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How to Identify Food Deserts: Measuring Physical and Economic Access to Supermarkets in King County, Washington

Junfeng Jiao, PhD, Anne Vernez Moudon, DrSc, Jared Ulmer, MPH, Philip M. Hurvitz, PhD, and Adam Drewnowski, PhD

Objectives. We explored new ways to identify food deserts.

Methods. We estimated physical and economic access to supermarkets for 5 low-income groups in Seattle–King County, Washington. We used geographic information system data to measure physical access: service areas around each supermarket were delineated by ability to walk, bicycle, ride transit, or drive within 10 minutes. We assessed economic access by stratifying supermarkets into low, medium, and high cost. Combining income and access criteria generated multiple ways to estimate food deserts.

Results. The 5 low-income group definitions yielded total vulnerable populations ranging from 4% to 33% of the county's population. Almost all of the vulnerable populations lived within a 10-minute drive or bus ride of a low- or medium-cost supermarket. Yet at most 34% of the vulnerable populations could walk to any supermarket, and as few as 3% could walk to a low-cost supermarket.

Conclusions. The criteria used to define low-income status and access to supermarkets greatly affect estimates of populations living in food deserts. Measures of access to food must include travel duration and mode and supermarket food costs. (*Am J Public Health*. Published online ahead of print August 16, 2012: e1–e8. doi:10.2105/AJPH.2012.300675)

Inequitable access to healthy, affordable foods in some US communities may be one reason for the observed social disparities in health.[1–3] The term "food desert," originally coined in the United Kingdom,[4,5] describes low-income neighborhoods, both urban and rural, that have limited access to full-service supermarkets or grocery stores.[2,6] Because supermarkets generally offer a variety of healthy foods at reasonable cost, food access is defined by proximity to a supermarket or large grocery store.[2,7,8]

Eliminating food deserts has become a priority issue in national-level food and nutrition policies. Implementation of these policies requires accurate definition and identification of food deserts. The 2008 Farm Bill, Section 7527, defines a food desert as "an area . . . with limited access to affordable and nutritious food, particularly such an area composed of predominantly lower-income . . . communities."[9(p1031)] The Institute of Medicine and the National Research Council use a similar definition.[10]

Studies in public health and urban planning have applied both criteria—low-income status and low access to supermarkets—to identify food deserts.[2,7,11–13] Various geographic boundaries, such as zip codes,[14–16] census tracts,[7,17–22] and census block groups,[12,23,24] have also been used. A national study by the US Department of Agriculture relied on a 1-by-1-kilometer grid.[2] Measures to define a low-income area and its vulnerable population have included zip codes with a median household income at the bottom quintile of the national level (≤ 80% of the surrounding area),[19] census tracts with more than 20% of the population living below the poverty level,[22] and a 1-by-1-kilometer grid with more than 40% of its population at or below 2 times the poverty level.[2]

Food access has typically been measured as the physical distance between the centroids of spatial units of analysis (e.g., census tracts or the 1-km grid as the neighborhood), or between the centroids of spatial units housing the population and the closest supermarket or large grocery store. Various distance thresholds have been used for urban residents: 0.8 kilometers,[25] 1 kilometer,[18] 1 mile,[2,23] 2 kilometers,[22] and 2.5 kilometers.[8] In rural areas, 10 miles has been used.[2,15]

Methodological limitations of past studies included coarse levels of income data aggregation, such as zip codes or census tracts. Analyses based on census block groups, the finest unit for which income data are available, provide more accurate figures of economically challenged populations. Distances between places where people live and shop for food have often been measured as straight-line (Euclidian) distance. Some studies have employed the more realistic street network distance measure.[7,24,26–28] Most studies have focused on driving as the default transportation mode, although some investigated access to a supermarket by walking[2,25,26,29] or taking public transit.[26,29] Finally, with few exceptions,[30–32] most studies have not considered food cost differences among supermarket chains, assuming that all supermarkets offer the same variety of healthy foods at the same cost to consumers.

We sought to introduce an improved approach to measuring food deserts and to refine measures of access to supermarkets. In addition to income, we used 2 access criteria to determine food deserts at the census block group level in Seattle–King County, Washington. We evaluated physical access for different modes of travel. We measured economic access by stratifying supermarkets by food price, with the assumption that low-income populations need to access low-cost supermarkets. We added car ownership as a measure of population vulnerability.[27]

METHODS

Data on population, households, income, car ownership, and poverty rates came from the

2000 US Census.[33] The study's area extent was King County within its urban growth boundary, which contained 90% of the county's population.

We examined 5 groups of low-income populations to test the effect of different measures of low income on the definition of food deserts. We summed population counts for block groups with more than 20% of the population at or below the poverty level,[22,33] with more than 40% of the population at or below twice the poverty level,[2] and with a median household income less than 80% of the median income of King County.[19,33] Two additional measures of vulnerability were block groups in which more than 30% of the households did not own a car and block groups in which more than 20% of the population were below the poverty level and more than 30% of the households had no car.

Supermarkets

Data and geocoding. We identified supermarkets from the 2008 food establishment permits provided by Public Health Seattle and King County. We defined supermarkets as stores that were run by national or regional chains and sold a broad selection of foods, such as canned and frozen foods, fresh fruit and vegetables, and fresh and prepared meats, fish, seafood, and poultry. The data comprised 10 254 permit records, 926 of which belonged to 207 unique supermarkets (most individual supermarkets had multiple permits). Urban Form Lab geocoded all permit addresses and matched them to King County parcel centroids with ArcGIS, version 9.3.1 (ESRI, Redlands, CA). Addresses that failed automatic geocoding (n = 1500) were manually located with Google Maps and Microsoft Live Local searches. A total of 10 215 (99.6%) food permit addresses were geocoded.

Classification by food cost. To measure economic access to food, the University of Washington Center for Obesity Research classified supermarkets into 3 categories: high, medium, and low cost. The classification was based on the cost of a market basket of commonly consumed food items across 8 supermarket chains.[34] The market basket data were collected between January and April 2009 and analyzed according to a method described and used in previous studies.[35,36] Our study priced fewer foods than the earlier studies (100 vs 384), but the pricing rules and procedures were the same.

The market basket cost in the lowest-cost supermarket chain served as a baseline for the classification: chains with a market basket cost 40% higher than baseline were classified as medium-cost chains, and those with a market basket cost 60% above baseline were classified as high-cost chains.[34] Of the 8 supermarket chains, 2 were low cost, 3 medium cost, and 3 high cost. We conducted further market basket research both on-site and online for 6 local supermarkets chains that respondents in a parallel study in King County had reported using as their primary supermarket.[37] We compared the results with the baseline market basket and classified all 6 as low cost. We also classified the county's 3 warehouse chains as low-cost supermarkets. Of the 207 supermarkets in King County, 80 were low cost, 110 medium cost, and 17 high cost.

Physical and Economic Access

A service area around each supermarket defined the population that could reach the store by a predefined travel distance or duration along the road network.[26] Thus individuals living within a service area had access to a supermarket, and residents outside service areas were in potential food deserts. We identified 5 service areas for each supermarket. First, an area of 1 mile or less from a supermarket served as a baseline, because this distance was used in previous research.[2,3,23,38] The other 4 service areas encompassed a 10-minute travel time to a supermarket by either walking, bicycling, riding transit, or driving. This 10-minute travel threshold came from previous research in which 60% of respondents reported traveling less than 10 minutes, and 38% reported traveling 10 to 30 minutes to their primary grocery store.[37]

We delineated service areas in 2 steps with the network analyst in ArcGIS 9.3.1 (ESRI). We first identified the farthest points that could be reached away from a supermarket location following the network of streets within the 1-mile distance or the 10 minutes for each travel mode. Second, we connected each point identified along the network to its closest points by straight lines, which eventually created a service area as the smallest polygon delineated by the points. If the service areas of 2 or more supermarkets overlaid each other, the network analysis merged them into 1 polygon.

Street network data came from ESRI StreetMap Premium North America NAVTEQ 2009 release 1. These data were encoded with mode restrictions, estimated car travel speeds, and physical accessibility (e.g., limited-access roadway on- and off-ramp restrictions), allowing distances to be calculated by either physical distance or travel duration impedances. Service area delineation employed the following distance measures: for the baseline, a physical distance of 1 mile or less; for a 10-minute walk or bicycle trip, a physical distance of 0.5 and 2 miles, respectively; for driving, the 10-minute driving travel impedance, which took into account vehicular travel speeds and directional restrictions; and for riding transit, the 10-minute transit travel impedance. The transit service area also excluded areas that were farther than 0.25 miles of a bus route, a documented median walking distance to a bus stop.[39] Bus route data came from King County Metro Transit.

We applied service areas created for the 1-mile baseline distance and for the 4 travel modes separately to all supermarket locations as well as to the 3 classes of supermarkets by food cost, yielding a total of 20 geographic definitions of service areas.

Populations

To identify the populations living within and outside of supermarket service areas, we intersected census block groups with the service area layers, by geographic information system overlay methods. Where block group boundaries only partially intersected with the service area, we adjusted the service area population proportionally to the area of block groups falling within it. We designated areas outside the service areas but within the King County urban growth boundary as food deserts.

Analyses compared vulnerable populations' access to supermarkets according to the different criteria and measures to define food deserts (Figure 1). First, a set of baseline measures followed the traditional definition of a food desert and included the 5 low-income population groups living within or beyond

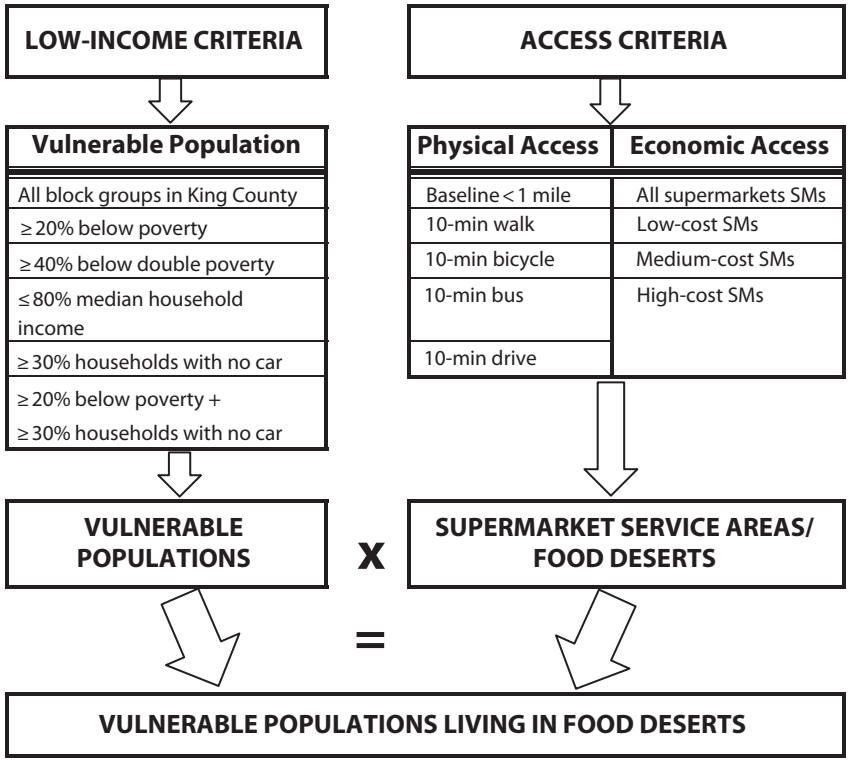


FIGURE 1—Methodological grid to identify food deserts in Seattle–King County, Washington.

1 mile of a supermarket. Second, we stratified economic access to a supermarket by the 3 supermarket cost levels. Third, we measured physical access for the vulnerable populations residing within or beyond a 10-minute travel duration from a supermarket, stratified by mode of travel. Finally, we derived a combined physical and economic access measure from food cost and travel duration by mode.

RESULTS

King County had 1445 census block groups. The population residing in block groups with a median household income of less than 80% of the county's median income constituted 36% of the county's population; 9% of the county's population lived in block groups with more than 20% of the population below the poverty level, 12% lived in block groups with more than 40% below twice the poverty level, 5% lived in block groups in which more than 30% of the households had no car, and 3% lived in block groups with more than 20% of the population below the poverty level and more than 30% of the households lacking a car (data not shown).

The 80 low- and 110 medium-cost supermarkets were evenly distributed across the county. By contrast, most of the 17 high-cost supermarkets were located in North King County (Figure 2).

Baseline data showed that only up to 29% of the vulnerable population (and 44% of the county's total population) lived farther than 1 mile from any supermarket (Table 1). The smallest proportion of the population in low-income groups lived beyond 1 mile of a medium-cost supermarket (26%–42%; 57% of the total population), 69% to 82% (and 78% of the total population) lived more than 1 mile from a low-cost supermarket, and 58% to 85% (and 87% of the total population) lived farther than 1 mile from a high-cost supermarket. The largest proportion of the low-income population whose neighborhoods were food deserts resided in block groups with a median household income of less than 80% of the county's median income: 166 000 persons lived beyond 1 mile of any supermarket, 263 000 lacked access to a medium-cost supermarket, 395 000 (and 0.9 million of the total population) lacked access to a low-cost supermarket, and 486 000 (and 1.2 million of the total population) lacked access to a high-cost supermarket.

When we measured access as a 10-minute trip by different travel modes, we found that less than 8% of the vulnerable population groups lived beyond a 10-minute bicycle or transit ride or drive of any supermarket, but 45% to 66% were beyond a 10-minute walk of any supermarket; 78% of the total population had more than a 10-minute walk.

Considering both travel duration by mode and supermarket by cost yielded different sizes, shapes, and geographic locations of service areas (Figure 3). These in turn generated different population estimates. Access to a high-cost supermarket was limited for all travel modes, but fewer than 2% of persons in vulnerable population groups lived beyond a 10-minute drive of a low- and medium-cost supermarket. Fewer than 8% lived beyond a 10-minute bus ride of these 2 types of supermarkets. Although fewer than 14% of low-income persons lived beyond a 10-minute bicycling distance of a medium-cost supermarket, up to 37% could not bicycle to a low-cost supermarket. We observed a similar pattern in access by walking, but the populations affected were substantially greater: up to 75% of low-income individuals could not take a short walk to a medium-cost supermarket, and up to 97% were farther than 10 minutes by foot from a low-cost supermarket.

DISCUSSION

Eliminating food deserts has become a priority issue in food policy at the national level.[2,3,9,10] To qualify for funding under the Community Foods Project Competitive Grants Program[2] or the Healthy Food Financing Initiative, communities must meet both criteria: low income and low access.[3] Our results demonstrated that estimates of populations living in food deserts depend on how the criteria are defined and what measurement techniques are employed.

Five different ways of identifying low-income populations yielded different group sizes. Median household income at less than 80% of

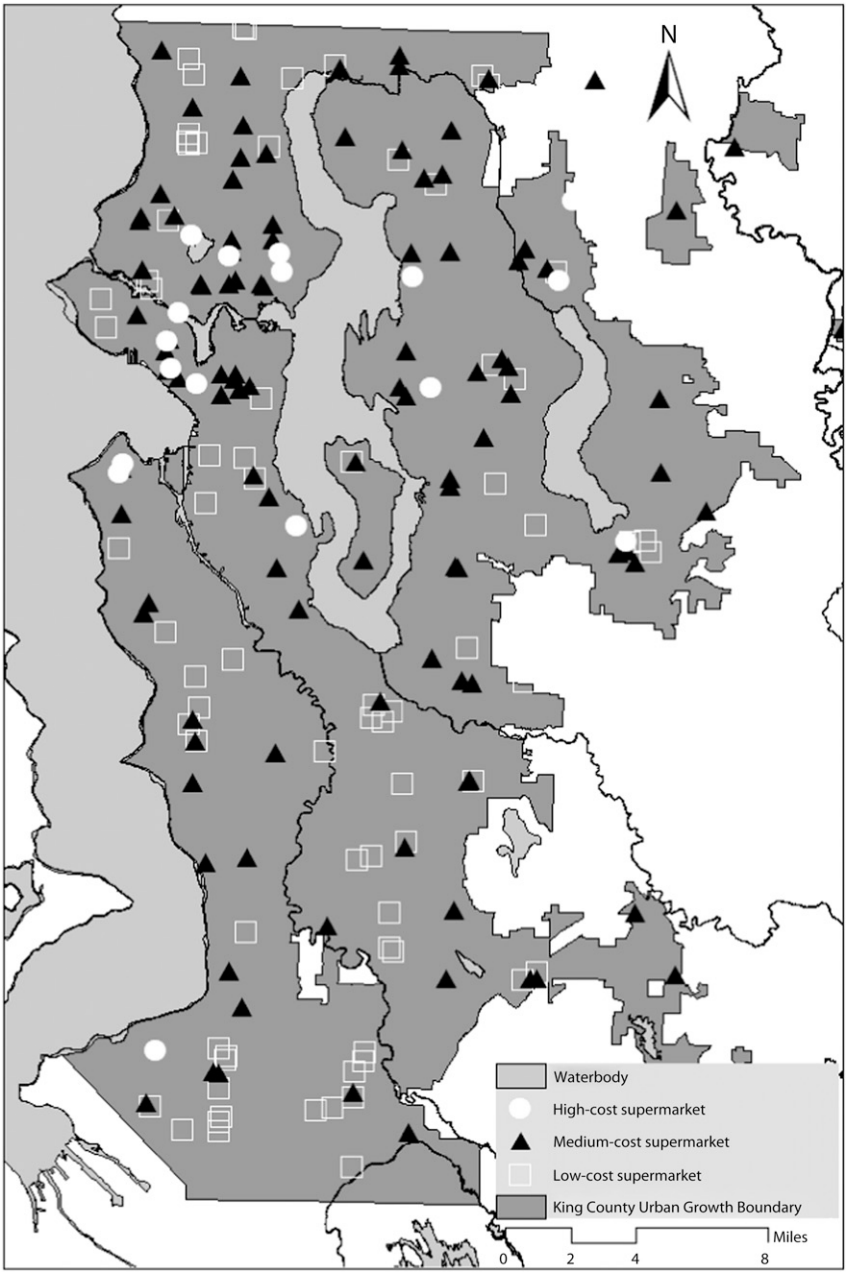


FIGURE 2—Distribution of supermarkets by food cost in Seattle–King County, Washington.

the county's median income produced the largest low-income sample: 36% of the county population. This measure was selected by a study used by the New York City departments of planning and health and mental hygiene.[40] When our measure was 40% of the population at or below twice the poverty level[2] and 20% of the population at or below the poverty level,[20,22] our low-income samples were 11.7% and 9.2% of the county population, respectively. By contrast, defining a low-income group as persons living in census block groups in which 30% of the residents did not have a car[22] and more than 20% lived in poverty yielded a low-income sample of a mere 4% of the county population. Although national data such as the 2003 to 2007 American Time Use Survey showed that more than 90% of the US population drove to the grocery store as either the driver or a passenger,[2] lack of access to a car helped identify areas of concentrated poverty in New Orleans,[22] Detroit,[41] and Chicago.[42]

The geographic delineation of service areas offered a promising approach to measure both physical and economic access to a supermarket.[26] The technique helped assess the effects of street networks, mode of transport, and supermarket food costs on estimating the size of populations living within and outside of service areas. Altogether, our 20 supermarket service areas, combined with our 5 definitions of low-income groups, allowed for multiple ways of estimating the extent of food deserts.

Including supermarket food affordability in the definition of a food desert seemed essential, because vulnerable populations are a priori more sensitive than the general population to food costs. Physical proximity to a high-cost supermarket might not be experienced as access by a low-income household. Classifying supermarkets by food cost clearly changed the identification of food deserts. As expected, low-income families were within easier reach of a supermarket of any type than of a low-cost one. Countywide, the low-income population living beyond 1 mile of a low-cost supermarket was at least twice as large as that living beyond 1 mile of any supermarket.

Driving and taking the bus to a supermarket allowed almost all of the vulnerable populations to reach a low- or medium-cost supermarket. However, when we restricted supermarket access to a 10-minute walk to the nearest low-cost supermarket, the food desert area increased dramatically: more than 89% of low-income individuals were beyond walking distance of low-cost supermarkets. This was likely because stores offering low-cost foods located in lower-density areas with lower land prices, allowing for large inexpensive buildings and large parking areas.[43] Medium-cost supermarkets were more accessible, because they were more numerous and more evenly distributed than either low- or high-cost supermarkets. Of the vulnerable populations 25% to 48% were within walking distance of a medium-cost supermarket.

TABLE 1—Vulnerable Populations and Food Deserts: Seattle–King County, Washington.

Vulnerable Population, by Block Group	Travel Distance or Trip Time From Supermarket				
	1 Mile, %	10-Min Walk, %	10-Min Bicycle Ride, %	10-Min Transit Ride, %	10-Min Drive, %
All supermarkets					
Below poverty level, ≥ 20%	24	60	3	5	1
Below double the poverty level, ≥ 40%	27	65	4	5	1
Median income ≤ 80% of county median income	29	66	5	8	1
Households with no car, ≥ 30%	9	45	0	1	0
Below poverty level, ≥ 20% and ≥ 30% with no car	14	55	1	1	1
Total county population[a]	44	78	11	16	2
Low-cost supermarkets					
Below poverty level, ≥ 20%	72	90	37	6	2
Below double the poverty level, ≥ 40%	69	89	34	6	2
Median income ≤ 80% of county median income	69	90	29	8	2
Households with no car, ≥ 30%	81	95	34	1	0
Below poverty level, ≥ 20% and ≥ 30% with no car	82	97	36	1	1
Total county population[a]	78	94	42	17	3
Medium-cost supermarkets					
Below poverty level, ≥ 20%	42	69	8	5	1
Below double the poverty level, ≥ 40%	46	75	12	5	1
Median income ≤ 80% of county median income	46	74	14	8	2
Households with no car, ≥ 30%	26	52	1	1	0
Below poverty level, ≥ 20% and ≥ 30% with no car	31	61	2	1	1
Total county population[a]	57	84	19	16	2
High-cost supermarkets					
Below poverty level, ≥ 20%	79	97	51	27	26
Below double the poverty level, ≥ 40%	85	98	61	37	1
Median income ≤ 80% of county median income	85	96	67	39	37
Households with no car, ≥ 30%	58	91	23	6	5
Below poverty level, ≥ 20% and ≥ 30% with no car	64	96	23	8	8
Total county population[a]	87	96	72	41	35

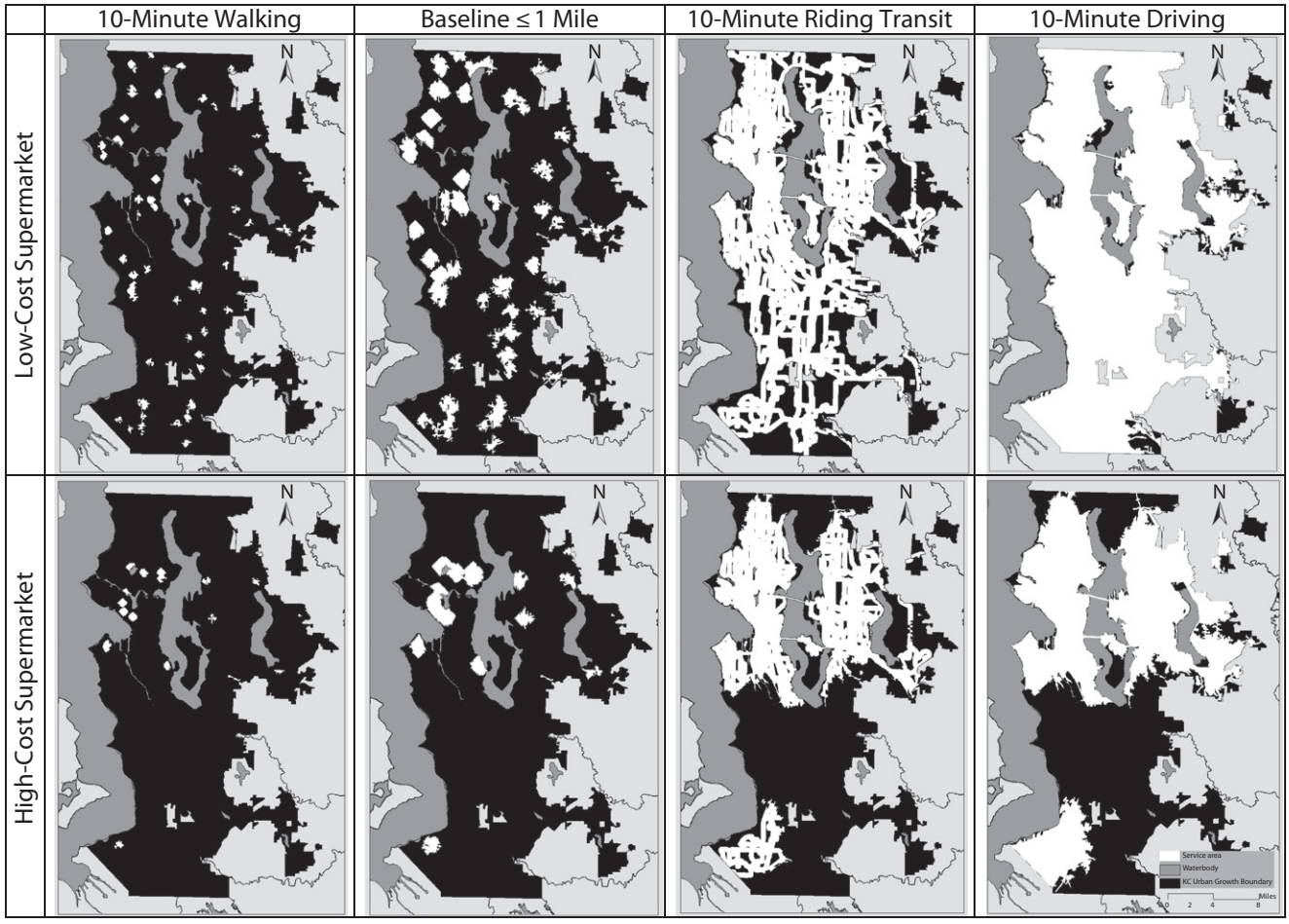
[a]Within urban growth boundary.

The highest proportion of the county's population living in a food desert was 29%; we derived this figure from the measures of the population living in block groups with a median household income of less than 80% of the county's median income and living within a network distance of more than 1 mile from any supermarket. Nationally, more than 20% of low-income urban residents are estimated to live in food deserts, defined as places located more than 1 mile from the closest supermarket[2]; almost 42% live within 0.5 to 1 mile; and 38% within a half mile or less. In rural areas, almost 90% of low-income persons live within 10 miles of a supermarket, almost 9% live within 10 to 20 miles, and about 2% more than 20 miles away.[2]

Other communities wanting to use our approach should select among the criteria and measures listed in Figure 1. The use of median household income will identify the largest vulnerable population that will be at risk for residing in a food desert. By contrast, defining the low-income population as block groups in which 40% are below double the poverty level will target the populations with the lowest income. Census data provide readily available estimates of these populations.

Physical access and travel mode criteria differ by type of community. In general, both car ownership and driving distance should be included in food desert research.[28,41] For research focused on large cities, especially those with high rates of poverty and low rates of car ownership, transit and walk access greatly matter.[20,22,42,44] For research on rural food deserts, distance to food stores serves as a measure for driving time and costs.[2,24] The street network data we used are available commercially (Google Maps uses the same data). Travel mode restrictions encoded in these data help to estimate physical access by travel mode. However, simple distance measures can also define service areas around supermarkets as long as they are weighted by estimates of travel mode impedances (0.5, 2, and 5 miles are commonly used as approximate distances for a 10-minute walk, bicycle ride, and transit ride, respectively).[45]

Finally, economic access as captured by supermarket food costs is best assessed through



Note. KC = King County.

FIGURE 3—Food deserts (black) and service areas (white) around low- and high-cost supermarkets defined as baseline (1 mile) and 10-minute walking, riding transit, and driving network distances in Seattle–King County, Washington.

market basket studies. These types of studies have been undertaken in several areas, and food cost information is readily available from such studies or online for national and regional chains.[6,46–48] However, food costs in nonchain supermarkets and grocery stores are more difficult to assess and may require primary data collection. Survey or focus group techniques may be sufficient to establish relative food cost by supermarket in specific areas.

Limitations

Our methodological innovations are generalizable to other communities. However, the population estimates of food deserts and supermarket access are limited to the conditions in King County. For example, low-income communities were more likely to live within a supermarket service area than was the county population as a whole. This was true regardless of the supermarket type and the mode of travel, suggesting that King County supermarkets tended to locate in areas with a dense and mixed-income population. By contrast, studies conducted in older US metropolitan areas showed that supermarkets had a less uniform spatial distribution and appeared to locate in higher-income areas.[6]

The calculation of transit and driving distances did not capture the entire duration of a door-to-door trip from home to a supermarket. Specifically, bus travel did not take into account time spent walking to and waiting for the bus or bus service frequency, which varies considerably among neighborhoods and between weekdays and weekends. Our driving measure was for the estimated shortest travel duration from home to a supermarket location, along drivable streets and within posted speed limits. It did not consider delays caused by traffic congestion. In addition, the time needed to walk to and park a car and to walk between the parking lot and the store was not part of the travel duration measure. Finally, estimated bicycle distances did not consider topographical barriers. However, the 10-minute impedance for the delineation of service areas was relatively short. Adding 5 minutes to the trip to adjust for likely delays would not drastically alter our results, because a 15-minute trip to a supermarket would remain a realistic

estimate of convenient travel time for grocery shopping.

Block groups have limitations as spatial units of analysis. Our use of the proportion of the block group area falling within a supermarket service area as a way to distribute the population in the service area assumed that the population was evenly distributed within the block group, which was not necessarily the case.

Our definition of supermarket ensured that the stores had a broad selection of products, including dry goods and fresh fruit and vegetables. Although we measured the cost of the food, we did not assess the quality of the products. The assumption that high-cost supermarkets have fresher products than do low-cost stores needs further research. Finally, future studies might also consider stores that supply socially relevant foods for particular populations.[44,49]

Conclusions

We found that the identification of vulnerable populations living in food deserts is highly dependent on the definition and measurement of low-income status and of economic and physical access to supermarkets. Although King County's low-income groups had good access to a supermarket, their access to a low-cost supermarket was more limited. Access by transit was satisfactory for travel duration to affordable food, but this assumed that vulnerable populations' time schedule for shopping coincided with bus service frequency in their neighborhood. Having access to a car was the best guarantee for the majority of the vulnerable populations to reach any supermarket within 10 minutes, making food shopping a car-dependent activity. When supermarket access was defined as pedestrian access to a low-cost supermarket, the area defined as a food desert dramatically increased. ■

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Contributors

J. Jiao developed the research design, finished the data analysis, and led the writing. A. V. Moudon helped interpret findings, write the article, and review drafts. J. Ulmer and P. M. Hurvitz assisted with the study and data analysis. A. Drewnowski helped write the article and review drafts.

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Human Participant Protection

The institutional review board of the University of Washington approved the study.

References

1. Treuhaft S, Karpyn A. *The Grocery Gap: Who has Access to Healthy Food and Why It Matters.* Oakland, CA: PolicyLink and Food Trust; 2010. Available at: http://www.policylink.org/atf/cf/{97C6D565-BB43-406D-A6D5-ECA3BBF35AF0}/FINALGroceryGap.pdf. Accessed April 9, 2011.

2. US Department of Agriculture. Access to affordable and nutritious food: measuring and understanding food deserts and their consequences. 2009. Available at: http://www.ers.usda.gov/Publications/AP/AP036. Accessed April 11, 2011.

3. The White House. *First Lady Michelle Obama Launches Let's Move: America's Move to Raise a Healthier Generation of Kids.* Washington, DC: Office of the First Lady; 2010. Available at: http://www.whitehouse.gov/the-press-office/first-lady-michelle-obama-launches-lets-move-americas-move-raise-a-healthier-genera. Accessed April 9, 2011.

4. Cummins S, Macintyre S. "Food deserts"—evidence and assumption in health policy making. *BMJ.* 2002;325 (7361):436–438.

5. Lang T, Caraher M. Access to healthy foods: part II. Food poverty and shopping deserts: what are the implications for health promotion policy and practice? *Health Educ J.* 1998;57(3):202–211.

6. Walker RE, Keane CR, Burke JG. Disparities and access to healthy food in the United States: a review of food deserts literature. *Health Place.* 2010;16(5):876–884.

7. Apparicio P, Cloutier M-S, Shearmur R. The case of Montreal's missing food deserts: evaluation of accessibility to food supermarkets. *Int J Health Geogr.* 2007;6(4).

8. Coveney J, O'Dwyer LA. Effects of mobility and location on food access. *Health Place.* 2009;15(1):45–55.

9. Food, Conservation, and Energy Act of 2008, 110th Cong, 2nd Sess, HR 6124, Title VII. Available at: http://www.gpo.gov/fdsys/pkg/BILLS-110hr6124eh/pdf/BILLS-110hr6124eh.pdf. Accessed April 12, 2011.

10. Whitacre PT, Tsai P. Janet Mulligan. *The Public Health Effects of Food Deserts.* Washington, DC: Food and Nutrition Board; 2009. Available at: http://www.nap.edu/catalog.php?record_id=12623. Accessed April 9, 2011.

11. Wrigley N. 'Food deserts' in British cities: policy context and research priorities. *Urban Stud.* 2002;39 (11):2029–2040.

12. Kowaleski-Jones L, Fan JX, Yamada I, Zick CD, Smith KR, Brown BB. Alternative measures of food deserts: fruitful options or empty cupboards? National Poverty Center working paper. 2009. Available at: http://www.npc.umich.edu/news/events/food-access/kowaleski-jones_et_al.pdf. Accessed April 9, 2011.

13. Powell LM, Auld MC, Chaloupka FJ, O'Malley PM, Johnston LD. Associations between access to food stores and adolescent body mass index. *Am J Prev Med.* 2007;33(4 suppl):S301–S307.

14. Alwitt LF, Donley TD. Retail stores in poor urban neighborhoods. *J Consum Aff.* 1997;31(1):139–164.

15. Blanchard T, Lyson T. *Access to Low Cost Groceries in Nonmetropolitan Counties: Large Retailers and the Creation of Food Deserts.* Starkville: Mississippi State University–Southern Rural Development Center; 2006. Available at: http://srdc.msstate.edu/trainings/presentations_archive/2002/2002_blanchard.pdf. Accessed April 9, 2011.

16. Kaufman PR. Rural poor have less access to supermarkets, large grocery stores. *Rural Dev Perspect.* 1999;13(3):19–25.

17. Baker EA, Schootman M, Barnidge E, Kelly C. The role of race and poverty in access to foods that enable individuals to adhere to dietary guidelines. *Prev Chronic Dis.* 2006;3(3):A76.

18. Bodor JN, Rose D, Farley TA, Swalm C, Scott SK. Neighbourhood fruit and vegetable availability and consumption: the role of small food stores in an urban environment. *Public Health Nutr.* 2008;11(4):413–420.

19. Powell LM, Slater S, Mirtcheva D, Bao Y, Chaloupka FJ. Food store availability and neighborhood characteristics in the United States. *Prev Med.* 2007;44(3):189–195.

20. Sparks A, Bania N, Leete L. Finding food deserts: methodology and measurement of food access in Portland, Oregon. Paper presented at: National Poverty Center–US Department of Agriculture Economic Research Service conference, Understanding the Economic Concepts and Characteristics of Food Access; February 2009; Washington, DC. Available at: http://www.npc.umich.edu/news/events/food-access/sparks_et_al.pdf. Accessed April 9, 2011.

21. Morland K, Wing S, Diez Roux A, Poole C. Neighborhood characteristics associated with the location of food stores and food service places. *Am J Prev Med.* 2002;22(1):23–29.

22. Rose D, Bodor JN, Swalm CM, Rice JC, Farley TA, Hutchinson PL. Deserts in New Orleans? Illustrations of urban food access and implications for policy. Paper presented at: National Poverty Center–US Department of Agriculture Economic Research Service conference, Understanding the Economic Concepts and Characteristics of Food Access; February 2009; Washington, DC. Available at: http://www.npc.umich.edu/news/events/food-access/rose_et_al.pdf. Accessed April 9, 2011.

23. Berg N, Murdoch J. Access to grocery stores in Dallas. *Int J Behav Healthc Res.* 2008;1(1):22–37.

24. Sharkey JR, Horel S. Neighborhood socioeconomic deprivation and minority composition are associated with

better potential spatial access to the ground-truthed food environment in a large rural area. *J Nutr.* 2008;138 (3):620–627.

25. Algert SJ, Agrawal A, Lewis DS. Disparities in access to fresh produce in low-income neighborhoods in Los Angeles. *Am J Prev Med.* 2006;30(5):365–370.

26. Larsen K, Gilliland J. Mapping the evolution of 'food deserts' in a Canadian city: supermarket accessibility in London, Ontario, 1961–2005. *Int J Health Geogr.* 2008;7:16.

27. O'Dwyer LA, Coveney J. Scoping supermarket availability and accessibility by socio-economic status in Adelaide. *Health Promot J Austr.* 2006;17(3):240–246.

28. Smoyer-Tomic KE, Spence JC, Amrhein C. Food deserts in the prairies? Supermarket accessibility and neighborhood need in Edmonton, Canada. *Prof Geogr.* 2006;58(3):307–326.

29. Pearson T, Russell J, Campbell MJ, Barker ME. Do 'food deserts' influence fruit and vegetable consumption? A cross-sectional study. *Appetite.* 2005;45(2):195–197.

30. Chung C, Myers SL. Do the poor pay more for food? An analysis of grocery store availability and food price disparities. *J Consum Aff.* 1999;33(2):276–296.

31. Andrews M, Kantor LS, Lino M, Ripplinger D. Using USDA's Thrifty Food Plan To Assess Food Availability and Affordability. *Food Access.* 2001;24(2):45–53.

32. MacDonald JM, Nelson PE Jr. Do the poor still pay more? Food price variations in large metropolitan areas. *J Urban Econ.* 1991;30(3):344–359.

33. US Bureau of the Census. Direct file access, 2000 census. Available at: http://www.census.gov/main/www/access.html. Accessed April 12, 2011.

34. Mahmud NK, Monsivais P, Drewnowski A. *The Search for Affordable Nutrient Rich Foods: A Comparison of Supermarket Food Prices in Seattle–King County.* Seattle, WA: Center for Public Health Nutrition; 2009. Available at: http://depts.washington.edu/uwcphn/reports/cphnbrf2.pdf. Accessed April 9, 2011.

35. Monsivais P, Drewnowski A. The rising cost of low-energy-density foods. *J Am Diet Assoc.* 2007;107 (12):2071–2076.

36. Monsivais P, Drewnowski A. Lower energy-density diets are associated with higher monetary costs per kilocalorie and are consumed by women of higher socioeconomic status. *J Am Diet Assoc.* 2009;109(5): 814–822.

37. Jiao J, Moudon AV, Drewnowski A. Grocery shopping: how individuals and built environments influence choice of travel mode. *Transp Res Rec.* 2011; 2230:85–95.

38. Sharkey JR, Horel S. Characteristics of potential spatial access to a variety of fruits and vegetables in a large rural area. Paper presented at: National Poverty Center–US Department of Agriculture Economic Research Service conference, Understanding the Economic Concepts and Characteristics of Food Access; February 2009; Washington, DC. Available at: http://www.npc.umich.edu/news/events/food-access/sharkey.pdf. Accessed April 9, 2011.

39. Lee C, Moudon AV. Correlates of walking for transportation or recreation purposes. *J Phys Act Health.* 2006;3(suppl 1):S77–S98.

40. Smith L, Goranson C, Bryon J, Kerker B, Nonas C. Developing a supermarket need index. In: Maantay J, McLafferty S, eds. *Geospatial Analysis of Environmental Health.* Dordrecht, Netherlands: Springer; 2011:205–221.

41. Zenk SN, Schulz AJ, Israel BA, James SA, Bao S, Wilson ML. Neighborhood racial composition, neighborhood poverty, and the spatial accessibility of supermarkets in metropolitan Detroit. *Am J Public Health.* 2005;95(4):660–667.

42. Gallagher, M. *Examining the Impact of Food Deserts on Public Health in Chicago.* Chicago, IL: Mari Gallagher Research and Consulting Group; 2006. Available at: http://www.marigallagher.com/site_media/dynamic/project_files/Chicago_Food_Desert_Report.pdf. Accessed December 19, 2011.

43. Dunkley B, Helling A, Sawicki DS. Accessibility versus scale: examining the tradeoffs in grocery stores. *J Plann Educ Res.* 2004;23(4):387–401.

44. Raja S, Ma C, Yadav P. Beyond food deserts: measuring and mapping racial disparities in neighborhood food environments. *J Plann Educ Res.* 2008;27 (4):469–482.

45. Bossard E, Hobbs J, Hondorp B, et al. *Envisioning Neighborhoods With Transit-Oriented Development Potential.* Washington, DC: US Department of Transportation; 2002. Report FHWA/CA/OR-2001-25. Available at: http://transweb.sjsu.edu/MTIportal/research/publications/documents/01-15.pdf. Accessed December 19, 2011.

46. Beaulac J, Kristjansson E, Cummins S. A systematic review of food deserts, 1966–2007. *Prev Chronic Dis.* 2009;6(3):A105.

47. Anderson AS, Dewar J, Marshall D, et al. The development of a healthy eating indicator shopping basket tool (HEISB) for use in food access studies—identification of key food items. *Public Health Nutr.* 2007;10(12):1440–1447.

48. Kelly B, Flood VM, Yeatman H. Measuring local food environments: an overview of available methods and measures. *Health Place.* 2011;17(6):1284–1293.

49. Wang MC, Kim S, Gonzalez AA, MacLeod KE, Winkleby MA. Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index. *J Epidemiol Community Health.* 2007;61(6):491–498.