CADMUS

HEAT SENSITIVITY-EXPOSURE INDEX METHODOLOGY REPORT

CLIMATE READY DC

May 2022

Prepared for:

Washington DC
Department of Energy and Environment

CADMUS

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I. Introduction

To advance the extreme heat planning efforts in the District of Columbia, the Cadmus Team conducted a heat sensitivity and exposure indexing assessment. A series of heat risk index maps were produced for this exercise; the methodology is detailed in this report. Among other things, these maps were used to support Working Group discussions with numerous DC agencies and partners to drive well informed policy decisions.

A. Variable Selection

To create and refine a list of index variables, the Cadmus Team conducted research on extreme heat, its health impacts, and factors that can worsen and individual's sensitivity to heat or heat exposure. This included a literature review of heat assessments and vulnerability indices from other U.S. jurisdictions including: New York City, NY; Boston, MA; Minneapolis, MN; Philadelphia, PA; San Francisco, CA; Milwaukee, WI; Louisville, KY; Richmond, VA; Phoenix, AZ; and the state of Georgia.

From this initial list, Cadmus developed case studies for New York City, Boston, Minneapolis, Philadelphia, and San Francisco for a more in-depth analysis, as detailed in the Desk Research Memo. These cities were selected based on varying methods of analysis and variables used (e.g., Boston and Minneapolis use unweighted aggregation method for indexing, whereas and Philadelphia, New York City, and San Francisco used Principal Component Analysis). Following this review, Cadmus conducted interviews with city representatives to discuss best practices and lessons learned for index variables, methodology, and post-mapping interventions. These include:

- Jason Hammer, Public Health Preparedness Planner, **Philadelphia Department of Public Health**
- Matt Wolff, Geospatial Analyst, **San Francisco Department of Public Health**
- Kelly Muellman, Sustainability Program Coordinator, **City of Minneapolis**

Cadmus also conducted an email interview with:

- Julia Eiferman and Kizzy Charles-Guzman, Senior Policy Advisory and Deputy Director, respectively, **NYC Mayor's Office of Resiliency**

Cadmus coupled the research from other jurisdictions with DC-specific heat vulnerability work. Cadmus reviewed existing DC-specific heat vulnerability literature, such as the 2018 Mapping Extreme Heat Vulnerability Study and interviewed lead author Juan Declet-Barreto, Union of Concerned Scientists, for additional methodology recommendations.

Based on the results from the desk research and stakeholder interviews, Cadmus proposed a set of indicator variables for inclusion in the sensitivity and exposure indices. To discuss data availability and receive feedback on the proposed variables, Cadmus then met with Extreme Heat Working Group members from DC Homeland Security and Emergency Management Agency (HSEMA), DC Health, District Department of Transportation (DDOT), and DOEE. In November of 2019, Cadmus hosted a webinar with representatives from DOEE, HSEMA, Office of Planning (OP), Office of Civil Rights (OCR), DDOT, and DC Water to present the proposed methodology and indicator variables and receive input. The final list of variables is outlined in Table 1. The methodology is described in Section II. Data Collection and Processing and Section III. Indexing and Mapping

Table 1. Variables included in the Heat Sensitivity-Exposure Index

Variable	Unit/Measure	Data Year[1]	Data Source	Rationale for Inclusion
People of Color	Percent who did not identify as 'Not Hispanic or Latino, White Alone'	2015 – 2019 (Last updated 2021)	OpenData DC ("ACS Demographic Characteristics DC Census Tract")	▪ Historical and structural patterns of inequity, marginalization, and discrimination can lead to significantly divergent health risks and outcomes
Elderly	Percent of population aged 65+	2015 – 2019 (Last updated 2021)	OpenData DC ("ACS Demographic Characteristics DC Census Tract")	▪ Physiologically more sensitive to heat: greater risk of dehydration ▪ More likely to have limited mobility and/or physical or cognitive health conditions ▪ More likely to be dependent on caretakers
Young Children	Percent of population aged 0-5	2015 – 2019 (Last updated 2021)	OpenData DC ("ACS Demographic Characteristics DC Census Tract")	▪ Physiologically more sensitive to heat: takes longer to cool due to more rapid heat intake and reduced sweating capacity ▪ More likely to be dependent on caretakers
Low-Income	Percent under 200% the Federal Poverty Line rate	2015 – 2019 (Last updated 2021)	Census Bureau ("Poverty Status in the Past 12 Months")	▪ More likely to have lesser adaptive capacity (e.g., economic resources to withstand heat) and/or be energy burdened (i.e., lack ability to run air conditioning) ▪ Often face longer post-hazard recovery time
Disability	Percent reported having a disability	2015 – 2019 (Last updated 2021)	OpenData DC ("ACS Social Characteristics DC Census Tract")	▪ Physical and/or mental constraints can cause limited mobility and ability to protect themselves ▪ More likely to be dependent on caretakers and may require additional support (e.g., transportation, specialized care)
English Proficiency	Percent that speak English less than very well	2015 – 2019 (Last updated 2021)	OpenData DC ("ACS Demographic Characteristics DC Census Tract")	▪ Language barrier may prevent access to emergency services or ability to recognize or understand emergency warnings
Asthma	Percent of adults with asthma	2021	CDC PLACES Data	▪ High heat and humidity trap pollutants in the air, exacerbating asthma symptoms and complications

[1] Values with a range (i.e., 2015 – 2019) indicate American Community Survey (ACS) 5-year estimates. More information on 5-year estimates can be found here: https://data-planet.libguides.com/ACS

Variable	Unit/Measure	Data Year[1]	Data Source	Rationale for Inclusion
Obesity	Percent of adults reporting to be obese[2]	2021	CDC PLACES Data	▪ Obesity is a noted health risk factor for heat-related illnesses, as overweight individuals retain more body heat
Coronary Heart Disease (CHD)	Percent of adults ever diagnosed with CHD	2021	CDC PLACES Data	▪ Chronic conditions like CHD can be exacerbated by extreme heat, and can impairs the body's ability to properly regulate temperature
Ambient Air Temperature	Degrees Fahrenheit	2019	OSF	▪ Used as the measure for heat exposure Compared to land surface temperature, ambient air temperature is more representative of perceived heat
Impervious Surfaces	Percent of impervious surfaces	2021	OpenData DC ("Impervious Surface 2021")	▪ Surfaces such as parking lots, buildings, and streets absorb heat and re-radiate it, contributing to the UHI effect and increasing energy consumption
Tree Canopy Cover	Percent without tree canopy cover	2020	Urban Forestry Division District, Department of Transportation	▪ Trees have a cooling effect by providing shade, facilitating evapotranspiration, and absorbing CO_2 ▪ Neighborhoods with fewer trees are more physically sensitive to extreme heat

II. Data Collection and Processing

The Heat Sensitivity-Exposure Index is the final product of this analysis. This Index combines a Heat Sensitivity Index and a Heat Exposure Index allowing users to visualize which census tracts in DC are most heat sensitive and/or exposed.

The Heat Sensitivity Index is made up of variables that influence an individual's ability to adapt to, cope with, or recover from extreme heat and includes six socio-economic and demographic variables and three health variables. The Heat Exposure Index includes ambient air temperature as the heat exposure variable and two physical variables that contributes to heat retention (i.e., impervious surfaces and lack of tree canopy cover).

The following sections outline the data gathering processes for these sensitivity and exposure variables.

A. Heat Sensitivity Index Variables

This section describes the data sources for the variables included in the Heat Sensitivity Index.

[2] Measured as a body mass index of 30 or greater.

1. *Socio-Economic and Demographic Variables*

Data for the six socio-economic and demographic variables outlined in Table 2 were pulled from the American Community Survey (ACS) across census tracts, found here: https://data.census.gov/cedsci/.

Table 2. Source data for 6 socio-economic variables.

Variable	ACS Table ID	ACS Table Description	Measure
People of Color	DP05_0077E	HISPANIC OR LATINO AND RACE	100 – (Percent; Total population not Hispanic or Latino, White Alone)
Elderly	DP05_0024E	SEX AND AGE	Total population: 65 years and over
Children	DP05_0005E	SEX AND AGE	Total population: Under 5 years
Low Income	S1701	POVERTY STATUS IN THE PAST 12 MONTHS	All Individuals With Income Below the Following Poverty Ratio: 200%
Disability	DP02_0072E	DISABILITY STATUS OF THE CIVILIAN NONINSTITUTIONALIZED POPULATION	Total Civilian Noninstitutionalized Population: With a disability
English Proficiency	DP02_0114E	LANGUAGE SPOKEN AT HOME	Population 5 years and over: Language other than English: Speak English less than very well

2. *Health Variables*

Data for the three health variables outlined in Table 3 were downloaded from the CDC's PLACES: Local Data for Better Health dataset, found here: https://www.cdc.gov/places/index.html. PLACES data provides estimates for chronic disease risk factors, health outcomes, and clinical preventive services.

Table 3. Source data for 3 health variables.

Variable	Table Attribute	Attribute Description
Asthma	CASTHMA_CrudePrev	Model-based estimate for crude prevalence of arthritis among adults aged >=18 years, 2019
Obesity	OBESITY_CrudePrev	Model-based estimate for crude prevalence of obesity among adults aged >=18 years, 2019
Coronary Heart Disease	CHD_CrudePrev	Model-based estimate for crude prevalence of coronary heart disease among adults aged >=18 years, 2019

B. Heat Exposure Index Variables

This section describes the data sources for the variables included in the Heat Exposure Index.

1. *Ambient Air Temperature*

Data for ambient air temperature was downloaded from Open Science Framework: Washington, D.C. Urban Heat Island Assessment, found here: https://osf.io/qfjwz/

Data was collected from days where maximum air temperatures were above the 90th percentile of historic averages and processed through geocomputational machine learning. For more detail on the data acquisition process, see the accompanying paper: *Shandas, V.; Voelkel, J.; Williams, J.; Hoffman, J. Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat. Climate 2019, 7, 5.*

This dataset included 3 rasters of predicted ambient air temperature acquired at different times of day:

- Morning (6am)
- Afternoon (3pm)
- Evening (7pm)

The Afternoon layer was used because it had the highest temperature range (i.e., 85.4-101.9 degrees Fahrenheit).

2. Impervious Surfaces

Impervious surfaces are structures covered in water-resistance pavement, such as buildings, roads, sidewalks, etc. This layer was prepared by the D.C. Office of the Chief of Technology Officer (OCTO) and is available on Open Data DC.

3. Tree Canopy Cover

The DDOT Urban Forestry Division shared a tree canopy cover layer with the project team (i.e., this data is not publicly available). This layer is a generalized vector extracted from the 2020 landcover raster and was created during OCTO's planimetric data capture (i.e., physical features are extracted from aerial photography). The mapping standards and planimetric base layer mapping resources from OCTO provide more detail on planimetric data and the data capture process.

Despite being a generalized layer (i.e., not appropriate for precise scientific purposes), this layer was suitable for the purposes of this aggregation analysis and provides a sufficiently granular assessment of tree canopy cover in the District.

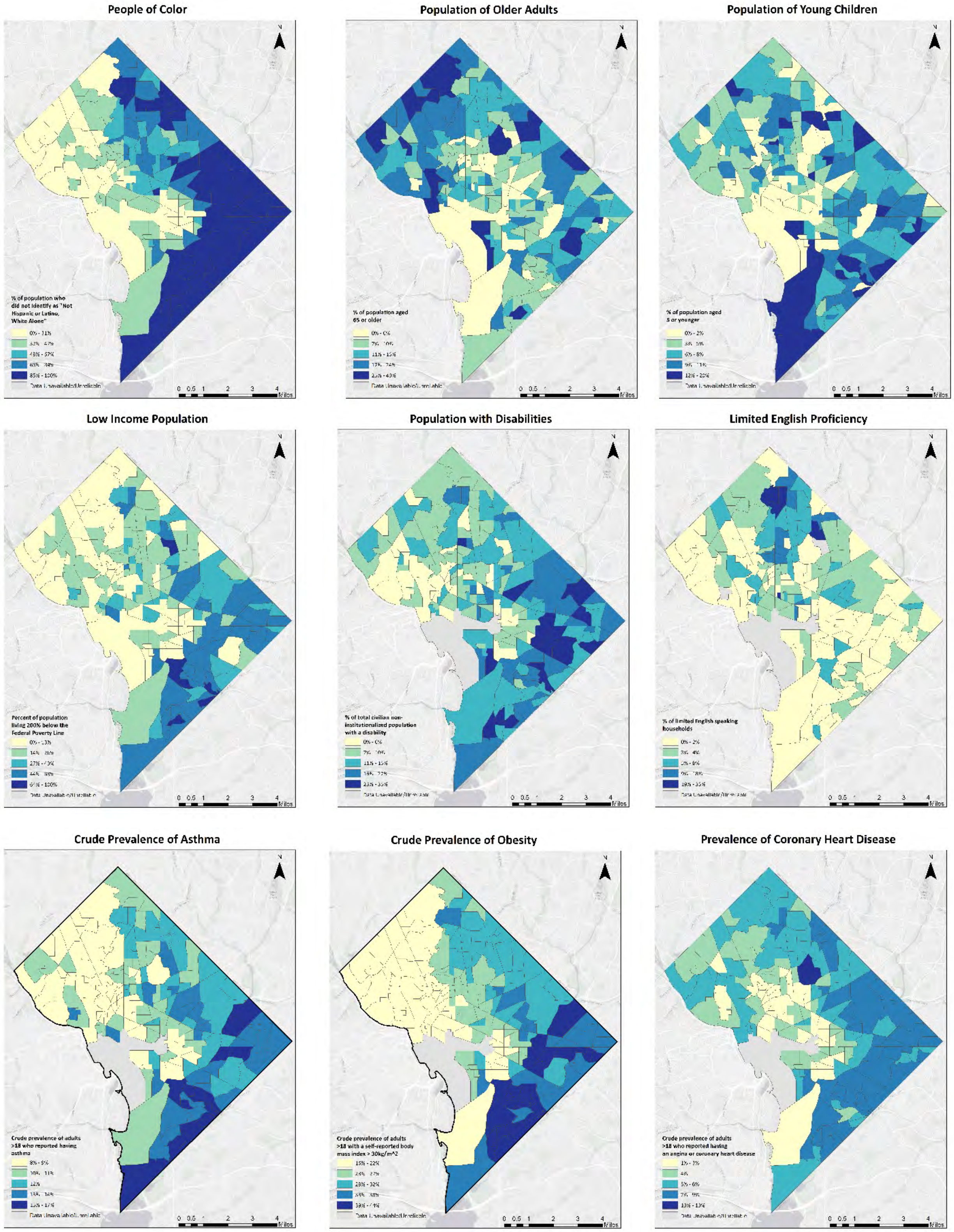
III. Indexing and Mapping

The following section describes the processes used to create the Heat Sensitivity Index, the Heat Exposure Index, and how these two were combined to make a produce the Heat Sensitivity-Exposure Index. This section includes a description of the geospatial processes used. ArcMap 10.8.1 was used, and all maps were classified using Natural Breaks (Jenks).

A. Heat Sensitivity

The 6 socio-economic and demographic variables were downloaded from ACS and merged with the 3 health variables by Census Tract ID. Together, these 9 variables make up the Heat Sensitivity Index. Figure 1 displays the 9 sensitivity variables by census tract in Washington DC. See Figures 8 – 16 in the Appendix for full size maps.

Figure 1. Maps of the six socio-economic and three health variables used to produce the Heat Sensitivity Index.



1. *Heat Sensitivity Index*

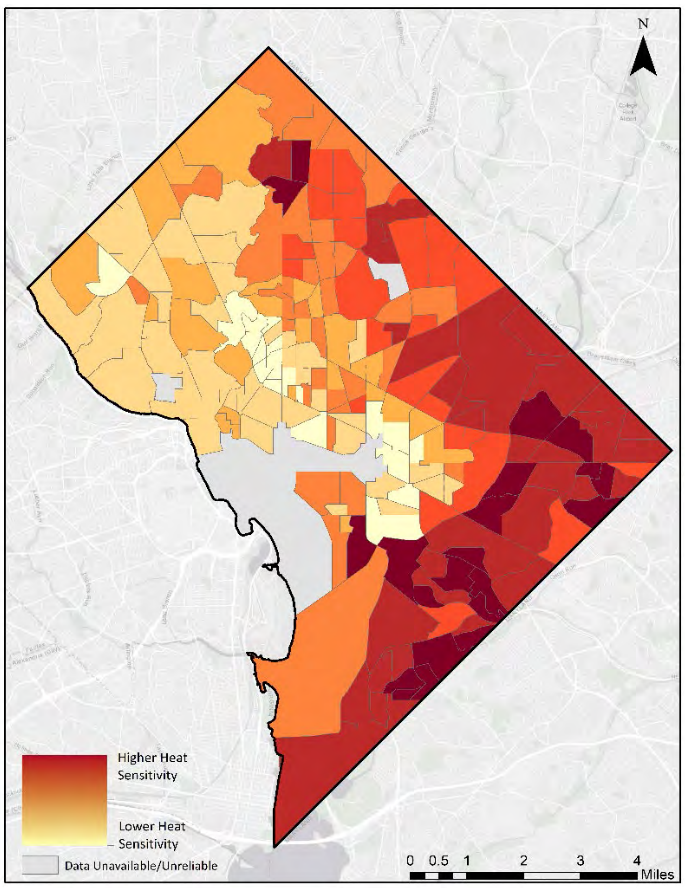
The nine socio-economic and health variables described above were combined to build the Heat Sensitivity Index. Variables were standardized and indexed using the following unweighted aggregation formula:

$$Component\ Index_i = \left(\frac{population\ share_j - minimum\ census\ tract\ share}{maximum\ census\ tract\ share - minimum\ census\ tract\ share}\right) \times \left(\frac{1}{n}\right)$$

Where:
i = variable; *j* = census tract; n = number of variables (in the case of heat sensitivity, n = 9)

The nine component indices were then summed to calculate the Heat Sensitivity Index value for each census tract. Three census tracts were removed from analysis due to issues with data reliability or availability. Figure 2 depicts the final Heat Sensitivity Index map, see Figure 17 in the Appendix for full size maps.

Figure 2. Heat Sensitivity Index Map



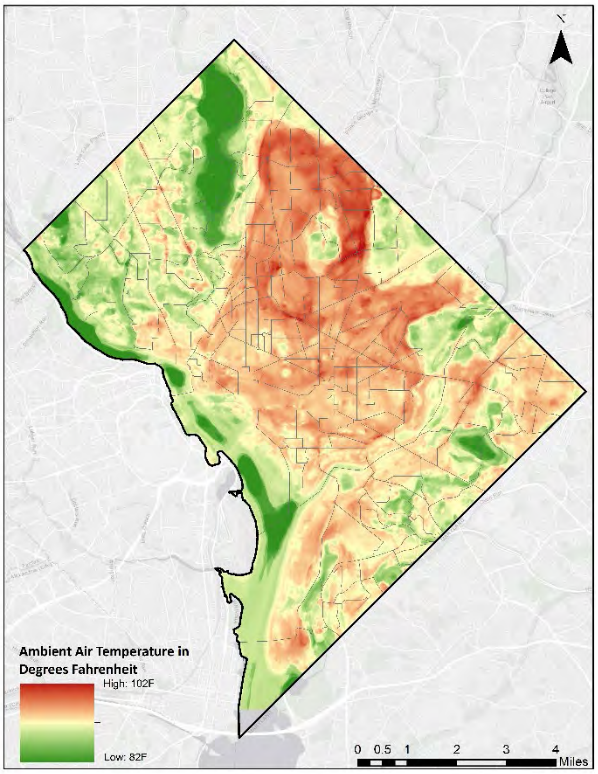
Heat Exposure

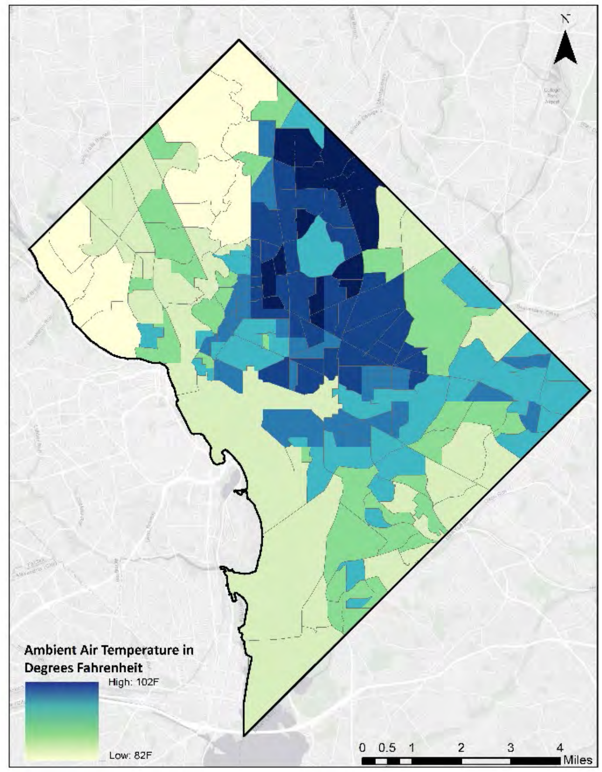
This section describes the course of geoprocessing the three exposure variables to aggregate into the Heat Exposure Index.

1. *Ambient Air Temperature*

Figure 3 (left) displays the raster data of predicted ambient air temperature data. The ***Zonal Statistics as Table*** tool was used to aggregate average temperature values by census tract. Census tracts were used as "zones" for this tool. Figure 3 (right) depicts the results of this exercise, or the average ambient air temperature of each census tract, with darker colors indicating higher average temperatures.

Figure 3. Map of ambient air temperature exposure in DC





See Figure 18 - 19 in the Appendix for full size maps.

2. *Impervious Surface Cover*

Figure 4 (left) pictures impervious surface cover throughout the District. To aggregate average impervious surface cover by census tract, the impervious surface layer was first joined to the census tract layer by spatial location (***Join data from another layer based on spatial location***, summarizing attributed "Average" and "Sum").

The ***Dissolve*** tool was used to calculate the following statistics:

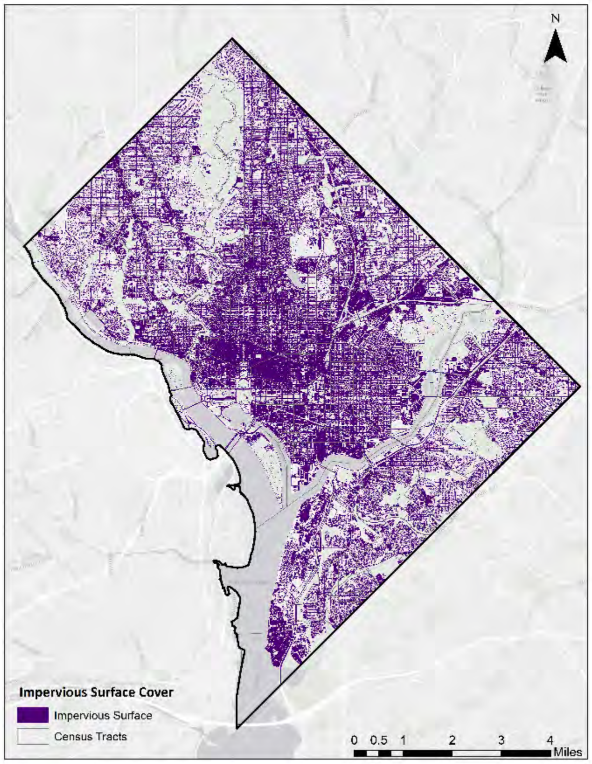
Field	Statistic Type	Resulting Dissolve Field
Area of the Impervious Surfaces	SUM	SUM_Area
Area of Census Tract	FIRST	FIRST_CT

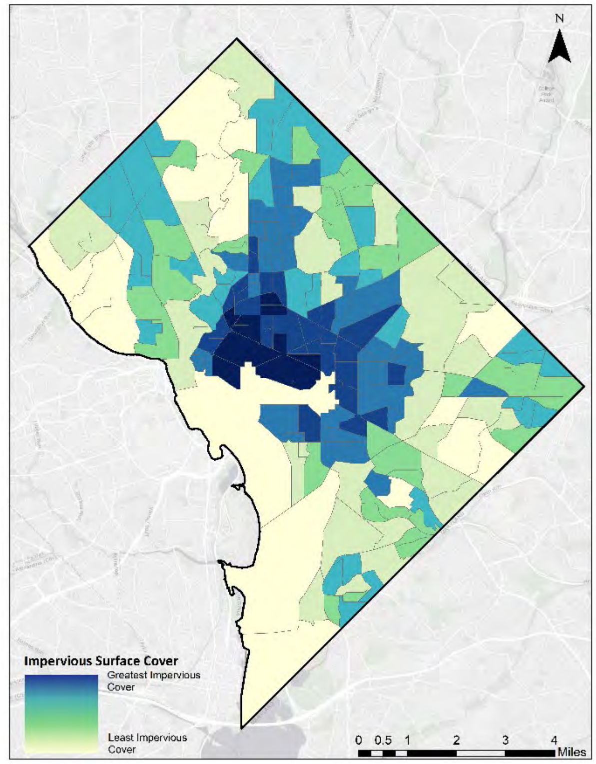
Then, the ***Field Calculator*** was used to measure percent cover for each census tract using the dissolved field values:

$$Percent\ Cover = \left(\frac{[\text{SUM\_Area}]}{[\text{FIRST\_CT}]}\right) \times 100$$

Figure 4 (right) depicts the results of this exercise, or the average impervious surface cover by census tract, with darker colors indicating greater average impervious cover.

Figure 4. Maps of impervious surface cover in DC





See Figure 20 - 21 in the Appendix for full size maps.

3. Tree Canopy Cover

Figure 5 (left) shows tree canopy cover across the District. The dataset provided by DDOT includes a raster layer classified by land surface cover. Tree canopy cover was extracted (Tree canopy cover = Code “101” in the dataset), then all features were merged. To aggregate average canopy cover by census tracts, the ***Tabulate Area*** tool was used. The census tracts layer was used as the ‘Feature Zone’ and tree canopy cover layer was used as the ‘Feature Class’. The output table of Tabulated Area tool was then joined to the census tract layer. A new field was created using the ***Field Calculator*** to calculate percent cover:

$$Percent\ Cover_j = \left(\frac{Area\ of\ Tree\ Canopy\ Cover}{Area\ of\ Census\ Tract}\right) \times 100$$

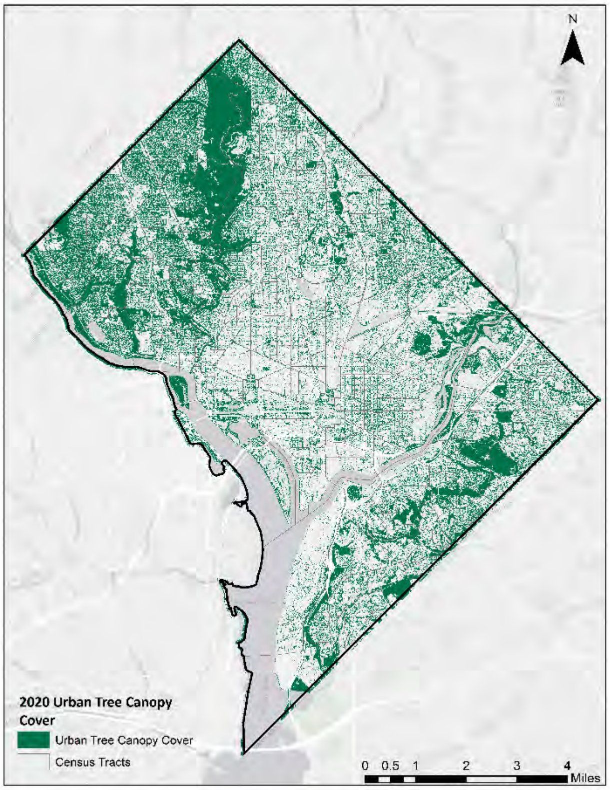
Where:
j = census tract

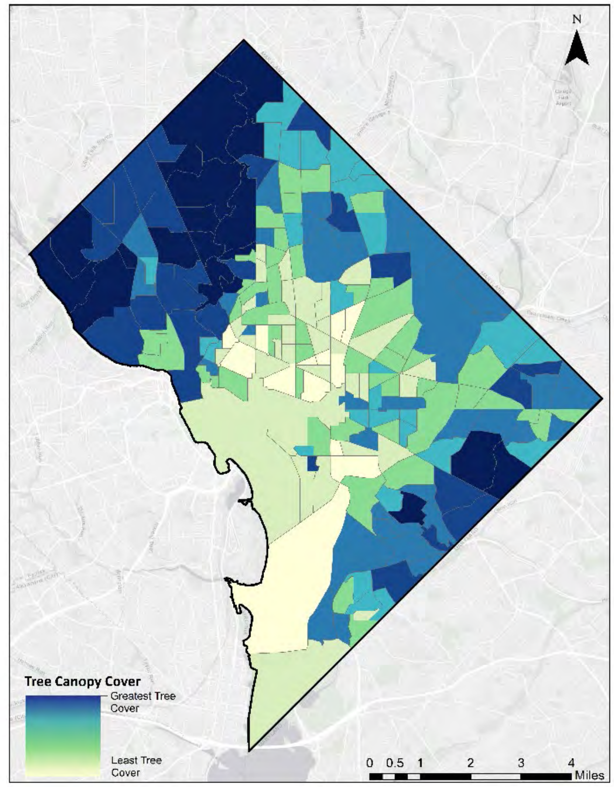
For indexing purposes, the *lack* of tree canopy cover is the variable of interest. Therefore, the ***Field Calculator*** was used again to determine the percent of census tract area *without* tree canopy cover:

$$Percent\ without\ Cover_j = 100 - \ Percent\ Cover_j$$

Figure 5 (right) shows average tree canopy cover by census tract, with darker colors indicating greater average canopy.

Figure 5. Maps of urban tree canopy cover





See Figure 22 - 23 in the Appendix for full size maps.

4. Heat Exposure Index

The three physical landscape variables described above were combined to build the Heat Exposure Index. Similar to the Heat Sensitivity Index, the values for each variable were standardized and indexed by converting them into component indices, then summing them together:

$$Component\ Index_i = \left(\frac{Census\ Tract\ value_j - minimum\ Census\ Tract\ value}{maximum\ Census\ Tract\ value - minimum\ Census\ Tract\ value}\right) \times \left(\frac{1}{x}\right)$$

Where:
i = variable; *j* = census tract; x = weight (value in between 0 and 1)[3]

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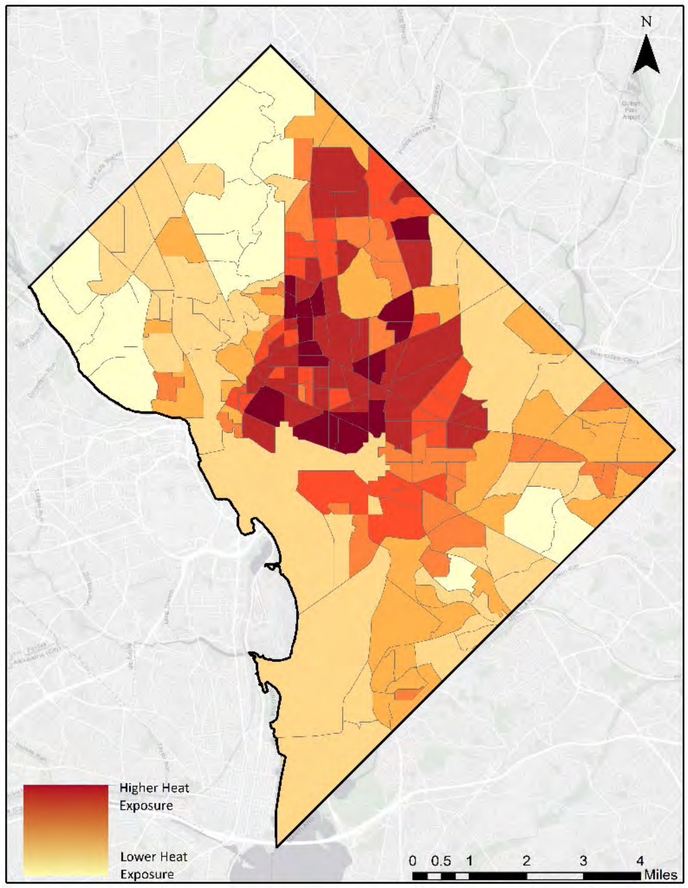
[3] The $\left(\frac{1}{x}\right)$ term indicates weighing scheme for each variable. Given the weighting scheme, the formula is: (standardized ambient air temperature value)*(0.50) + (standardized lack of tree canopy value)*(0.25) + (standardized impervious surface cover value)*(0.25).

Unlike the Heat Sensitivity Index, the exposure variables were weighted differently based on input from the Extreme Heat Working Group Members. Ambient air temperature was weighed more heavily, i.e.: 50% heat exposure, 25% lack of tree canopy, 25% impervious surfaces.

Figure 6. Heat Exposure Index (HEI).

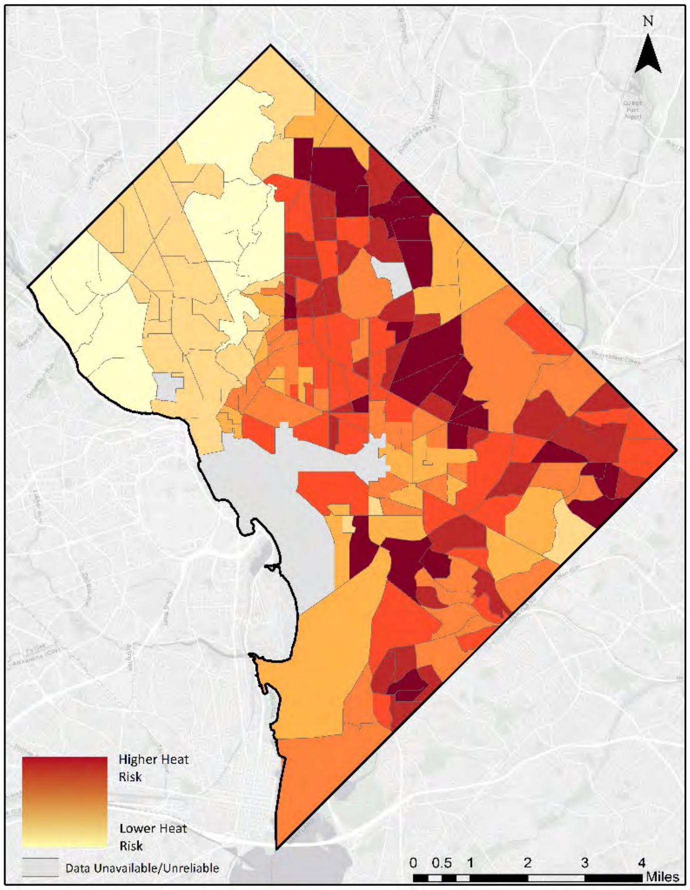


See Figure 24 in the Appendix for full size maps.

Heat Sensitivity-Exposure Index

Finally, the Heat Sensitivity Index and Heat Exposure Index were combined to create the Heat Sensitivity-Exposure Index (HSEI). The HSEI is equal parts sensitivity and exposure (i.e., 50% Heat Sensitivity, 50% Heat Exposure).

Figure 7. Heat Sensitivity-Exposure Index (HSEI)



See Figure 25 in the Appendix for full size maps.

Appendix A. Map Book

Figure 8. Map of population of people of color across DC census tracts.

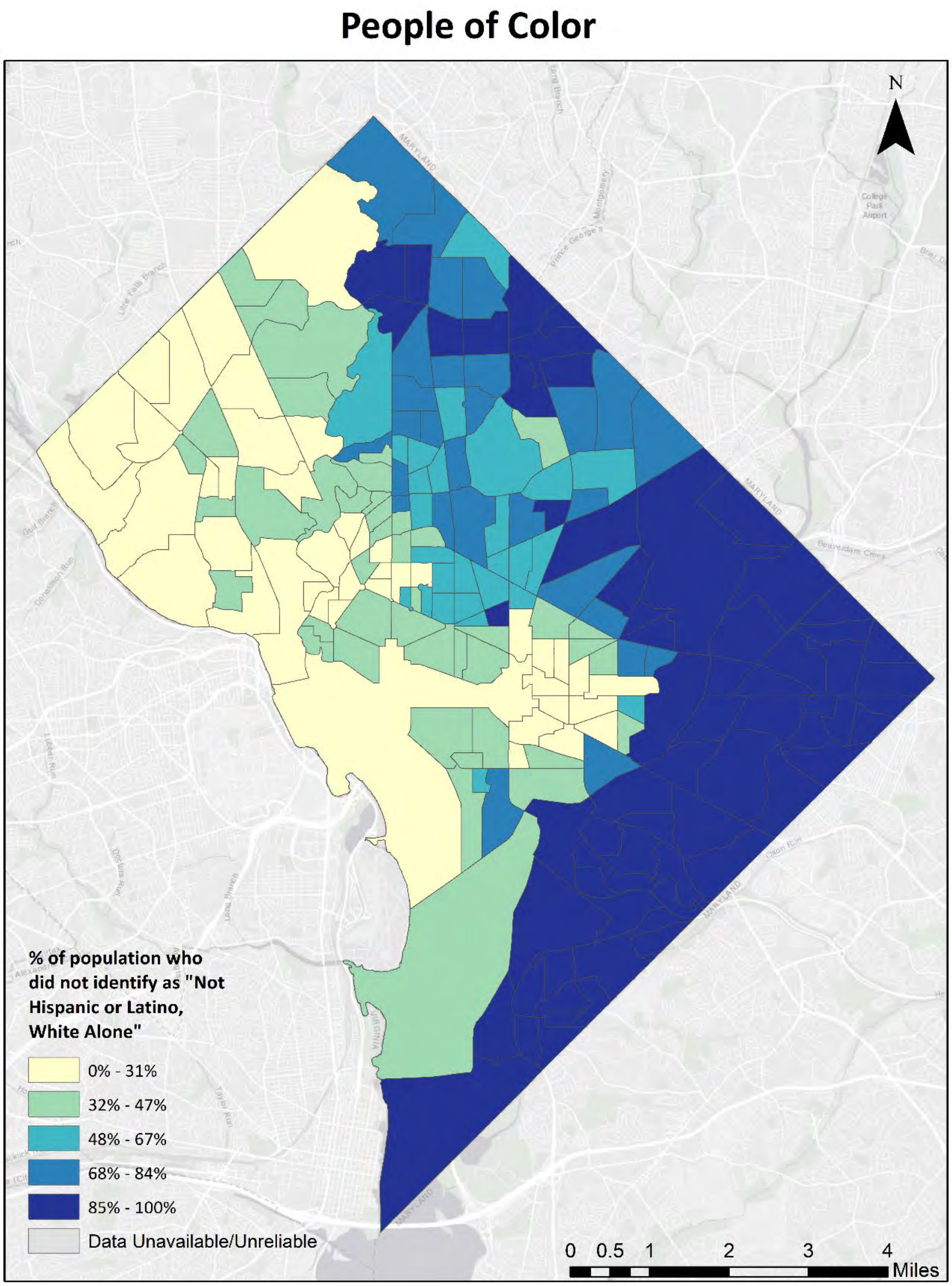


Figure 9. Map of population of young children across DC census tracts.

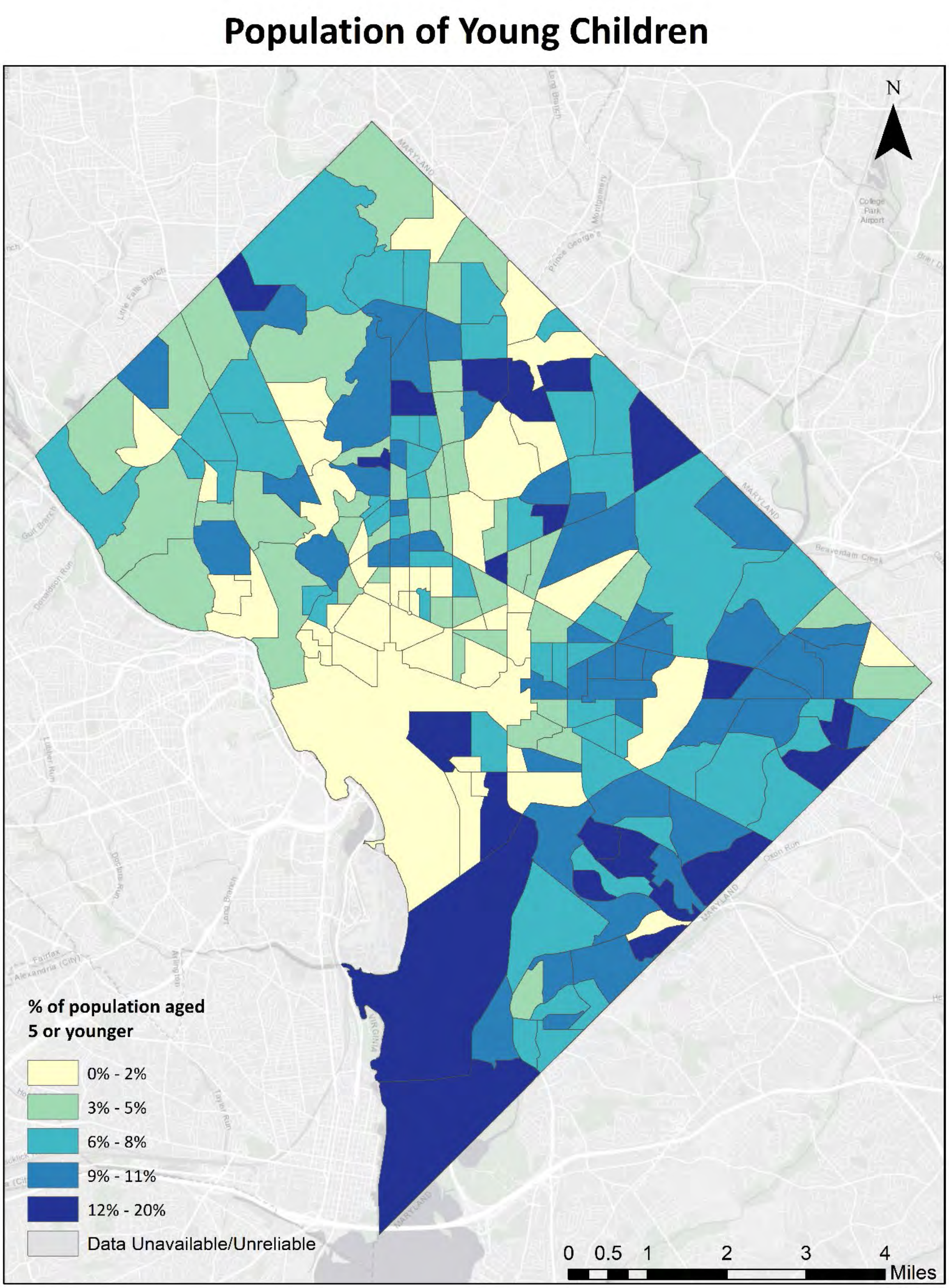


Figure 10. Map of population of older adults across DC census tracts.

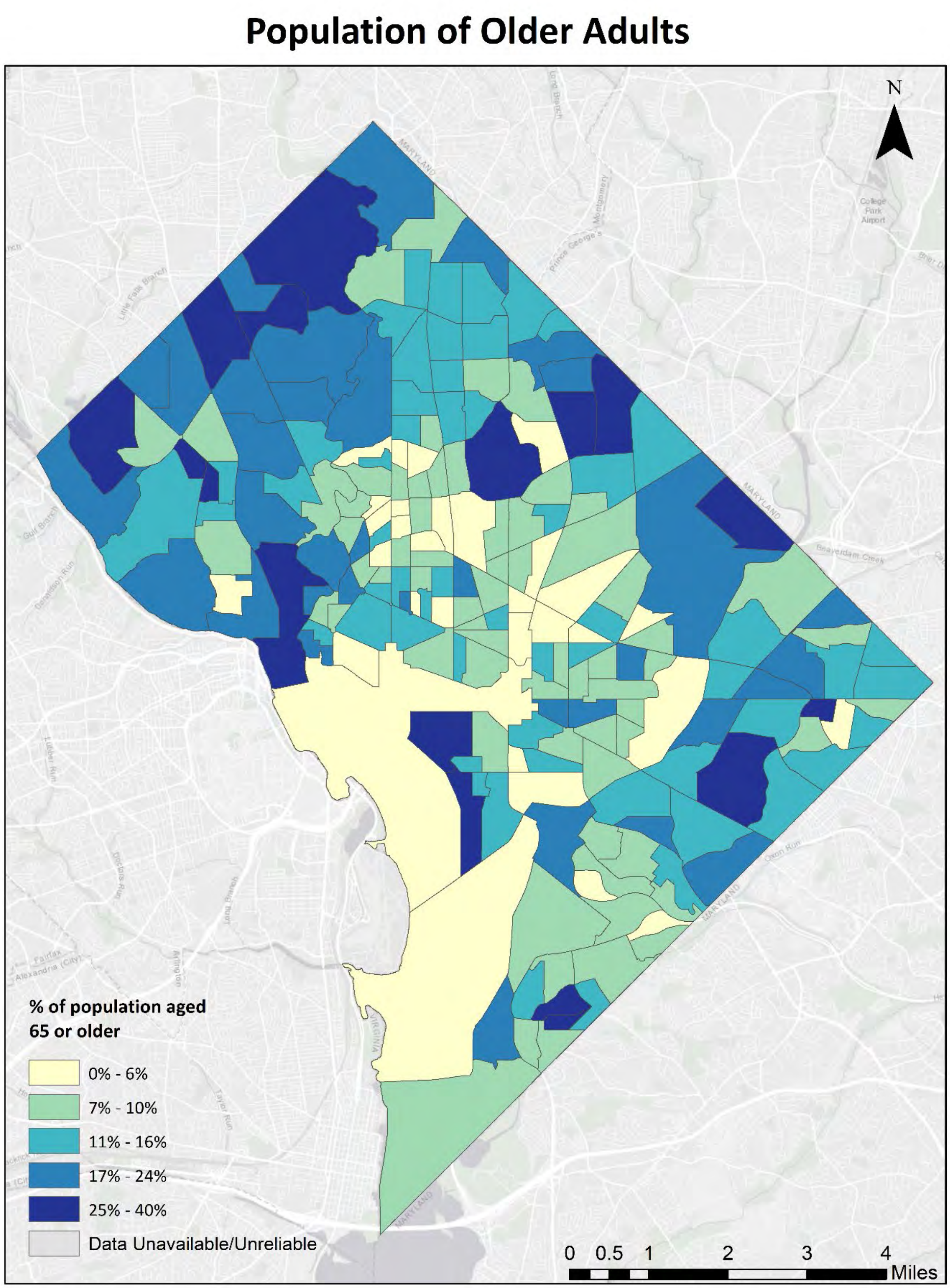


Figure 11. Map of low income population across DC census tracts.

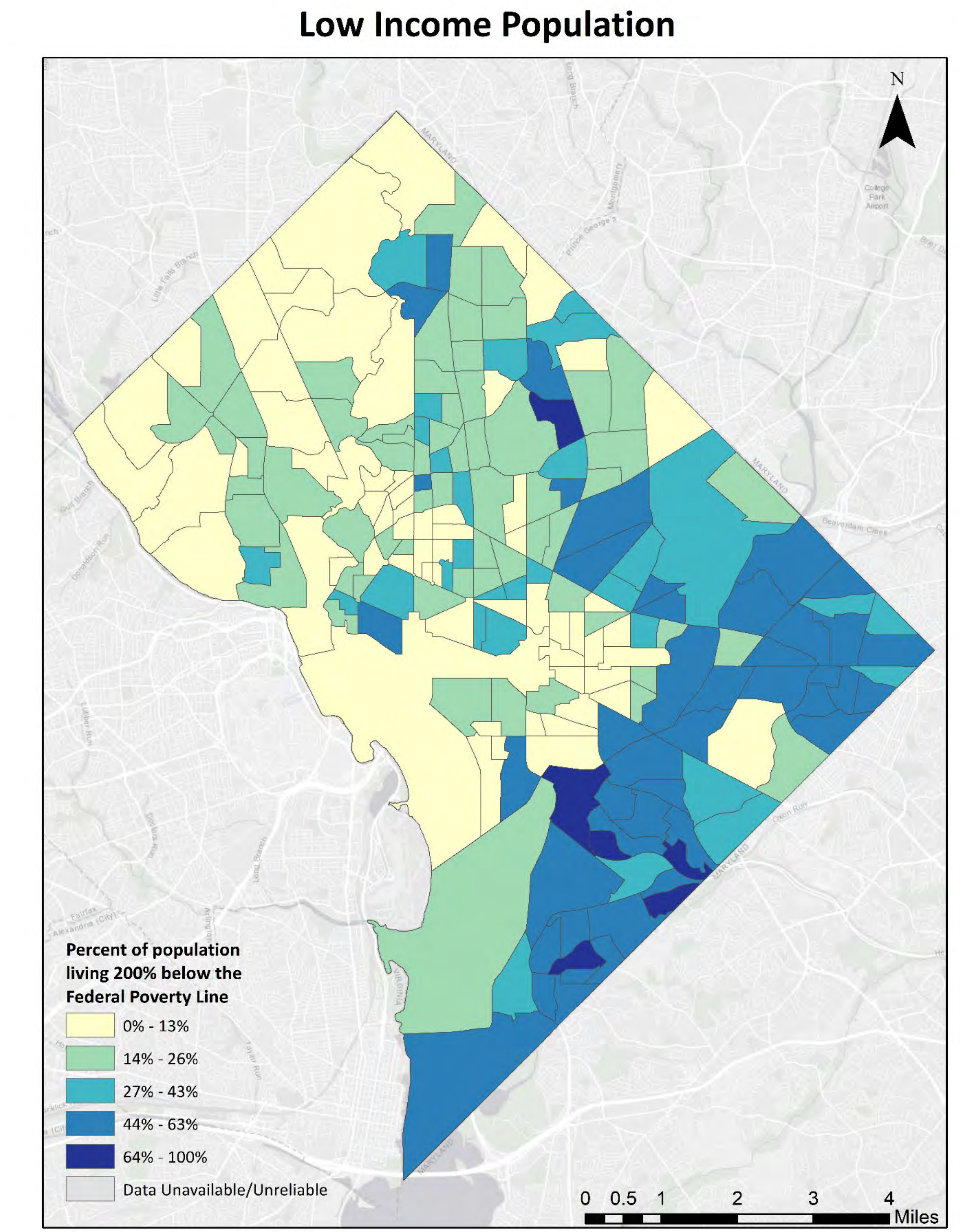


Figure 12. Map of population with limited English proficiency across DC census tracts.

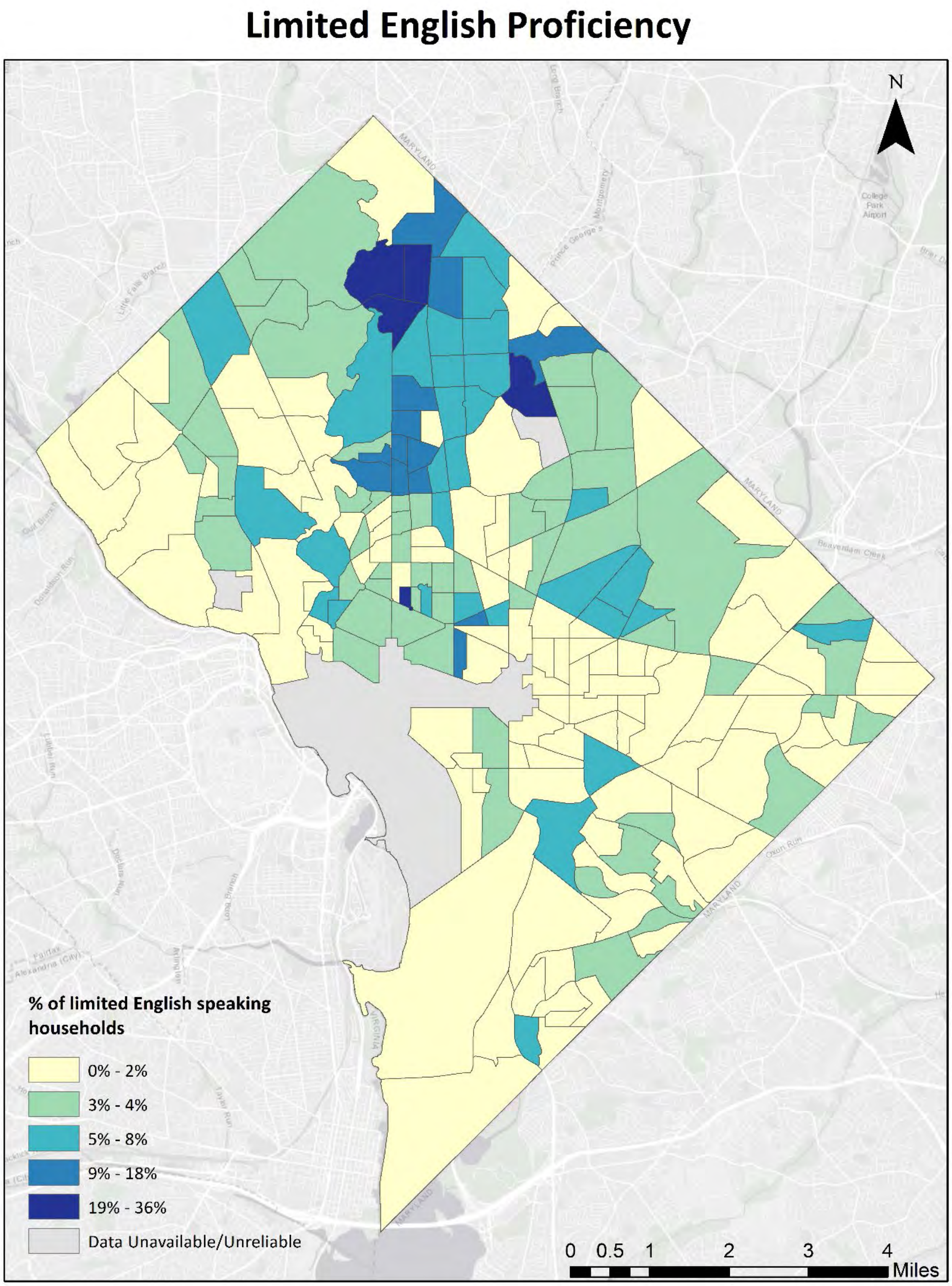


Figure 13. Map of population with disabilities across DC census tracts.

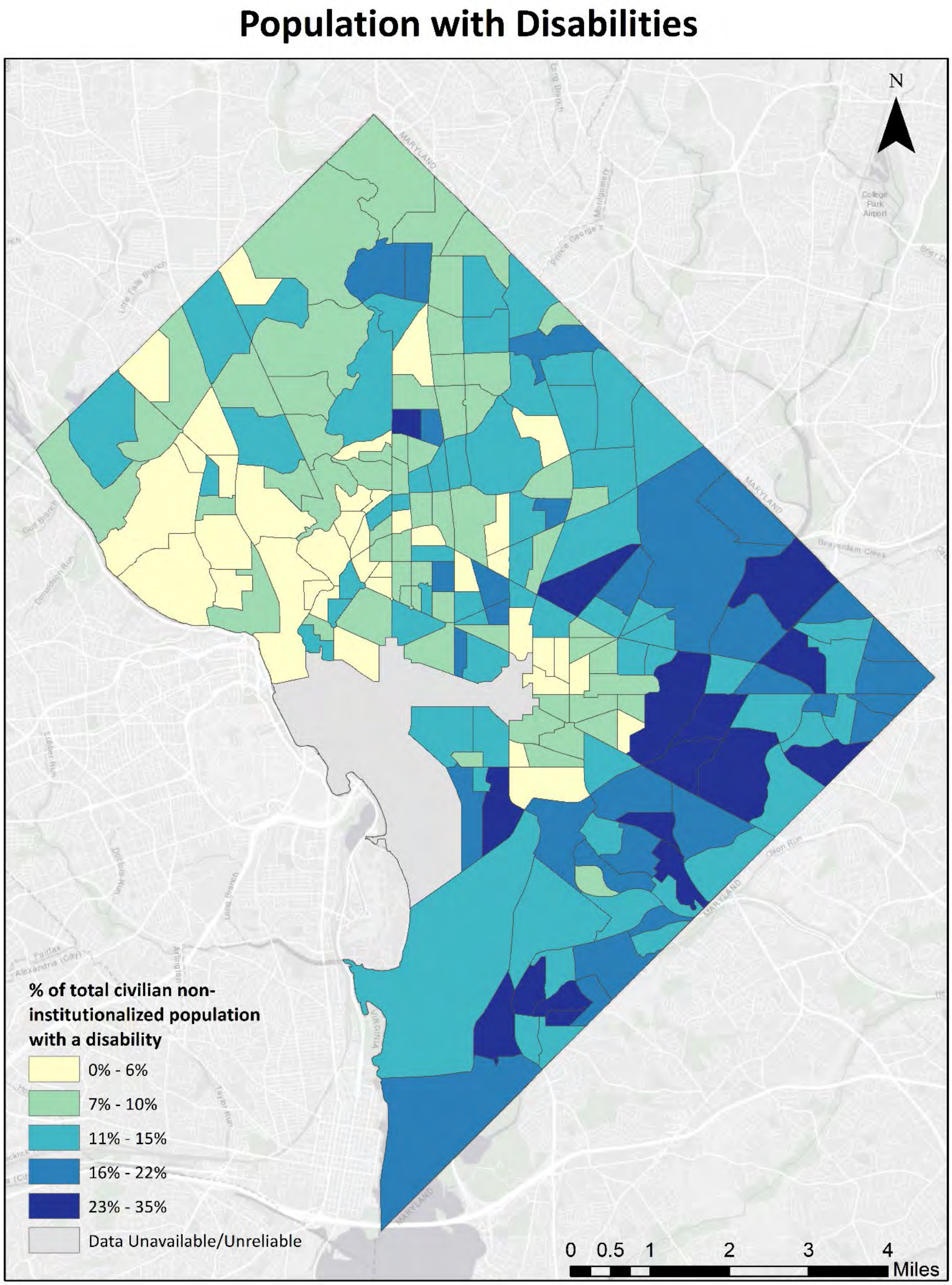


Figure 14. Map of asthma prevalence across DC census tracts.

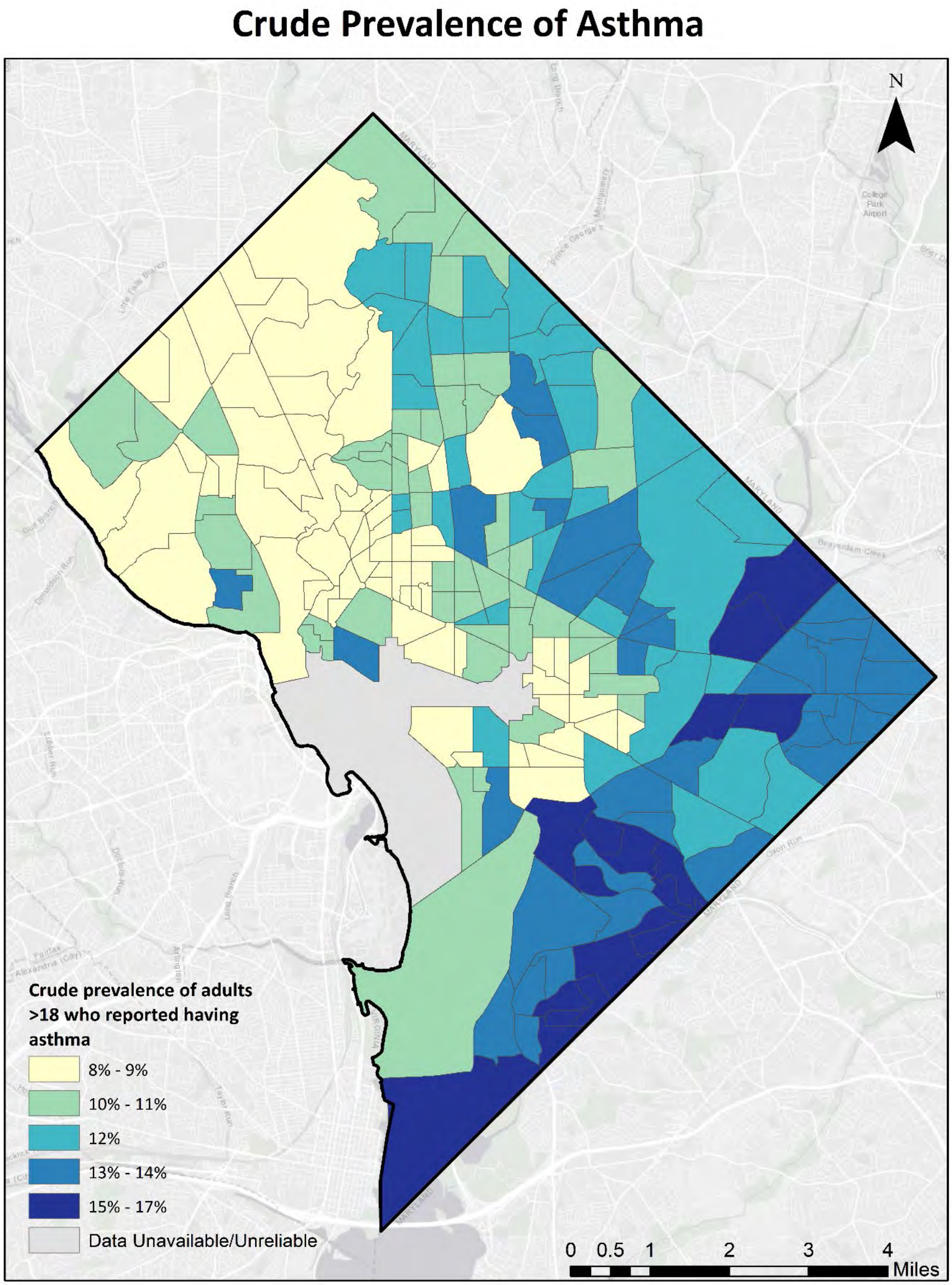


Figure 15. Map of obesity prevalence across DC census tracts.

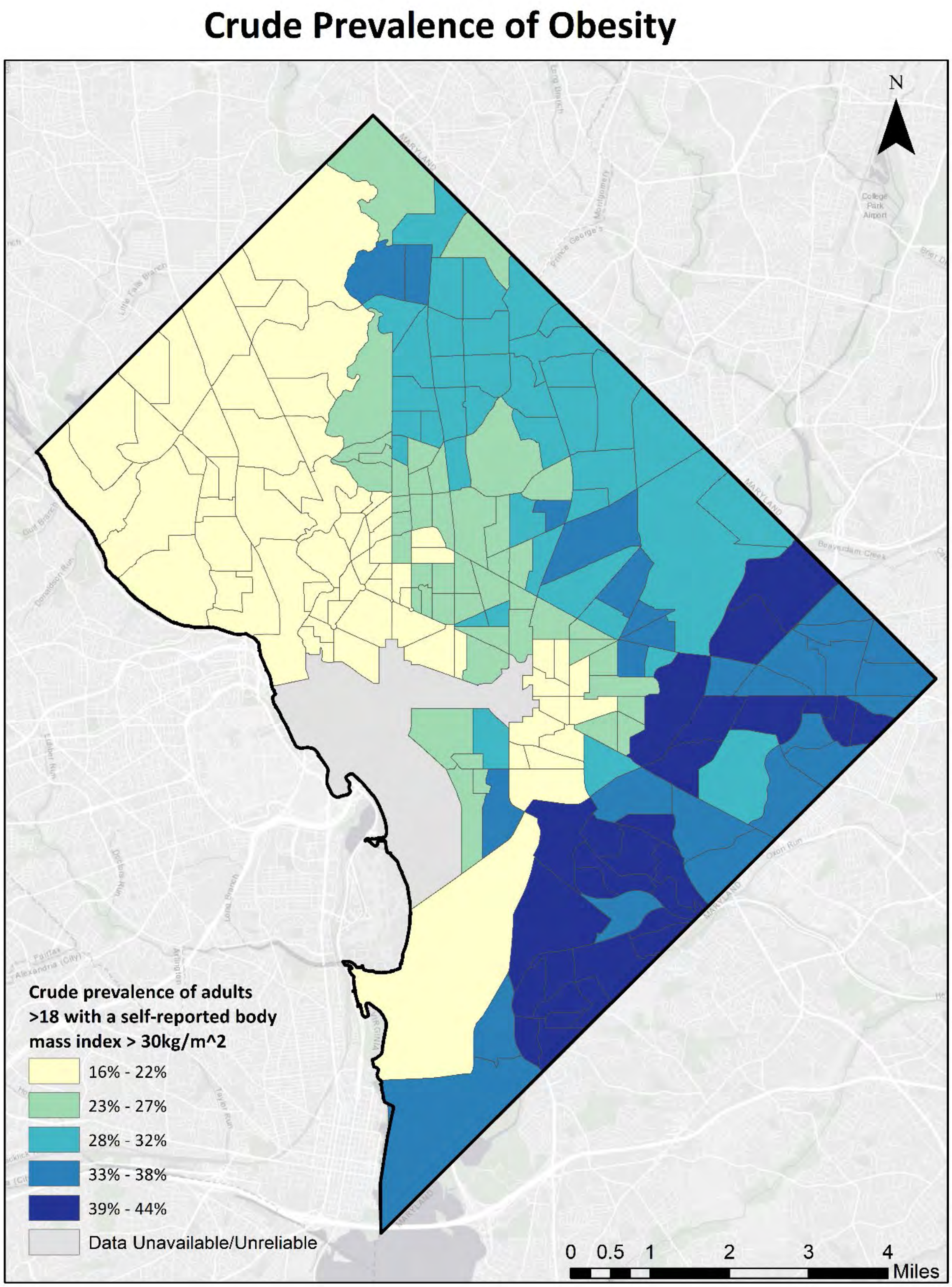


Figure 16. Map of coronary heart disease prevalence across DC census tracts.

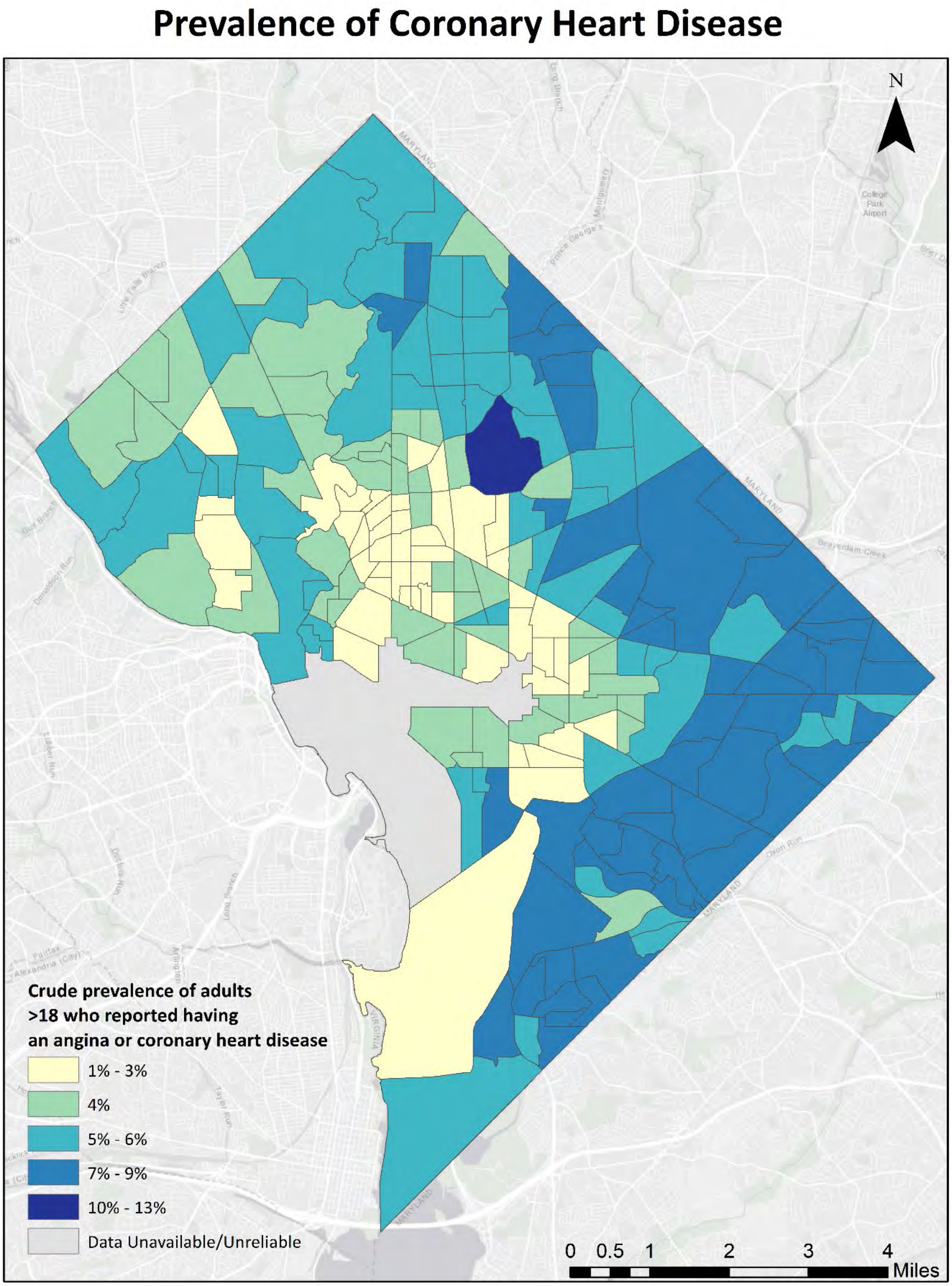


Figure 17. Map of heat sensitivity across DC census tracts.

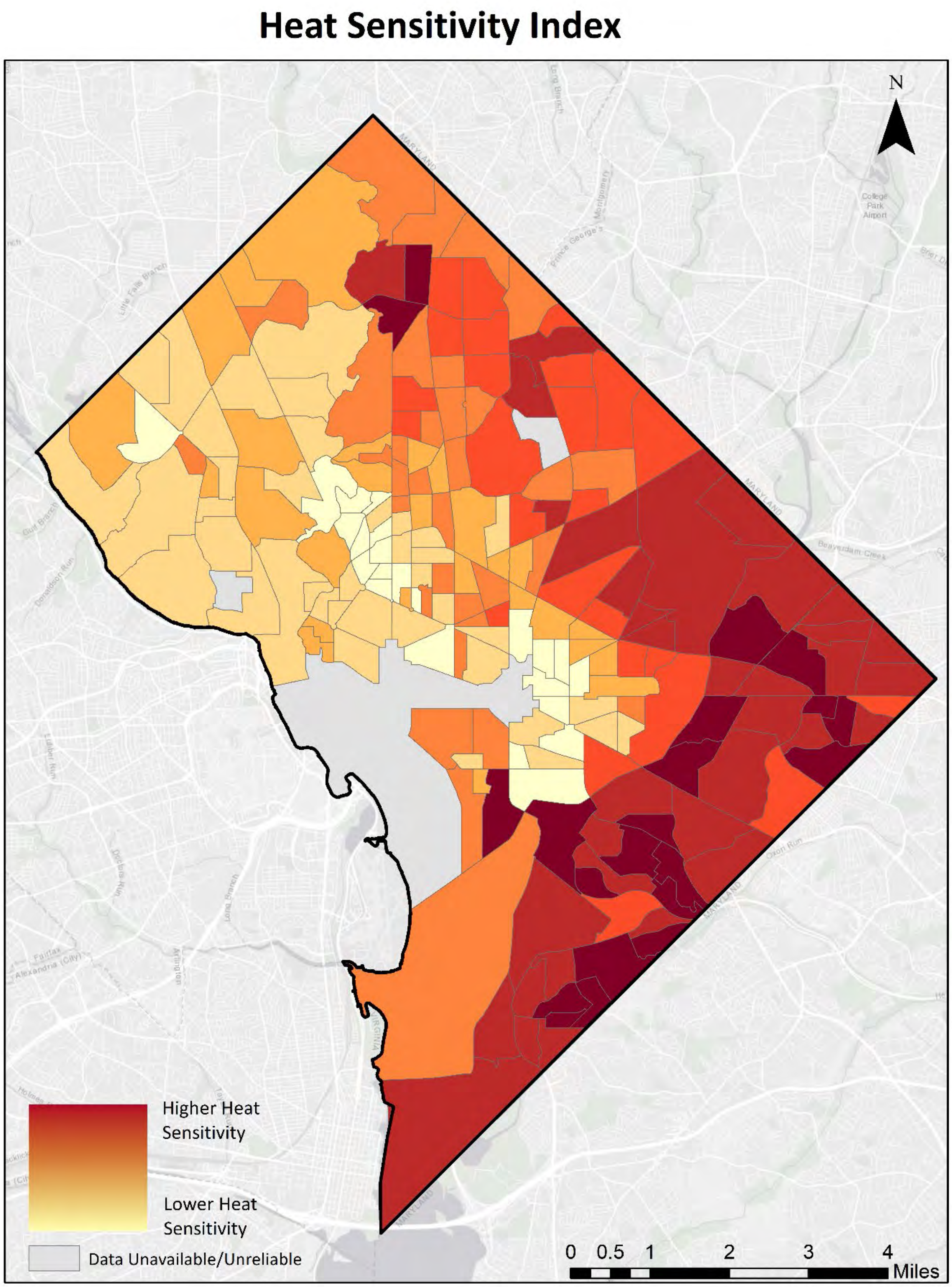


Figure 18. Map of ambient air temperature in DC.

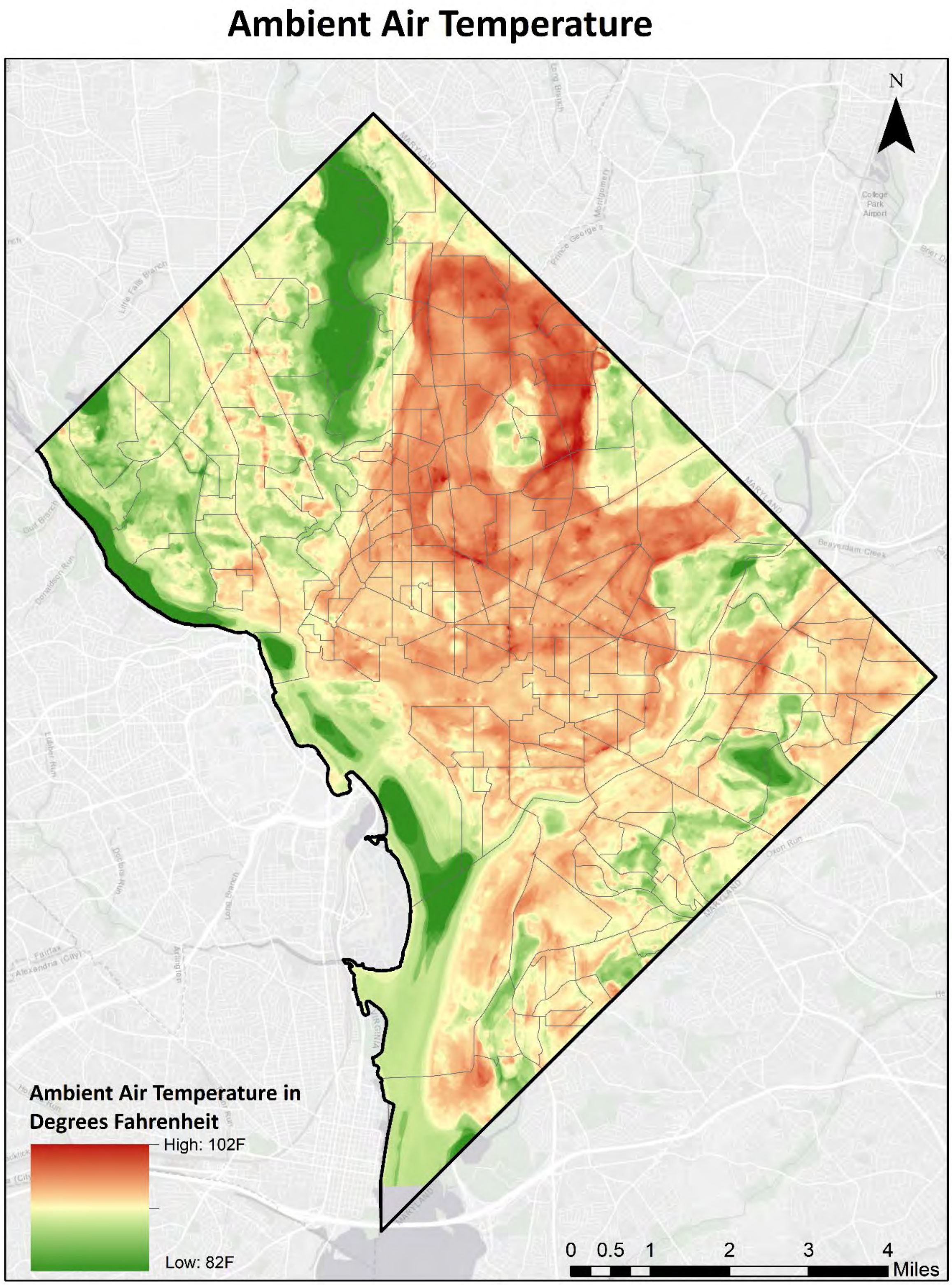


Figure 19. Map of average ambient air temperature, aggregated by DC census tracts.

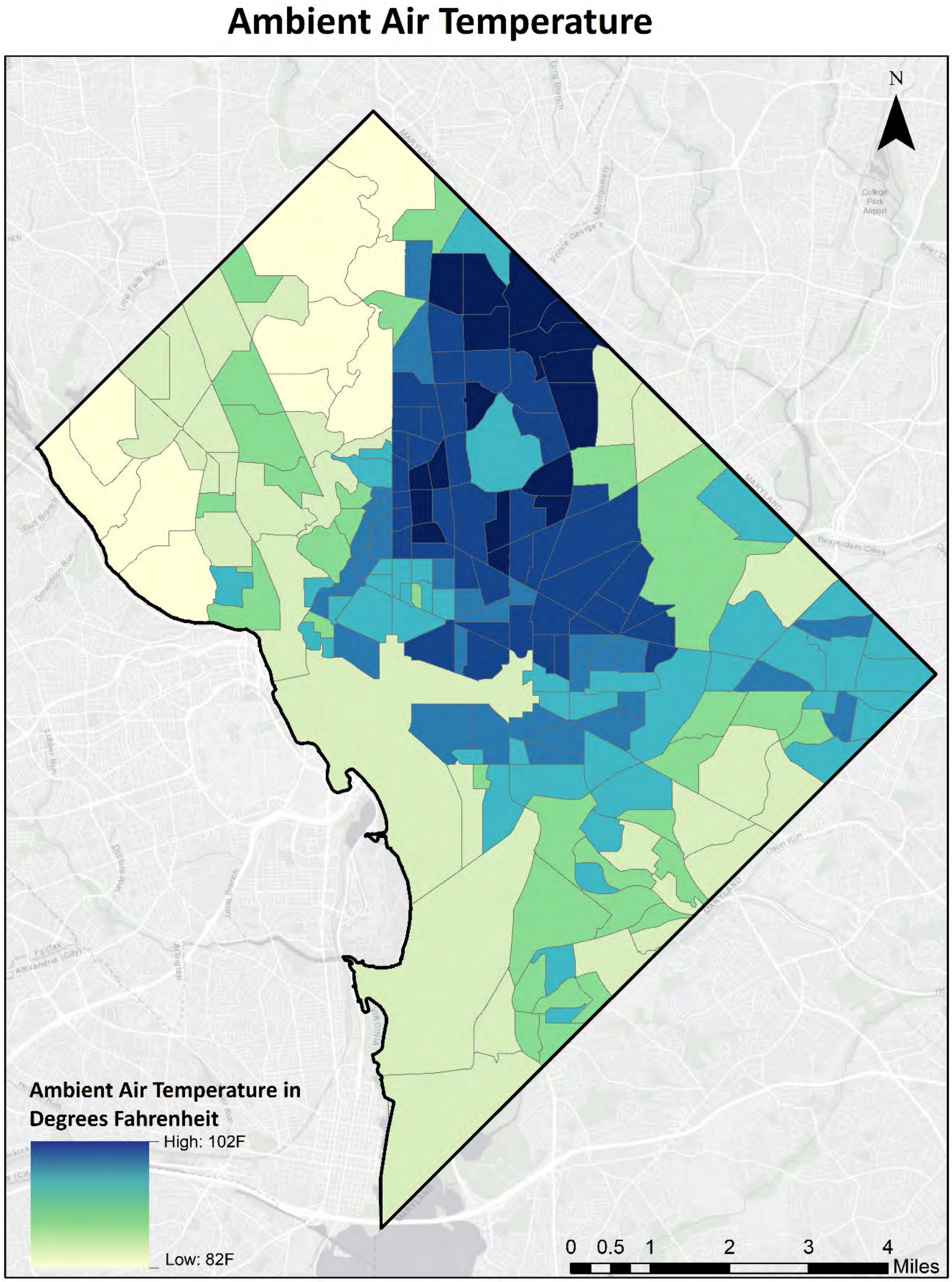


Figure 20. Map of impervious surface cover in DC.

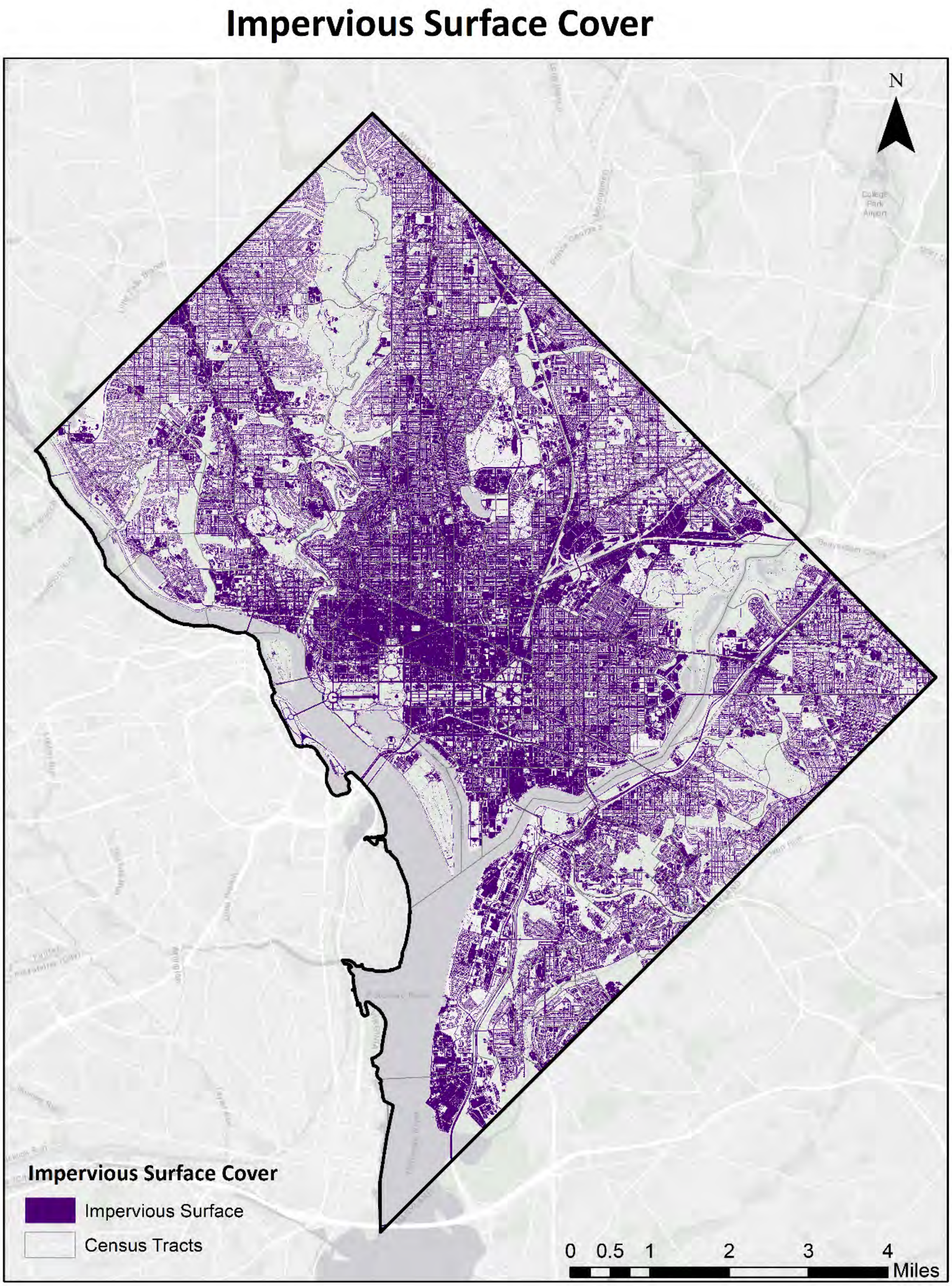


Figure 21. Map of average impervious surface cover, aggregated by DC census tracts.

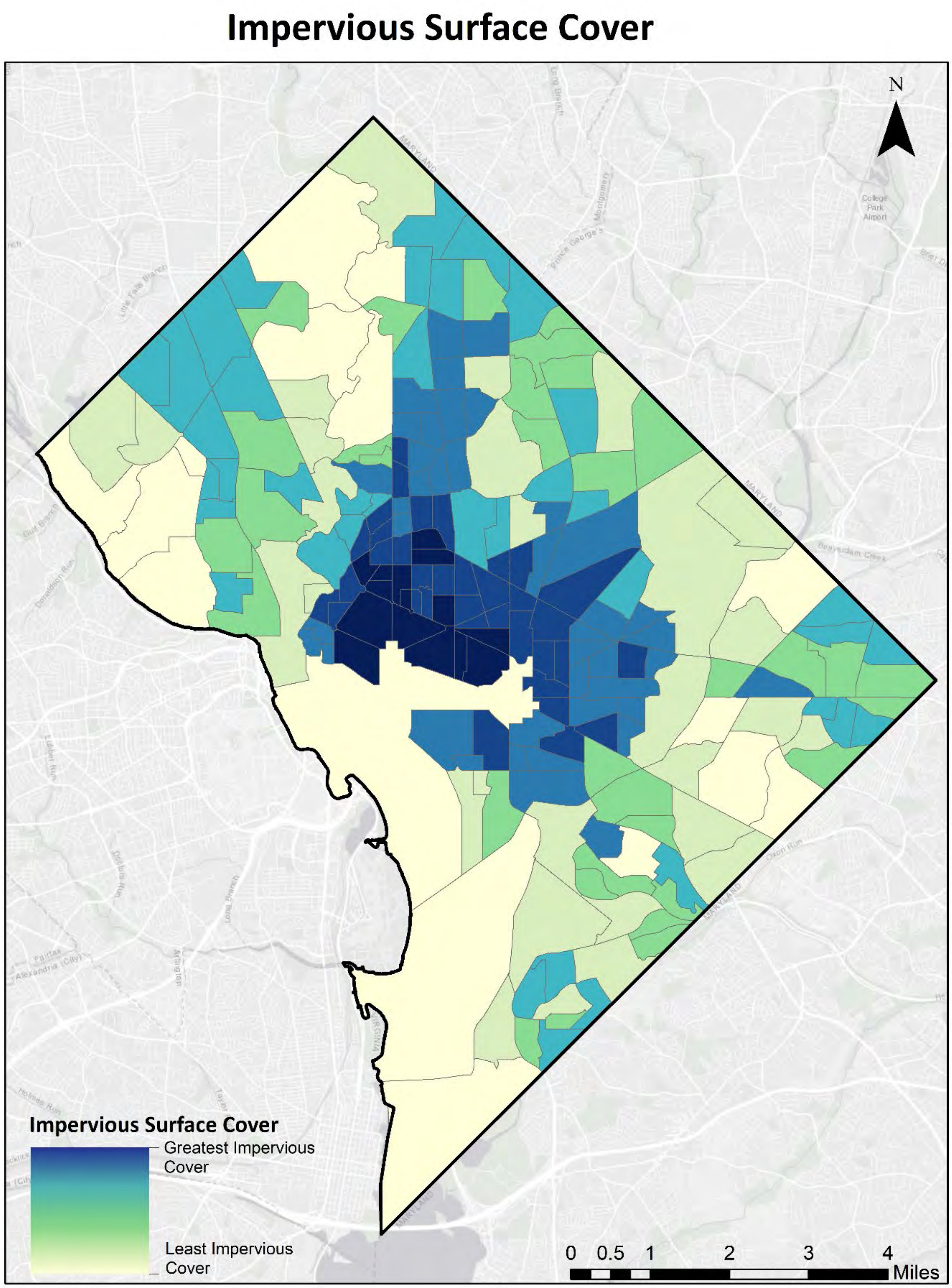


Figure 22. Map of tree canopy cover in DC.

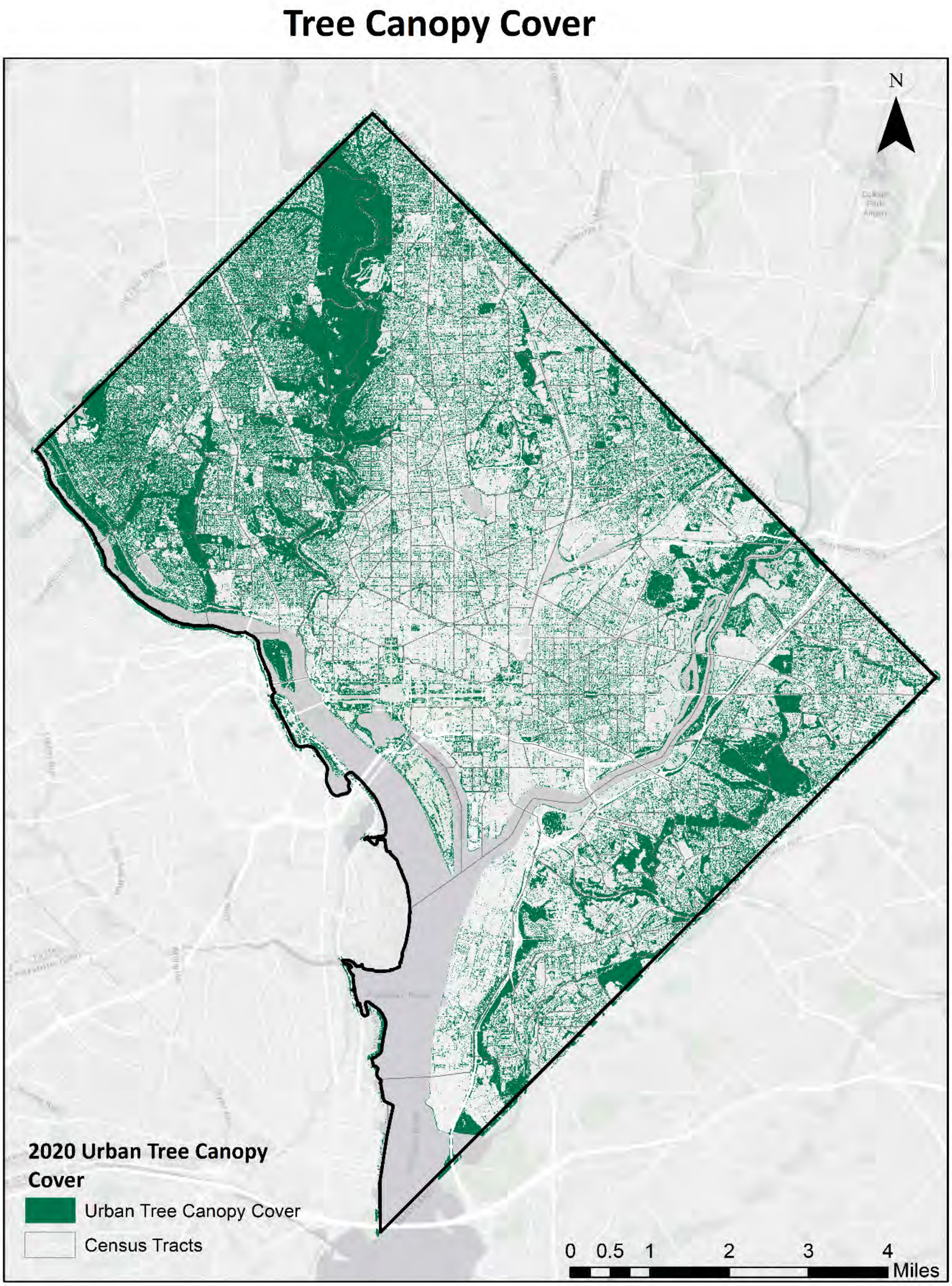


Figure 23. Map of average tree canopy cover, aggregated by DC census tracts.

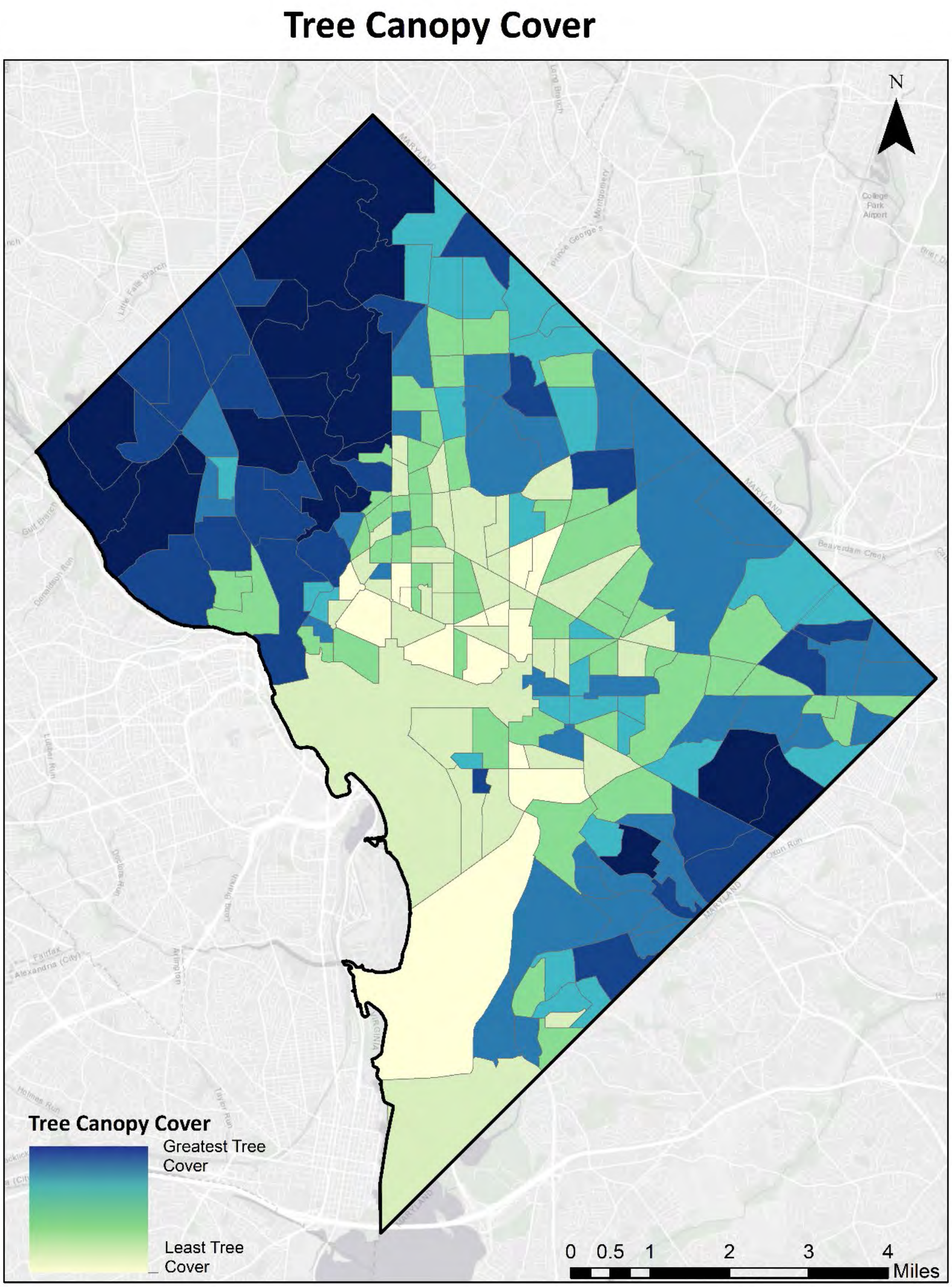


Figure 24. Map of heat exposure across DC census tracts.

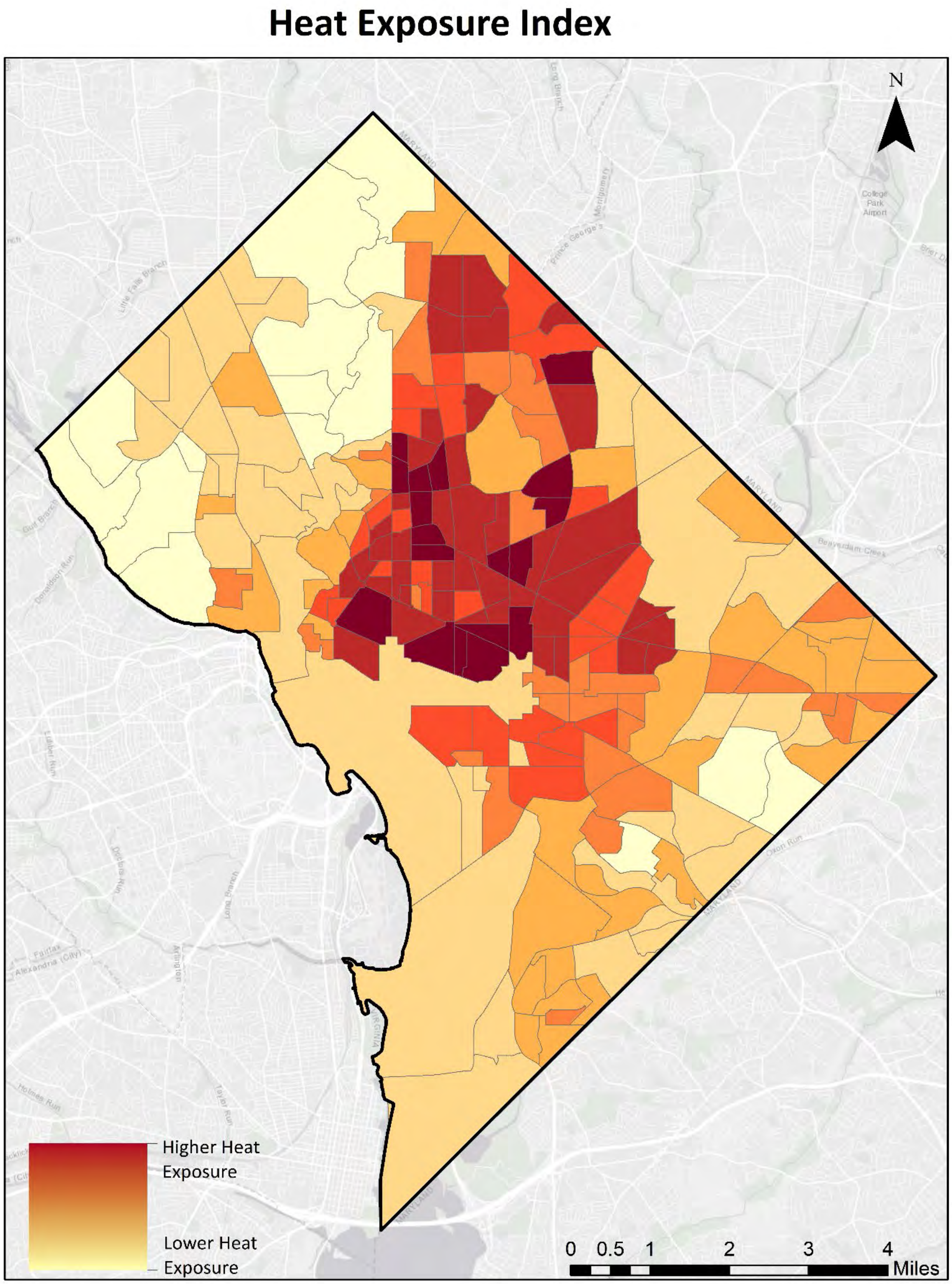


Figure 25. Map of heat risk across DC census tracts.