sweetened drinks. INCLUDE: DRINKS WITH ADDED SUGAR, TAMPICO, SUNNY DELIGHT, AND TWISTER. DO NOT INCLUDE: 100% FRUIT JUICES OR SODA, YOGURT DRINKS, CARBONATED WATER OR FRUIT-FLAVORED TEAS.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

8. How often do you eat **fruit**? Include fresh, frozen or canned fruit. Do not include juices. DO NOT INCLUDE: DRIED FRUITS.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

9. How often do you eat a **green leafy or lettuce salad**, with or without other vegetables? INCLUDE: SPINACH SALADS.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

10. How often do you eat any kind of **fried potatoes**, including french fries, home fries, or hash brown potatoes? DO NOT INCLUDE: POTATO CHIPS.

   → Answer: ________ time(s) per week / per month
   ☐ Never
   ☐ REFUSED

11. How often do you eat any **other kind of potatoes**, such as baked, boiled, mashed potatoes, sweet potatoes, or potato salad? INCLUDE: ALL TYPES OF POTATOES EXCEPT FRIED. INCLUDE POTATOES AU GRATIN, SCALLOPED POTATOES.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

12. How often do you eat refried **beans**, baked beans, beans in soup, pork and beans or any other type of cooked dried beans? Do not include green beans. INCLUDE: SOYBEANS, KIDNEY, PINTO, GARBANZO, LENTILS, BLACK, BLACK-EYED PEAS, COW PEAS, AND LIMA BEANS.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

13. Not including what you just told me about (lettuce salads, potatoes, cooked dried beans), how often do you eat **other vegetables**? DO NOT INCLUDE: RICE. EXAMPLES OF OTHER VEGETABLES INCLUDE: TOMATOES, GREEN BEANS, CARROTS, CORN, CABBAGE, BEAN SPROUTS, COLLARD GREENS, AND BROCCOLI. INCLUDE ANY FORM OF THE VEGETABLE (RAW, COOKED, CANNED, OR FROZEN).

→ Answer: ________ time(s) per week / per month

☐ Never

□ REFUSED

14. How often do you eat **pizza**? Include frozen pizza, fast food pizza, and homemade pizza.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

15. How often do you have Mexican-type **salsa** made with tomato? INCLUDE: ALL TOMATO-BASED SALSAS.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

16. How often do you have **tomato sauces** such as with spaghetti or noodles or mixed into foods such as lasagna? Please do not count tomato sauce on pizza.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

17. How often do you eat **red meat**, such as beef, pork, ham, or sausage? Do not include chicken, turkey or seafood.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

18. How often do you eat **processed meat**, such as bacon, lunch meats, or hot dogs? INCLUDE: PROCESSED POULTRY AND RED MEAT. DO NOT INCLUDE: CANNED TUNA FISH OR CHICKEN NUGGETS.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

19. How often do you eat any kind of **cheese**? Include cheese as a snack, cheese on burgers, sandwiches, and cheese in foods such as lasagna, quesadillas, or casseroles. Please do not count cheese on pizza. INCLUDE: MACARONI AND CHEESE, ENCHILADAS. DO NOT INCLUDE: CREAM CHEESE OR CHEESES MADE FROM NON-DAIRY FOODS, SUCH AS SOY OR RICE, OR CHEESE ON PIZZA.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

20. How often do you eat **whole grain bread** including toast, rolls and in sandwiches? Whole grain breads include whole wheat, rye, oatmeal and pumpernickel. Do not include white bread. INCLUDE: CRACKED WHEAT, MULTI-GRAIN, BRAN BREADS, WHOLE GRAIN WHITE BREAD.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

21. How often do you eat brown rice or other **cooked whole grains**, such as bulgur, cracked wheat, or millet? Do not include white rice.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

22. How often do you eat chocolate or any other types of **candy**? Do not include sugar-free candy.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

23. How often do you eat **doughnuts, sweet rolls, Danish, muffins, or pop-tarts**? Do not include sugar-free items. INCLUDE: LOW-FAT KINDS. DO NOT INCLUDE: PANCAKES, WAFFLES, FRENCH TOAST, CAKE, ICE CREAM AND OTHER FROZEN DESSERTS OR CANDY.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

24. How often do you eat **cookies, cake, pie or brownies**? Do not include sugar-free kinds. INCLUDE: LOW-FAT KINDS, TWINKIES AND HOSTESS CUPCAKES. DO NOT INCLUDE: ICE CREAM AND OTHER FROZEN DESSERTS OR CANDY.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

25. How often do you eat **ice cream** or other frozen desserts? Do not include sugar-free kinds. INCLUDE: LOW-FAT KINDS. DO INCLUDE FROZEN YOGURT AND SHERBET. DO NOT INCLUDE: NON-DAIRY FROZEN DESSERTS, SUCH AS SORBET, SNO-CONES.

→ Answer: ________ time(s) per week / per month
☐ Never
☐ REFUSED

26. How often do you eat **popcorn**? INCLUDE: LOW-FAT POPCORN.

→ Answer: ________ time(s) per week / per month
 Never
 REFUSED

*   *   *

27. Are you currently **dieting to lose weight**?
    a. Yes
    b. No
    c. REFUSED

28. Are you a **vegetarian or vegan**?
    a. Yes—Vegetarian
    b. Yes—Vegan
    c. No
    d. REFUSED

29. Do you have any **food allergies or sensitivities** that affect your diet?
    a. Yes: → List here: ________________
    b. No

The next few questions will ask about where you shop for food and eat meals. Please try to estimate how many times PER WEEK or PER MONTH you personally buy food at each type of store or restaurant.

30. How often do you buy food at **superstores or warehouse stores**, such as Sam's Club or Costco?

→ Answer: ________ times per week / per month

□ Never

□ REFUSED

31. How often do you buy food at **supermarkets**, such as Kroger, Meijer, or Whole Foods?

→ Answer: ________ times per week / per month

□ Never

□ REFUSED

32. How often do you buy food at **farmer's markets**? These are usually open-air markets with many booths selling a variety of locally grown fruits, vegetables, and other foods.

→ Answer: ________ times per week / per month

□ Never

□ REFUSED

33. How often do you buy food at **specialty markets**? These stores often cater to national or ethnic cuisines, such as Asian groceries, and European and international markets.

→ Answer: ________ times per week / per month

□ Never

□ REFUSED

34. How often do you buy food at **independent or small groceries**? These are stores that are often much smaller than supermarkets, but still sell some fresh fruits and vegetables.

→ Answer: ________ times per week / per month

☐ Never

☐ REFUSED

35. How often do you buy food at **pharmacies**? These are stores such as RiteAid and CVS that sometimes sell packaged foods or frozen foods in addition to medicines and other non-food items.

→ Answer: ________ times per week / per month

☐ Never

☐ REFUSED

36. How often do you buy food at **convenience stores**? These stores are often attached to gas stations, truck stops, airports, or newsstands. They sell packaged foods and beverages, but DO NOT sell fresh fruits and vegetables.

→ Answer: ________ times per week / per month

☐ Never

☐ REFUSED

37. How often do you eat at **limited-service or 'fast food'** restaurants? These include restaurants where you order at a counter or 'drive-thru' and pay before you eat, as well as restaurants that deliver pizza or other foods to your home, and buffet-only restaurants.

→ Answer: ________ times per week / per month

☐ Never

☐ REFUSED

38. How often do you eat at **full-service or 'sit-down'** restaurants? Please include only restaurants where you order from your table and pay after eating.

→ Answer: ________ times per week / per month

☐ Never

☐ REFUSED

39. Are there any **other kinds of stores or restaurants** that I have not mentioned where you sometimes buy food? *(List up to 3 below.)*

* * *

40. How often does someone in your home **cook food for supper**? Include any meal that requires cooking, heating, or other preparation of ingredients. Do not include re-heated meals from restaurants.

→ Answer: ________ times per week / per month

☐ Never

☐ REFUSED

41. How often does someone in your home make a **big trip to the supermarket** to shop for groceries?

→ Answer: ________ times per week / per month

☐ Never

☐ REFUSED

42. Please list up to **three stores** where you most often buy groceries, and their locations:

43. How much of your household's **food shopping do you do yourself**? Only include shopping for food you take home to eat later.
    a. All
    b. Most
    c. Some
    d. A little
    e. None
    f. REFUSED

Next, I would like you to tell me how much you agree with the following statements. Please tell me whether you strongly agree, agree, neither agree nor disagree, disagree, or strongly disagree.

44. A large **selection of fruits and vegetables** is available to me in my daily life.
    a. Strongly agree (0)
    b. Agree (1)
    c. Neither agree nor disagree (2)
    d. Disagree (3)
    e. Strongly disagree (4)
    f. REFUSED

45. A large **selection of low-fat products** is available to me in my daily life.
    a. Strongly agree (0)
    b. Agree (1)
    c. Neither agree nor disagree (2)
    d. Disagree (3)
    e. Strongly disagree (4)
    f. REFUSED

46. The **fruits and vegetables** I see for sale are of **high quality**.
    a. Strongly agree (0)
    b. Agree (1)
    c. Neither agree nor disagree (2)
    d. Disagree (3)
    e. Strongly disagree (4)
    f. REFUSED

Next I will ask you to remember some details about the three days when you carried the GPS data logger with you. It might help to think about what you did on each of those days, starting from when you left home in the morning.

47. Did you **purchase food or drink on the FIRST day** you carried the GPS data logger? If so, **where**? Include any type of business where you purchased food or drinks of any kind, including fresh fruits and vegetables, packaged foods, meals at restaurants or snack bars, etc. You DO NOT need to include alcohol.

    EXAMPLES:

Starbucks at Main/Broadway	Thornton's on Winchester Rd
Parisa International Market on Richmond Rd	Target near Fayette Mall
Kroger supermarket in Beaumont area	Ramsey's on High St

48. Did you **purchase food or drink on the SECOND day** you carried the GPS data logger? If so, where?

49. Did you **purchase food or drink on the THIRD day** you carried the GPS data logger? If so, where?

50. On each of these days, was your **daily routine**…

Day 1:

g. Typical—with no real difference from usual;
h. Mostly typical—with only minor differences from usual;
i. Somewhat typical—with some differences from usual;
j. Not very typical—with only a few similarities to what you usually do; or
k. Atypical—with no similarity to your usual routine.
l. REFUSED

Day 2:

a. Typical—with no real difference from usual;
b. Mostly typical—with only minor differences from usual;
c. Somewhat typical—with some differences from usual;
d. Not very typical—with only a few similarities to what you usually do; or
e. Atypical—with no similarity to your usual routine.
f. REFUSED

Day 3:

a. Typical—with no real difference from usual;
b. Mostly typical—with only minor differences from usual;
c. Somewhat typical—with some differences from usual;
d. Not very typical—with only a few similarities to what you usually do; or
e. Atypical—with no similarity to your usual routine.
f. REFUSED

END OF QUESTIONNAIRE 2

This concludes your participation in the research study.

APPENDIX C: Network-based DPA results tables

Table C.1. Comparison of neighborhood- and nDPA-based food environment measures (n=101)

Neighborhood-based	Activity-based			
	Mean	Median	SD	Range
Area (sq. mi.)	8.83	8.34	4.75	1.20 – 23.59
Convenience stores	23.09	22	12.35	5 – 54
Limited-service restaurants	106.93	104	51.22	11 – 251
Full-service restaurants	78.22	78	34.46	1 – 183
Small groceries	11.30	11	5.61	2 – 27
Supermarkets	4.54	4	3.11	0 – 13
Convenience store density	2.66	2.58	0.59	1.44 – 5.82
Limited-service density	12.99	12.46	3.99	6.48 – 25.55
Full-service density	9.66	9.29	3.33	0.83 – 21.77
Small grocery density	1.47	1.36	0.80	0.44 – 5.22
Supermarket density	4.91	5.04	1.88	0.00 – 8.39
RFEI	13.73	13.18	3.86	5.25 – 25.00
Convenience store proportion	54.22	54.93	9.08	29.41 – 70.00
Limited-service proportion	57.63	57.58	5.34	44.90 – 91.67
Full-service proportion	42.37	42.42	5.34	8.33 – 55.10
Small grocery proportion	28.15	26.76	9.29	12.50 – 58.33
Supermarket proportion	10.36	10.53	4.48	0.00 – 22.58

Note: All differences between neighborhood- and DPA-based food environment measures were all highly significant ($p<0.01$) using the Wilcoxon signed-rank test

Table C.2. Spearman rank correlation coefficients for nDPA-based food environment measures (n=101)

	nDPA size	Conv. store density	Limited -service density	Full-service density	Small grocery density	Super-market density	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.
Conv. store density	-0.16	1.00									
p-value	0.12										
Lim.-serv. density	**-0.41**	**0.24**	1.00								
p-value	**0.00**	**0.02**									
Full-serv. density	**-0.45**	-0.01	**0.85**	1.00							
p-value	**0.00**	0.91	**0.00**								
Small groc. density	**-0.46**	**0.18**	**0.45**	**0.46**	1.00						
p-value	**0.00**	**0.07**	**0.00**	**0.00**							
Supermkt. density	**0.24**	0.05	**-0.19**	**-0.25**	**-0.33**	1.00					
p-value	**0.02**	0.63	**0.05**	**0.01**	**0.00**						
RFEI	0.05	**0.42**	**0.19**	0.01	0.00	**-0.54**	1.00				
p-value	0.60	**0.00**	**0.06**	0.92	0.96	**0.00**					
Conv. store prop.	**0.42**	**0.38**	**-0.39**	**-0.52**	**-0.76**	0.13	**0.40**	1.00			
p-value	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	0.21	**0.00**				
Lim.-serv. prop.	0.07	**0.54**	0.06	**-0.43**	-0.04	0.12	**0.29**	**0.30**	1.00		
p-value	0.49	**0.00**	0.56	**0.00**	0.70	0.22	**0.00**	**0.00**			
Full-serv. prop.	-0.07	**-0.54**	-0.06	**0.43**	0.04	-0.12	**-0.29**	**-0.30**	**-1.00**	1.00	
p-value	0.49	**0.00**	0.56	**0.00**	0.70	0.22	**0.00**	**0.00**	**0.00**		
Small groc. prop.	**-0.40**	-0.09	**0.35**	**0.41**	**0.92**	**-0.42**	0.00	**-0.86**	-0.13	0.13	1.00
p-value	**0.00**	0.37	**0.00**	**0.00**	**0.00**	**0.00**	1.00	**0.00**	0.21	0.21	
Supermarket prop.	**0.41**	**-0.30**	**-0.42**	**-0.38**	**-0.62**	**0.87**	**-0.55**	**0.27**	-0.06	0.06	**-0.62**
p-value	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	0.53	0.53	**0.00**

Table C.3. Personal characteristics by median nDPA-based food environment measures (n=101)

	nDPA size	Conv. store density	Limited -service density	Full-service density	Small grocery density	Super-market density
Gender						
Female	8.06	2.64	12.30	9.07	1.43	**4.88***
Male	8.57	2.51	12.47	9.31	1.25	**5.50**
Age group						
18-34	7.28	2.61	**14.55†**	**9.58***	1.52	5.18
35-54	7.42	2.59	**12.47**	**9.34**	1.33	4.89
55+	10.02	2.52	**10.74**	**7.93**	1.10	5.82
Race/ethnicity						
White, non-Hispanic	8.57	2.60	12.38	9.11	1.38	5.22
All others	6.58	2.50	12.86	10.44	1.17	4.95
Household income[a]						
<$50k/yr	7.55	**2.67†**	12.86	9.35	**1.47†**	5.37
$50k-100k/yr	8.55	**2.69**	12.29	8.93	**1.47**	4.91
$100k+/yr	10.44	**2.34**	10.64	9.58	**1.09**	5.40
Education						
No Bachelor's degree	**10.15†**	2.47	**10.64†**	7.58	1.35	4.97
Bachelor's degree	**8.73**	2.63	**11.94**	9.33	1.21	5.22
Graduate degree	**6.58**	2.56	**13.02**	9.95	1.42	5.04
Employment						
Full-time	8.13	2.56	12.46	**9.07†**	**1.36†**	5.00
Part-time	8.83	2.71	13.56	**9.95**	**1.06**	5.18
Not employed	8.56	2.67	11.63	**9.69**	**1.73**	5.30
Marital status						
Now or previously married	9.32	**2.56***	**11.74†**	9.07	**1.18†**	5.25
Never married	6.89	**2.80**	**15.34**	10.28	**1.70**	4.93
Weight status						
Underweight/Normal (BMI<25.0)	9.41	2.53	12.58	9.43	1.35	5.27
Overweight (25<=BMI<30)	7.28	2.59	12.53	9.35	1.26	5.51
Obese (BMI>=30.0)	6.56	2.79	11.59	8.51	1.45	3.95

[a]Two participants refused to answer household income question
* p<0.10
† p<0.05

Table C.3. Personal characteristics by median nDPA-based food environment measures (n=101), cont.

	RFEI	Conv. store prop.	Limited -service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
<u>Gender</u>						
Female	13.13	55.17	57.07	42.93	27.27	10.00
Male	13.23	53.91	57.83	42.17	26.71	11.09
<u>Age group</u>						
18-34	13.20	54.79	57.99	42.01	27.42	10.53
35-54	13.09	55.40	57.42	42.58	26.84	10.00
55+	13.84	56.34	57.65	42.35	24.44	12.63
<u>Race/ethnicity</u>						
White, non-Hispanic	13.15	55.05	57.54	42.46	26.84	10.53
All others	13.36	52.00	58.39	41.61	24.14	10.34
<u>Household income</u>[a]						
<$50k/yr	13.13	52.73	58.66	41.34	27.59	10.34
$50k-100k/yr	13.67	57.50	57.38	42.62	27.84	10.00
$100k+/yr	12.67	56.25	57.59	42.41	25.53	12.00
<u>Education</u>						
No Bachelor's degree	13.61	**57.44†**	58.31	41.69	25.45	11.33
Bachelor's degree	12.87	**55.96**	56.47	43.53	26.79	10.44
Graduate degree	13.50	**53.23**	57.58	42.42	27.27	10.00
<u>Employment</u>						
Full-time	13.25	54.79	57.82	42.18	27.84	10.00
Part-time	12.88	57.59	56.27	43.73	24.29	11.36
Not employed	12.91	50.86	56.80	43.20	33.62	10.44
<u>Marital status</u>						
Now or previously married	**12.86†**	55.17	**57.07†**	**42.93†**	**26.32†**	**10.64***
Never married	**14.58**	52.16	**59.50**	**40.50**	**29.55**	**9.57**
<u>Weight status</u>						
Underweight/Normal (BMI<25.0)	13.06	54.86	57.54	42.46	26.76	10.92
Overweight (25<=BMI<30)	12.93	56.25	57.83	42.17	26.67	10.64
Obese (BMI>=30.0)	13.94	55.45	57.26	42.74	27.64	7.97

[a]Two participants refused to answer household income question
* p<0.10
† p<0.05

Table C.4. Spearman rank correlation coefficients: nDPA-based food environment measures, diet, purchasing outcomes (n=99)

	nDPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density	RFEI	Conv. store prop.	Limited -service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Added sugar	**0.18**	0.03	-0.03	-0.14	-0.07	0.08	0.00	0.10	**0.18**	**-0.18**	-0.10	0.08
p-value	**0.08**	0.78	0.77	0.17	0.49	0.46	0.97	0.32	**0.07**	**0.07**	0.34	0.42
Red meat	-0.08	0.08	-0.07	-0.13	0.02	0.05	0.03	0.07	0.13	-0.13	0.01	0.03
p-value	0.40	0.45	0.52	0.19	0.81	0.62	0.80	0.47	0.20	0.20	0.93	0.77
Fried potatoes	-0.06	0.01	0.03	-0.07	0.04	-0.12	0.13	0.05	0.16	-0.16	0.05	-0.12
p-value	0.57	0.94	0.74	0.49	0.69	0.23	0.19	0.61	0.11	0.11	0.61	0.23
Fruits & vegs.	0.06	-0.07	0.07	0.16	0.06	0.00	-0.05	-0.12	**-0.18**	**0.18**	0.08	-0.01
p-value	0.55	0.52	0.50	0.11	0.57	0.99	0.61	0.24	**0.08**	**0.08**	0.45	0.92
Whole grains	0.03	-0.06	**0.21**	**0.19**	0.13	0.16	**-0.22**	**-0.24**	-0.04	0.04	0.11	0.05
p-value	0.77	0.56	**0.04**	**0.06**	0.19	0.12	**0.03**	**0.02**	0.72	0.72	0.28	0.61
Conv. stores	0.11	**-0.17**	-0.05	-0.12	0.00	0.02	-0.07	-0.05	0.06	-0.06	0.05	0.08
p-value	0.28	**0.10**	0.63	0.25	0.97	0.85	0.50	0.64	0.55	0.55	0.61	0.43
Limited-service	0.08	0.03	0.05	-0.01	-0.08	0.02	0.02	0.10	0.09	-0.09	-0.10	0.05
p-value	0.45	0.78	0.62	0.90	0.45	0.85	0.85	0.34	0.36	0.36	0.34	0.61
Full-service	0.11	-0.09	0.03	0.04	0.04	0.00	0.03	-0.07	0.14	-0.14	0.10	0.02
p-value	0.28	0.38	0.75	0.67	0.68	0.99	0.80	0.52	0.18	0.18	0.33	0.86
Small groceries	0.01	-0.05	0.07	0.04	**0.18**	-0.13	0.03	-0.15	0.04	-0.04	**0.23**	-0.12
p-value	0.89	0.66	0.52	0.67	**0.07**	0.19	0.75	0.14	0.70	0.70	**0.02**	0.24
Supermarkets	0.06	-0.04	0.05	0.00	-0.02	-0.08	0.13	0.00	0.03	-0.03	0.04	-0.05
p-value	0.53	0.67	0.63	0.97	0.86	0.44	0.20	0.96	0.79	0.79	0.70	0.60

Table C.5. Adjusted odds ratios and confidence intervals for weekly dietary intake, by nDPA-based food environment measures (n=99)[a]

Odds ratios for high (4Q) dietary intake of:	nDPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density
Added sugar (13.375+/wk)	1.11	1.15	0.88	**0.83**	0.53	1.15
Conf. Int.	0.99 – 1.25	0.48 – 2.75	0.75 – 1.03	**0.67 – 1.01**	0.22 – 1.26	0.85 – 1.55
Red meat (3+/wk)	0.97	1.25	0.90	0.87	0.74	1.09
Conf. Int.	0.87 – 1.08	0.52 – 3.00	0.78 – 1.03	0.73 – 1.03	0.38 – 1.42	0.84 – 1.41
Fried potatoes (1+/wk)	0.99	**0.33**	0.95	1.01	0.82	0.94
Conf. Int.	0.88 – 1.12	**0.13 – 0.88**	0.81 – 1.11	0.84 – 1.21	0.40 – 1.67	0.70 – 1.28
Fruits & vegetables (32.625+/wk)	0.98	**0.34**	1.06	**1.19**	1.18	1.09
Conf. Int.	0.87 – 1.11	**0.10 – 1.18**	0.91 – 1.23	**0.99 – 1.43**	0.59 – 2.36	0.82 – 1.44
Whole grains (12.75+/wk)	1.01	0.58	1.14	1.10	**1.88**	1.13
Conf. Int.	0.90 – 1.13	0.20 – 1.70	0.97 – 1.34	0.93 – 1.31	**0.94 – 3.76**	0.84 – 1.51

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table C.5. Adjusted odds ratios and confidence intervals for weekly dietary intake, by nDPA-based food environment measures (n=99)[a], cont.

Odds ratios for high (4Q) dietary intake of:	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Added sugar (13.375+/wk)	0.96	1.04	1.07	0.94	0.95	1.09
Conf. Int.	0.83 – 1.10	0.98 – 1.11	0.95 – 1.20	0.83 – 1.05	0.89 – 1.02	0.96 – 1.24
Red meat (3+/wk)	1.03	1.02	1.04	0.96	0.98	1.04
Conf. Int.	0.91 – 1.16	0.97 – 1.08	0.94 – 1.15	0.87 – 1.07	0.93 – 1.03	0.93 – 1.17
Fried potatoes (1+/wk)	1.06	0.99	**0.90**	**1.11**	1.01	1.02
Conf. Int.	0.93 – 1.21	0.94 – 1.05	**0.81 – 1.00**	**1.00 – 1.23**	0.95 – 1.07	0.89 – 1.16
Fruits & vegetables (32.625+/wk)	**0.84**	**0.94**	**0.85**	**1.18**	1.04	1.01
Conf. Int.	**0.72 – 0.99**	**0.88 – 1.00**	**0.73 – 0.99**	**1.01 – 1.37**	0.98 – 1.10	0.89 – 1.14
Whole grains (12.75+/wk)	**0.86**	**0.92**	1.01	0.99	**1.06**	1.00
Conf. Int.	**0.73 – 1.01**	**0.86 – 0.98**	0.92 – 1.12	0.90 – 1.09	**1.00 – 1.13**	0.89 – 1.13

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table C.6. Adjusted odds ratios and confidence intervals for weekly food purchases, by nDPA-based food environment measures (n=99)[a]

Odds ratios for high (4Q) dietary intake of:	nDPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density
Convenience stores (0.5+/wk)	0.97	0.53	0.94	1.00	1.30	0.91
Conf. Int.	0.86 – 1.10	0.21 – 1.30	0.81 – 1.10	0.83 – 1.20	0.66 – 2.58	0.68 – 1.21
Limited-service restaurants (2+/wk)	1.02	1.10	1.03	0.98	0.84	1.03
Conf. Int.	0.91 – 1.14	0.47 – 2.55	0.89 – 1.19	0.83 – 1.17	0.42 – 1.69	0.78 – 1.35
Full-service restaurants (2+/wk)	1.08	1.18	0.98	0.94	0.72	0.89
Conf. Int.	0.96 – 1.22	0.41 – 3.35	0.84 – 1.15	0.78 – 1.13	0.33 – 1.61	0.66 – 1.19
Small groceries (1+/wk)	1.02	0.45	**1.14**	**1.21**	**1.89**	**0.77**
Conf. Int.	0.91 – 1.14	0.17 – 1.21	**0.98 – 1.33**	**1.01 – 1.44**	**0.95 – 3.77**	**0.58 – 1.04**
Supermarkets (3+/wk)	1.03	0.76	1.01	0.99	0.71	0.94
Conf. Int.	0.93 – 1.14	0.33 – 1.75	0.88 – 1.16	0.84 – 1.17	0.34 – 1.49	0.72 – 1.24

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table C.6. Adjusted odds ratios and confidence intervals for weekly food purchases, by nDPA-based food environment measures (n=99)[a], cont.

Odds ratios for high (4Q) dietary intake of:	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Convenience stores (0.5+/wk)	0.96	0.97	0.95	1.05	1.04	0.97
Conf. Int.	0.83 – 1.10	0.91 – 1.02	0.86 – 1.04	0.96 – 1.16	0.98 – 1.11	0.85 – 1.10
Limited-service restaurants (2+/wk)	1.00	1.02	0.99	1.01	0.97	1.02
Conf. Int.	0.88 – 1.14	0.97 – 1.09	0.90 – 1.08	0.93 – 1.11	0.92 – 1.03	0.90 – 1.14
Full-service restaurants (2+/wk)	1.08	1.02	1.06	0.94	0.99	0.95
Conf. Int.	0.94 – 1.24	0.96 – 1.09	0.96 – 1.18	0.85 – 1.04	0.93 – 1.05	0.83 – 1.08
Small groceries (1+/wk)	1.00	**0.92**	0.93	1.07	**1.09**	**0.89**
Conf. Int.	0.88 – 1.15	**0.87 – 0.98**	0.84 – 1.04	0.97 – 1.19	**1.02 – 1.17**	**0.78 – 1.02**
Supermarkets (3+/wk)	1.04	1.01	0.98	1.02	0.99	1.00
Conf. Int.	0.91 – 1.18	0.96 – 1.07	0.90 – 1.07	0.93 – 1.11	0.94 – 1.05	0.89 – 1.12

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

Table C.7. Adjusted odds ratios and confidence intervals for overweight and obesity, by nDPA-based food environment measures (n=99)[a]

Odds ratios for high (4Q) dietary intake of:	nDPA size	Conv. store density	Limited-service density	Full-service density	Small grocery density	Super-market density
Overweight (BMI 25.0+)	0.94	1.33	0.96	0.97	1.55	0.96
Conf. Int.	0.85 – 1.04	0.54 – 3.25	0.84 – 1.11	0.83 – 1.15	0.80 – 3.01	0.74 – 1.23
Obese (BMI 30.0+)	1.01	0.99	0.87	0.96	1.61	0.76
Conf. Int.	0.86 – 1.18	0.36 – 2.70	0.69 – 1.10	0.76 – 1.22	0.65 – 3.97	0.52 – 1.11

Odds ratios for high (4Q) dietary intake of:	RFEI	Conv. store prop.	Limited-service prop.	Full-service prop.	Small grocery prop.	Super-market prop.
Overweight (BMI 25.0+)	1.01	0.99	1.01	0.99	1.03	0.97
Conf. Int.	0.90 – 1.14	0.94 – 1.05	0.92 – 1.11	0.90 – 1.09	0.97 – 1.08	0.87 – 1.09
Obese (BMI 30.0+)	1.14	1.02	0.92	1.08	1.03	0.90
Conf. Int.	0.95 – 1.36	0.93 – 1.11	0.81 – 1.06	0.95 – 1.24	0.95 – 1.11	0.76 – 1.06

All ORs adjusted for age, gender, race/ethnicity, household income, education, employment status, and marital status.

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