Turning up the Heat

Urban Heat Islands in Snohomish County

Caitlin Moore

A Capstone project presented in partial fulfillment of the requirements for the degree of

Master of Arts in Policy Studies

Interdisciplinary Arts and Sciences

Table of Contents

List of Figures

Chapter 1- Purpose of the Study

Heat can kill. According to the Centers for Disease Control and Prevention, exposure to excessive heat kills more people than any other weather-related cause in North America. Between 1999-2009, there were 7,800 known cases of heat-related deaths in the United States (Centers for Disease Control). During the famous 1995 Chicago heat wave, over 700 people died, 215 on a single day (Rubin and Gorner 2015). In a 2006 heat wave, between 350-450 people died in the Los Angeles area (Chong 2009), and in 2016 at least five people died during a heat wave that struck Arizona (Barbash and Andrews 2016) before it moved east and killed dozens more (AP 2016, Wood 2016, ClickOnDetroit.com 2016).

Extreme heat can cause a potentially deadly condition called heat stroke, in which patients can experience denaturation of the cells, internal bleeding, and brain damage (New York Times, 1983). This is the result of exposure to conditions which prevent the body from cooling off; for example, two to three hot days followed by high nighttime temperatures. Heat also causes heat exhaustion, acute renal failure, and exacerbates existing health conditions such as asthma, diabetes, and cardiovascular conditions, increasing hospitalization for these health problems (Reid et al. 2009, Isaksen et al. 2014). Heat is especially hard on people aged 65+ and those living in poverty (Johnson et al. 2009). In racially-segregated cities like Chicago, it has been found that people of color can experience a greater risk of heat exposure than non-Hispanic white people due to the local urban environment (Jesdale et al. 2013).

Areas with a lack of vegetation and high amounts of non-reflective, heat-absorbing surfaces like concrete, pavement, and buildings, coupled with heat generating activities like running engines, can increase the local urban temperature as compared to adjacent suburban or rural environments. These hot environments are called Urban Heat Islands (UHIs).

Vegetation is known to shade areas underneath and decrease local temperature through a biological process called evapotranspiration, which is akin to an animal sweating. Removal of vegetation thus increases temperatures. Impervious surfaces contribute to UHIs via their “high heat capacity, thermal conductivity, and often low reflectance of solar radiation” (Jesdale et al. 2013). According to Akbari et al., “In many urban areas, pavements and roofs constitute over 60% of urban surfaces” (2008).

Daytime temperatures in UHIs average 7°F warmer than surrounding suburban or rural areas (Hewitt et al. 2014), but can be up to 27°F warmer in some areas (Climate Central, 2014). At night UHIs radiate heat, making nighttime temperatures up to 22°F higher than rural areas (Environmental Protection Agency, 2014). UHIs can also cause an increase in local ozone and particulate matter pollution. These effects are collectively called “Urban Heat-Island Effects” or “Heat-Island Effects”. During extreme heat events, this can cause even greater health risks for people living in those areas. It is expected there will be more impactful extreme heat events in the future resulting from climate change; specifically, that they will be “more intense, more frequent, and longer lasting” (Meehl and Tebaldi, 2004, Calkins et al., 2016). Extreme heat events are days or time periods where temperatures are higher than the norm for that time and place, above a measured threshold that varies based on location.

Populations adapted to extreme heat and cities built for heat have lower rates of mortality and morbidity when temperatures rise than populations living in temperate climates like the Pacific Northwest, which do not normally experience extreme heat (Isakson et al. 2014). For example, in the 2006 California heat wave the cool coastal cities saw the greatest number of people going to the emergency room, even though temperatures were more extreme inland (Knowlton et al. 2009). Understanding the regional heat-health relationship by examining local risks is key to policy makers' decision-making process.

Recent studies of extreme heat, UHIs, heat-health outcomes, and social equity have been performed in King County, Washington, yet nothing has been studied about these same effects and outcomes in Snohomish County, Washington. Snohomish County is the third most populous county in the state, and is also one of the fastest growing counties (OFM, 2016). Therefore, this study proposes to use the 2011 National Land Cover Dataset, National Oceanic and Atmospheric Administration temperature data, Wunderground.com temperature data, 2010 U.S. Census Block data, and the 2013 American Household Survey to: 1) determine if and where there are urban heat islands in Snohomish County, Washington 2) which populations of people are living in them, and 3) what percent of the population has air conditioners. Furthermore, this study proposes to examine where policies at the level of urban planning and public health can stall or decrease the urban heat island effect in future years based on a literature review of studies and results in other jurisdictions.

Current models to map UHIs and the populations living in them have been successful (Reid et al., 2009 Jesdale et al., 2013). In 2016, Whipple et al. conducted an analysis of land cover and census data in King County, Washington. They demonstrated Seattle and surrounding urban environments had extensive areas with a likelihood of being impacted by extreme heat due to impervious surface, lack of vegetation, and building characteristics. They also showed populations were racially and ethnically segregated within these areas, and are thus disproportionately exposed. Their data further showed variations in English proficiency, necessitating outreach and intervention materials be translated into more than one language. Snohomish County is a racially and culturally diverse area. According to the US Census bureau, it is the second most language-diverse county in the state, with over 100,000 people speaking a language other than English at home. Languages include Spanish, Russian, Chinese, Korean, Vietnamese, Tagalog, and Arabic. Creating outreach materials that target these groups of people and others would increase their positive heat-health outcomes, regardless of whether they live in UHIs or not.

Chapter 2- Review of Literature

2.0 Problem Framing

In the United States, 80% of people live in cities (Climate Central, 2014). These environments are markedly different than rural environments in their characteristics. Urban areas contain vastly more impervious surfaces such as roads, sidewalks, parking lots, and buildings. Most modern construction materials that make up the impervious surfaces like concrete, steel, asphalt, and stone have low reflectance, called albedo, and thus absorb radiant heat during the day and release it later (Matthews 2012). This makes cooling off at night comparatively more difficult for urban environments. For instance, a dark asphalt parking lot can heat up to 175° F on a 90° F day. After the sun sets, the asphalt releases the heat which subsequently heats up the air around it, maintaining high temperatures into the night (Gray and Finster, 1999).

Urban form and activity also impacts heat. The distribution, age, and height of structures, the construction materials used, and color of buildings and roofing can affect local temperatures (Gago et al. 2013, Johanssen 2006). Urban buildings are taller and more densely-sited than rural buildings, creating an urban canyon which can trap heat between the building and street (Kleerekoper et al 2012). The geometry of the urban form can also alter wind patterns, which slows down wind flow and speed. Slower speeds reduce the cooling effect of wind (Shahmohamadi et al., 2011). Sources of anthropogenic heat such as automobiles, power plants, and air conditioners are more abundant in urban environments and alter the local climate by increasing temperature (Salamanca et al.

2014, Ryu et al. 2013, Memon et al. 2007, Buchin et al. 2015). Proximity to other major cities can also increase effects (Stone, 2007).

Climate models are anticipating a general increase in temperatures between 1- 3° Fahrenheit in the first half of this century, and between 2-5° F for the second half, depending on latitude. This is significant because a 1.8°F increase in temperature can lead to a doubling of the risk of mortality (Vandentorren et al. 2006). Each increase in degree will impact each UHI differently, due to variations in the geography and makeup of the UHI. When temperatures increase, there is also a correlated increase in energy use. It was estimated that for cities with a population of at least 100,000 people, for every 1°F increase in temperature, there is a 1.5% to 2% increase in energy use (Environmental Protection Agency, 1992). Cooling is also expensive. 6% of all energy used in the United States is for cooling buildings at an estimated cost of $40 billion (Gray and Finster, 1999).

Both radiant and anthropogenic heat can be trapped in the troposphere (the atmosphere we live in and breath) by the greenhouse gas ozone. Ozone is created through chemical reactions between nitrogen oxides (NOx), volatile organic compounds (VOC), and sunlight. NOx and VOCs are emissions from “industrial facilities, electrical utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents” (EPA.gov). Ozone is detrimental to human health, and is considered an urban heat island “effect”. Ozone has been associated with “multiple health outcomes, including increases in prevalence, clinical utilization, and severity of cardiac and respiratory disease” (Jackson et al 2010). Ozone is also associated with premature death (Bell et al., 2004). Stott et al. determined that without emissions mitigation, by 2040 the temperatures experienced in the 2003 European heat wave that killed approximately 70,000 people will become normal—in fact, they expect those temperatures in half of all years (2004).

Vegetation is measurably lower in urban environments as compared to rural environments. Vegetation cools by shading and lowers ambient temperature through a process called evapotranspiration. This is a biochemical process that occurs as plants photosynthesize, in which they release water vapor. The water vapor dissipates heat, thus cooling the adjacent area down. The rate of evapotranspiration increases as temperatures increase (NCSU.edu). In addition, some plants are also known to reduce the pollutants that contribute to ozone accumulation and ozone itself (Nowak et al. 2014, Taha 1996).

Urban areas that have temperatures higher than surrounding suburban and rural areas resulting from impervious surface, urban form and canyons, and anthropogenic heat are called Urban Heat Islands (Memon et al. 2007, Martin-Vide et al. 2015). Cities don't experience heat islands uniformly. Isolated urban locations that produce a hot spot are called "micro-urban heat islands" (Aniello et al. 1995). These hot spots are detrimental because they represent an even greater risk for those living in the hot-spot. Causes are the same as for UHIs, but are revealed as areas with the highest concentration of buildings, roadways, parking areas, and lack of vegetation. Smargiassi et al. (2009) argue it is important to measure heat using both meteorological stations and thermal sensing, to find these hot spots.

Heat waves have been increasing all over the world in recent years as a result of climate change (Holthaus 2015). Wolfe et al. described a heat wave as 3 or more consecutive days where the ambient temperature was >90° F (2001). Researchers in Vancouver, Canada developed a *temperature* threshold at 84° F for two consecutive days on the coast and 93° F inland, based on a heat/mortality relationship (Henderson and Kosatsky, 2012). Isaksen et al. determined a *humidex* (temperature plus humidity) threshold of 96.2° F for King County, above which public health officials need to prepare for increased mortality (2014).

2.1 Heat and Population Impacts

Heat is known to impact human health. "It is estimated that 400-700 people die from documented thermal stress, or hyperthermia, each year in the USA" (Jackson et al., 2010) and this number may underestimate actual heat-related deaths due to death-certificate reporting protocols not listing heat when it is not the primary cause of death (Wolfe et al., 2001). For instance, people who suffer from respiratory illnesses like influenza, pneumonia, bronchitis, emphysema, and COPD are at greater risk of suffering symptoms and mortality during extreme heat events (Fuhrmann et al., 2016), yet cause of mortality is often listed as what the patient presented with. To illustrate, in the 1995 heat wave that killed over 700 people in Chicago, there were 3,300 excess emergency department visits with many people presenting with 'classic heat stroke'. In-hospital mortality was 21%. 33% of patients had "severe functional impairment" at the time of discharge. Some surviving patients were tracked for a year after the heat wave to monitor functionality and mortality. None had recovered full functionality, and a further 28% died within the year of causes exacerbated or created by the original heat exposure (Dematte et al., 1998). Similarly, people suffering from diabetes (Schwartz, 2005), obesity (Kenny et al., 2010), and those who are taking certain medications like diuretics and beta blockers are at greater risk during a heat event (Harmon 2010).

Many researchers have also looked at socio-economic groups who are at risk. Johnson et al. found that the most vulnerable populations to heat event impacts were the elderly, and those in poverty who were *also living in a UHI*. The same populations living in rural areas were at lower risk (2009). Schwartz found that people of color were more at risk to heat-related illness than whites (2005), as well as those who lacked access to air conditioning (Reid et al., 2009).

Jackson et al. (2010) examined the historical relationship between extreme heat and mortality in three metropolitan areas of Washington State and population growth estimates, to show heat-related illness and death will increase in the future. Two other studies demonstrate the impacts of extreme heat in King County, which is just south of Snohomish County. The first study, by Calkins et al (2016) showed that between 2007-2012, there was an 8% increase in basic life support calls, and a 14% increase in advanced life support calls on an extreme heat day for all age groups. In 2015, Isaksen et al. showed that there was a corresponding increase in hospital admissions with extreme heat exposure, without finding any populations other than the elderly particularly at risk. Both these studies' findings are believed to be due to the low numbers of people who own an air conditioner in Western Washington, which in 2009 was estimated to be about 8% of the population (Hamlet et al., 2010).

Air conditioning is the number one heat-related-illness personal preventative measure. During a two-week period in 2012, thirty-two people died from excessive heat exposure in Maryland, Ohio, Virginia and West Virginia. Lack of air conditioning in the home was reported in 91% of these deaths (Centers for Disease Control, 2013). However, air conditioners contribute to outdoor ambient temperature by shuttling hot air outside, they increase greenhouse gas emissions due to electricity use, stress the electric grid, and are largely owned by people within moderate- to high-income groups (Salamanca et al. 2014). People who do not own an air conditioner must therefore rely on fans, shade, cold showers, or "cooling centers" for relief during extreme heat events (Vandentorren et al. 2006).

2.2 Study Area

Climate Central, a research and reporting organization, analyzed 60 of the largest cities in the U.S. in 2014 and found that 57 had "measurable urban heat island effects over the past 10 years". Some metropolitan areas experienced single-day temperatures as much as 27°F higher than the surrounding rural areas. Seattle was among their top 10 cities with the most intense summer UHIs, averaging 4.1°F warmer temperatures than surrounding rural areas (Climate Central, 2014). Whipple et al. (2016) used ArcGIS and US Census data to demonstrate that low-income, elderly, non-white, and low-English proficiency people in King County, Washington are more at-risk during extreme heat events due to urban heat islands.

Despite proximity to King County, there has not yet been a study of heat islands in Snohomish County, which is the second fastest growing county in the state. The most at-risk group, those aged 65+, are expected to see the largest growth in Snohomish County in the future, with nearly a quarter of the population expected to be ≥65 by 2030 (Snohomish County, 2010). This makes heat-related illness an important issue for public health and urban planning in this region.

2.3 Modeling

To answer my first question—whether heat islands exist in Snohomish County—it is necessary to use models to visualize temperature in the built environment. Commonly researchers compare temperatures at urban and rural meteorological stations and map them over geographic layers of land cover to prove existence of Atmospheric UHIs (Martin-Vide et al. 2015, Memon et al., 2007).

Jesdale et al. (2013) used the National Land Cover Database and US Census data in a GIS to map block-group level tree canopy and impervious surface for densely populated urban areas of the United States and Puerto Rico in their paper, The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation. Using census data, they overlaid racial and ethnic groups within these areas to demonstrate residential segregation and relative heat-risk for populations based on membership.

Knowing who lives in these UHIs can help public health and urban planning policy makers in their decision making. To examine my second question— who lives in urban heat islands in Snohomish County—I looked to several researchers. In The Study of Group-Level Factors in Epidemiology, Ana V. Diez Roux (2004) discussed the importance of examining the groups to which people belong in order to understand the risks they are subject to in regards to health. She argues we must examine these groups when assessing risk because "population-level factors are invariant within a population and, hence, cannot be investigated in studies restricted to comparisons of individuals within a population."

Based on Roux's paper, Reid et al. (2009) looked at ten vulnerability factors found to be determinants of vulnerability to heat. These vulnerabilities include vegetative cover, two air conditioning variables (presence of- and single or central air), prevalence of diabetes, age, poverty, education, race, ethnicity, and living alone. Whipple et al. examined vulnerability in people of color, low English proficiency, the elderly, and the poor in King County, Washington (2016). Weber et al. (2015) examined vulnerability of groups in Philadelphia based on percent of households with a single person over the age of 65 living alone, percent of population within a census block living below the poverty line, percent of houses built before 1960, and percent of population without a high school diploma. Uejio et al. (2011) defined their social vulnerability demographics based on age, race, poverty, number of residents living in dwelling, people with disabilities, and linguistic isolation (English as a second language).

To answer my third question—what percent of the population owns an air conditioner— I again looked to Reid et al. (2009). They used the U.S. Census Bureau's

American Housing Survey to estimate the percent of people who owned an air conditioner, based on the Metropolitan Areas surveyed.

2.4 Risk-Reduction Measures

There are several ways to reduce the risks associated with extreme heat. Many jurisdictions including King County have published the local cooling centers in the area because air conditioning is one of the most important personal preventative measures during an extreme heat event (Buchin et al. 2016, O'Neill et al. 2005).

Philadelphia, Pennsylvania; and Vancouver, Canada have begun heat-health warning systems (Ebi et al. 2004, Henderson and Kosatsky 2012), including in-home visits by health department staff, hotlines, highway signs, email, through workplace notices, and media including television, radio, and newspaper (Uejio et al. 2011, Semenza et al. 2008). Following the European heat wave that killed nearly 70,000 in 2003, with over 14,000 in Paris alone, the French Government undertook studies to identify where gaps in policy exist, which populations were most at-risk, where those populations lived, and under which conditions they lived. It was found that heat islands contributed to mortality, and the elderly were the most at-risk. Since then, there has been concerted efforts to alter future heat-health outcomes using a critically-acclaimed heat warning system that includes phone calls to registered elderly people and special assistance once people who call have been evaluated (Cadot et al. 2007). Information about the languages used during the warnings is not described in any of these studies, but it is assumed to be limited to one or two even though "linguistic isolation may hinder protective behaviors during extreme heat events by impending and understanding of heat warnings" (Uejio et al. 2011).

Higher-level interventions include altering the local environment with plants. According to the EPA, through the process of evapotranspiration, trees can reduce local temperatures 2-9°F. (EPA.gov). Many cities, including Houston, Chicago, and Tacoma have begun massive tree planting campaigns to combat UHIs (Hewitt et al. 2014, City of Tacoma, City of Chicago). There are added health and economic benefits of trees in the urban landscape, including increased retail spending in areas with trees (Wolf 2005) and decreased respiratory and cardiovascular-related mortality due to presence of trees (Donovan et al. 2013). Green roofs, which are roofs with a vegetative layer grown on top, are used in cities such as Portland to reduce building temperatures and increase evapotranspiration (EPA, 2008).

Chicago's Green Alley Program "aims to use green construction techniques to repave over 1,900 miles of alleys" (EPA, 2012) by incorporating permeable pavement, or high-albedo pavement to reduce heat island effects (City of Chicago). Areas of Los Angeles are following suit with a Green Alley Program (Trust for Public Land).

Finally, cities such as New York, Houston, Philadelphia, New Orleans, and Sacramento are exploring how to decrease intensity of UHIs by exploiting the albedo effect of reflective roofing and other surfaces (Hewitt et al 2014, Akbari et al. 2008).

Chapter 3-Methodology

Using a cross-sectional case study of Snohomish County, Washington I used land cover and temperature data to map urban heat islands. I then used U.S. Census data to examine the entire county and demonstrate who lives in Urban Heat Islands, and what percent of the county population has air conditioning.

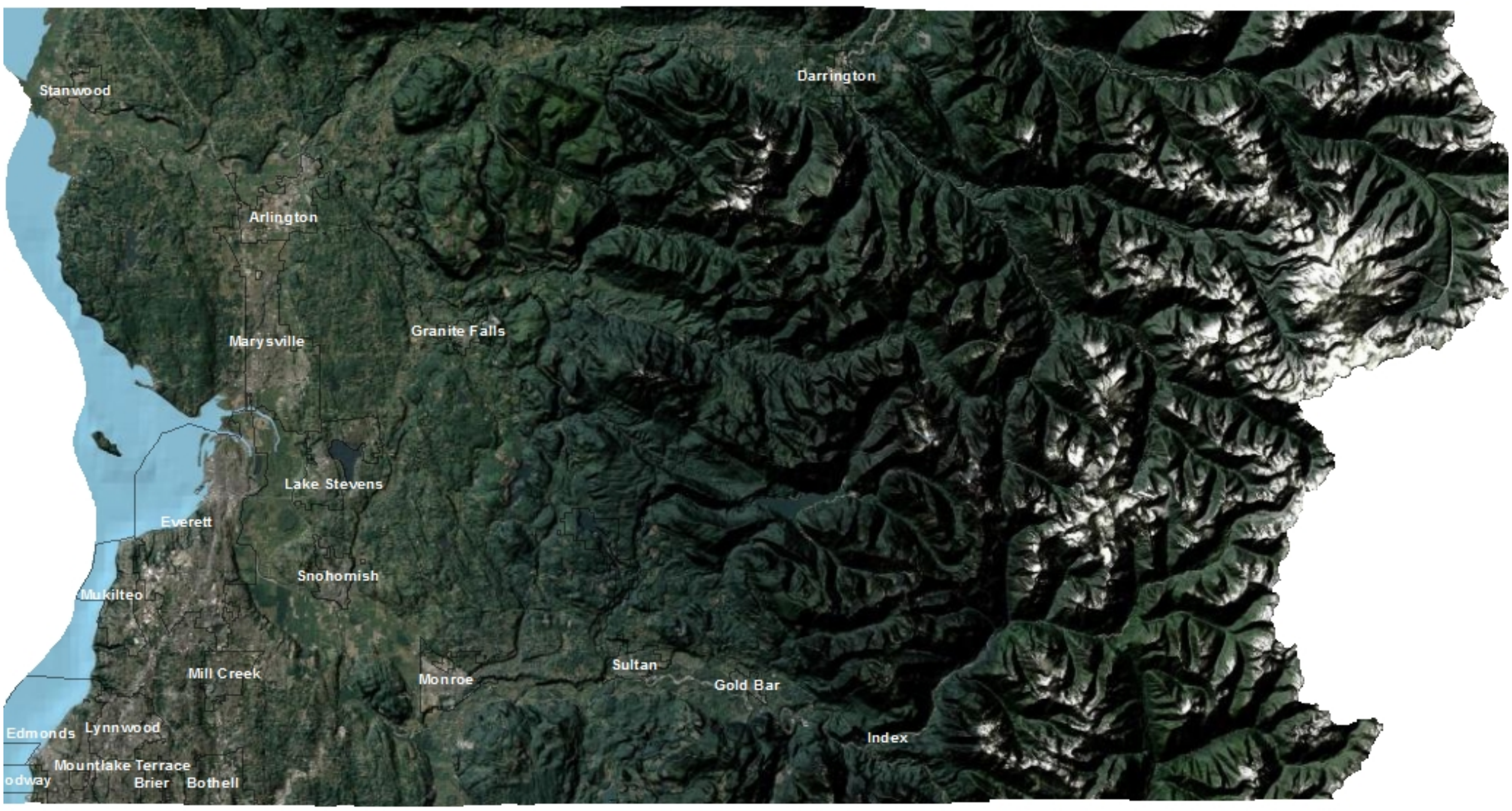

Figure 1 Terrain Map of Snohomish County, WA

Snohomish County is the third most populous county in the state, with a population of 713,335 according to the 2010 U.S. Census. It is the second fastest growing county in the state, behind King County by a .7% growth rate. There were 73,544 people ≥65 years of age living in Snohomish County in 2010. 78% of the population reported as white, 9%

Hispanic or Latino, 9% Asian, 3% African American, 1.5% American Indian or Native Alaskan, .5% Hawaiian or Pacific Islander, 3.8% were “other”, and over 4% were two or more races. The Washington State Office of Financial Management estimates that all these demographic variables increased in the last 6 years (OFM 2016).

For comparison, King County was recently surveyed by Whipple et al. (2016) and they showed there were vast areas with a lack of vegetation and extensive impervious surfaces, and segregated communities living in them. King County, the state’s largest, had a population of 1,931,249. As of 2010, the county was made up of people reporting as 72% White, 15% Asian, 9% Hispanic or Latino, 6.5% African American, 1% American Indian or Alaskan Native, .8% Hawaiian or Pacific Islander, 4.5% two or more races (OFM 2016).

Using ArcGIS software, I created a map of Snohomish County with layers accounting for 1) land cover including impervious surface 2) temperature, and 3) census tract information on income, race, ethnicity, and age. This is a common methodology used in many urban heat island mapping studies involving heat-health outcomes.

I used data from the Multi-Resolution Land Characteristics Consortium to build the first layer. The Consortium is a two-decades long partnership between the U.S. Geological Survey, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, U.S. Department of Agriculture- Forest Service, National Park Service, U.S. Fish and Wildlife Service, Bureau of Land Management, and USDA National Resources Conservation Service. Their National Land Cover Database

(NLCD) Land Cover 2011 is a satellite-based, thirty meter-resolution land cover file, and demonstrates sixteen classifications of land cover in the United States.

Four classifications are important for visualizing the built environment. Classification number 21 is defined as Developed, Open Space: “Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.” Classification 22, Developed, Low Intensity: “Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% of total cover. These areas most commonly include single-family housing units.” Classification 23, Developed, Medium Intensity: “Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.” Classification 24, Developed High Intensity- “Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover”.

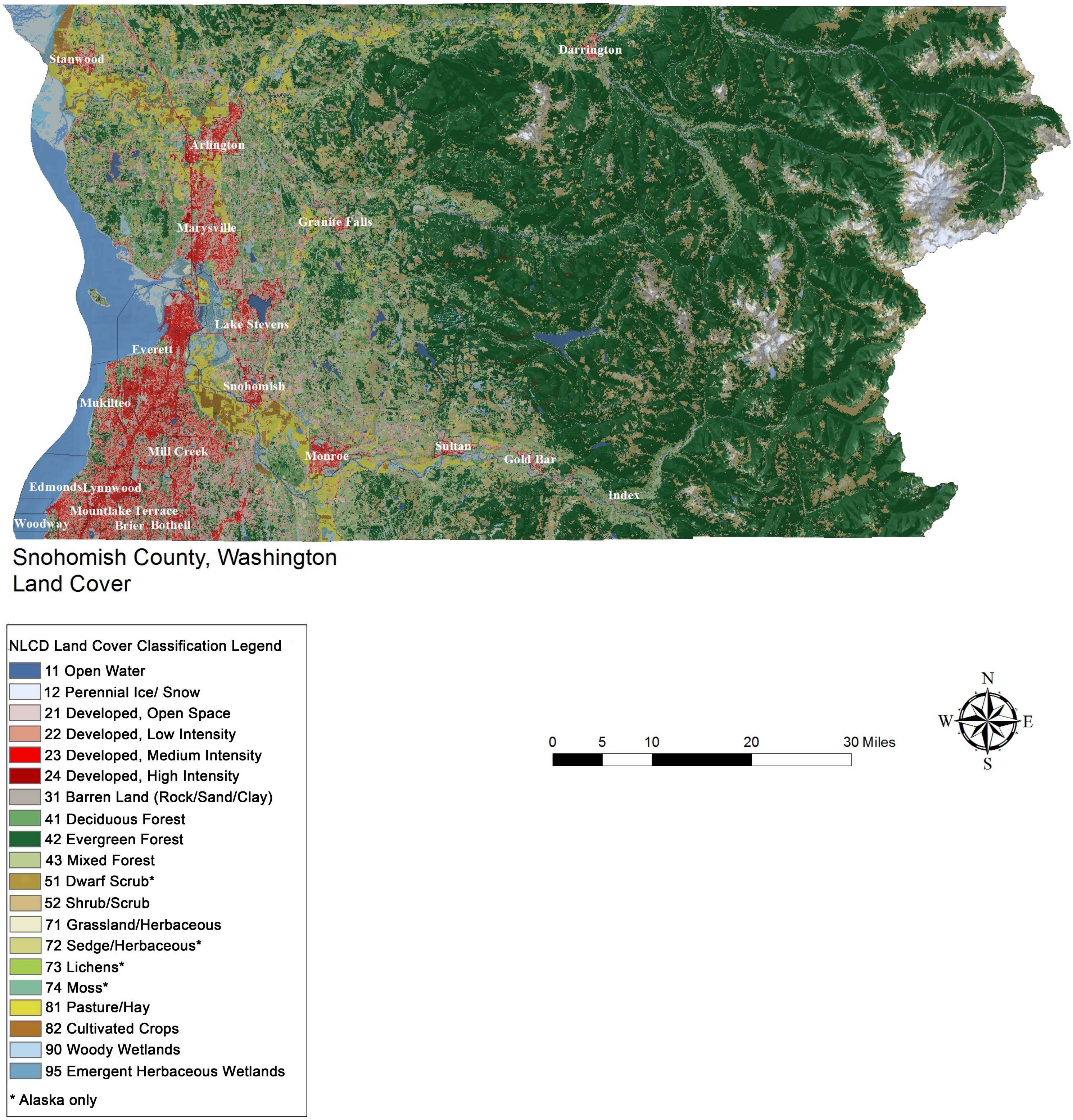

Figure 2 Land Cover Map, Snohomish County

For the second layer, I used temperature data from the National Oceanic and Atmospheric Administration (NOAA) and Wunderground.com to demonstrate average nighttime temperatures in different areas of Snohomish County. Oke (1973) and others discuss the choice of time frame when measuring an atmospheric heat island as described in Table 2 in the Appendix. Heat islands are present all times of year, but it is the intensity of the heat island that changes. To measure intensity, researchers choose temperatures during periods of clear and calm weather, absent of wind or cloud cover. Atmospheric heat island temperatures should be measured at night, and stations should be within ~30 meters in elevation of all other compared stations. I created classes for the NOAA stations based on elevation boundaries of no more than ~10 meters (~32.8 feet) to ensure greater accuracy and to ensure I didn't mask the 'urban effect', described in the Appendix. I then downloaded temperature data from Wunderground.com stations within those boundaries if it was available during the survey period. To demonstrate the human experience during a recent heat event, I chose to look at temperatures during a three-day heat event in the Pacific Northwest between August 18th- 20th, 2016. Together, the first two layers answered my first question: Do urban heat islands exist in Snohomish County?

For the third layer, I performed a secondary data analysis of the 2010 US Census. I extracted data from four important risk-factor categories known to increase vulnerability for heat-related illness: age, income, race, and ethnicity. I then calculated ratios of each category of people within each census tract for comparison, using equal intervals to define classifications between groups. This type of interval caused each classification to be equal in size, allowing for easier comparison of continuous data.

In 2010, the United States Census defined the poverty threshold based on age and size of family, as described in the table below.

Size of family unit	Weighted average thresholds	Related children under 18 years								
		None	One	Two	Three	Four	Five	Six	Seven	Eight+
One person (unrelated individual)..	11,139									
Under 65 years............................	11,344	11,344								
65 years and over........................	10,458	10,458								
Two people...................................	14,218									
Householder under 65 years.........	14,676	14,602	15,030							
Householder 65 years and over.....	13,194	13,180	14,973							
Three people................................	17,374	17,057	17,552	17,568						
Four people..................................	22,314	22,491	22,859	22,113	22,190					
Five people...................................	26,439	27,123	27,518	26,675	26,023	25,625				
Six people.....................................	29,897	31,197	31,320	30,675	30,056	29,137	28,591			
Seven people................................	34,009	35,896	36,120	35,347	34,809	33,805	32,635	31,351		
Eight people..................................	37,934	40,146	40,501	39,772	39,133	38,227	37,076	35,879	35,575	
Nine people or more......................	45,220	48,293	48,527	47,882	47,340	46,451	45,227	44,120	43,845	42,156

Source: U.S. Census Bureau.

Figure 3 Poverty Thresholds for 2010

According to the U.S. Census Bureau, “Asian” people refers to a person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian Subcontinent. “Black or African American” refers to a person having origins in any of the Black racial groups of Africa. “Hispanic or Latino” refers to a person of Cuban, Mexican, Puerto Rican, South, or Central American descent, or other Spanish culture or origin regardless of race. “White” refers to a person having origins in any of the original peoples of Europe, the Middle East, or North Africa. “American Indian or Alaska Native” refers to a person having origins in any of the original peoples of North, Central, or South America and who maintain tribal affiliation or community attachment. “Native Hawaiian or other Pacific Islander” refers to a person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands. “Other Race” refers to any person not identifying with any of the five race categories, regardless of membership in the ethnicity category (Humes et al. 2011). This third GIS layer answered my second question: Who lives in Snohomish County UHIs?

Finally, I calculated the percentage of households with an air conditioner. To determine level of ownership I performed secondary data analysis from the U.S. Census Bureau’s 2013 American Housing Survey (AHS). The AHS is a longitudinal housing unit survey performed every other year. Housing units are selected to represent a cross section of all housing in the nation. The same basic sample is surveyed every two years until updates are added by the U.S. Census Bureau based on new construction and newly “discovered” units. Each housing unit is weighted and represents approximately 2,000 housing units in the United States (Census.gov). This answered my third and final question: What percent of people in Snohomish County own air conditioners?

Chapter 4- Results and Discussion

Urban Heat Islands

Station ID	Location	Elev. in Feet	Avg. Nighttime Temp
GHCND:USC00452675	47.9752, -122.195	18.3	57.0
KWASTANW17	48.244, -122.348	20	56.1
GHCND:USC00450257	48.2005, -122.128	30.5	48.0
KWASNOHO48	47.915, -122.079	33	54.6
GHCND:USC00455525	47.8452, -121.9944	36.6	53.3
KWAEDMON23	47.819, -122.372	43	58.8
GHCND:USC00458034	47.8663, -121.7175	51.8	53.0
KWAMARYS31	48.041, -122.144	108	58.0
MT5526	47.916, -122.207	118	64.3
KWAMARYS34	48.057, -122.137	141	54.5
KWAEVERE60	47.978, -122.205	144	63.7
KWASNOHO46	47.998, -122.033	151	52.5
GHCND:USC00451992	48.26, -121.6036	167.6	56.3
GHCND:USW00024222	47.90778, -122.28028	184.7	61.0

Figure 4 Meteorological Stations surveyed during study period

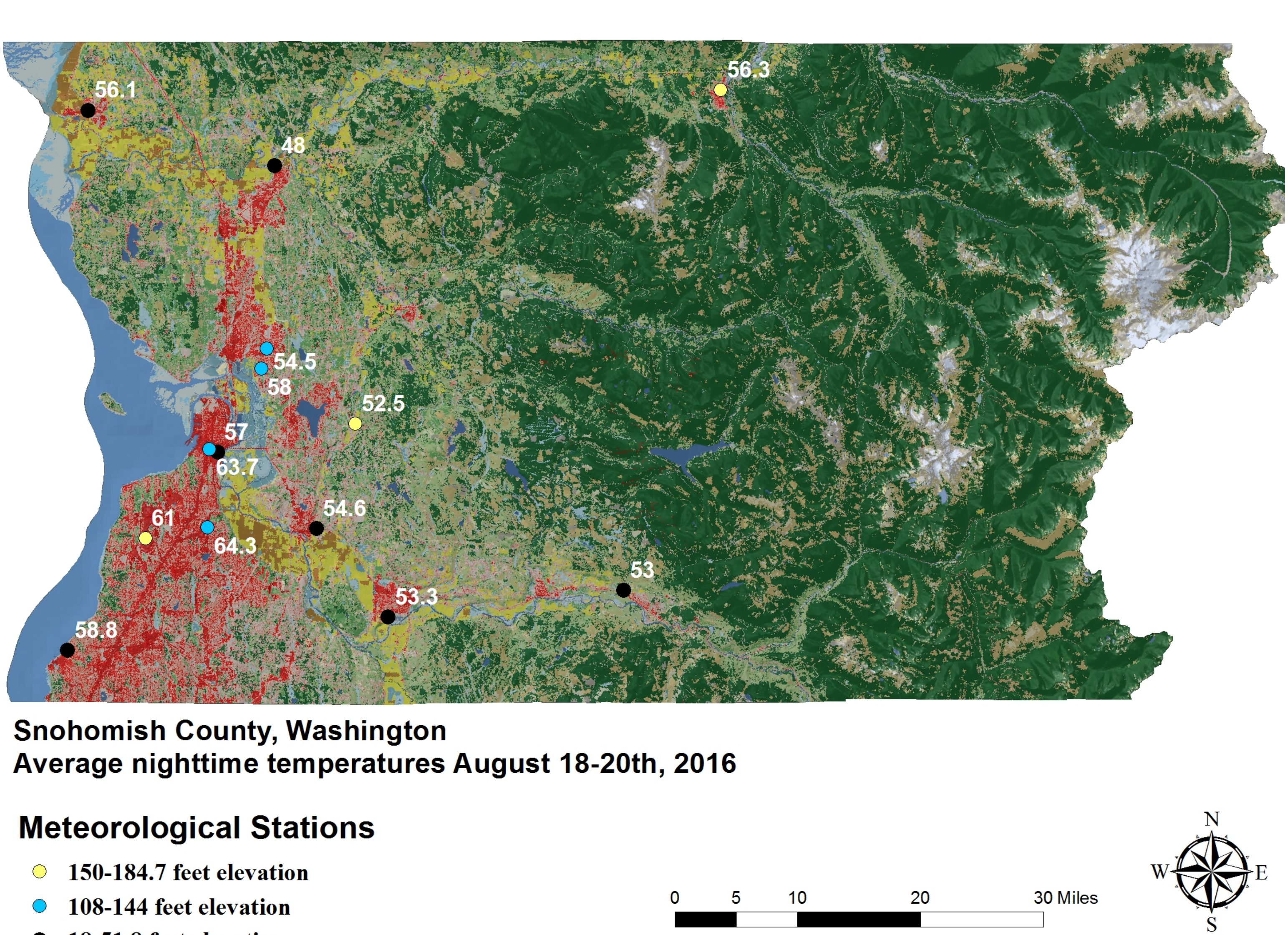

Figure 5 Average Nighttime Temperatures

When comparing meteorological stations bounded within three different elevation classes, temperature data from NOAA and Wunderground.com revealed there are urban heat islands in Snohomish County. Five meteorological stations located in the areas of Snohomish County with the most impervious surface measured consistently higher temperatures than adjacent suburban or rural areas within each elevation boundary classification. One station in Everett measuring 18 feet above sea level was on average

2.4ºF warmer than a station in City of Snohomish at 33 feet above sea level, yet only 10 miles apart in distance. Another station in Everett averaged nearly 10ºF warmer than a station in Marysville, yet only 15 miles apart in distance and 23 feet apart in elevation. A station in Mukilteo was on average 8.5ºF warmer than a station east of Lake Stevens, yet only ~20 miles away and located within a difference of 33.7 feet in elevation.

The single station located in City of Stanwood measured average temperatures of 56.1ºF, only .9ºF less than a station in Everett which differed by only 2 feet in elevation. Oke (1973) states that a 1ºC (1.8ºF) difference in temperatures is the "minimum urban/rural difference of significance", therefore this result warrants additional discussion.

Temperatures during the selected period are average lows over three days-time. On August 18th, the low in Everett was 53ºF but was 56.1ºF in Stanwood. However, the lows for August 19th and 20th in Everett were both 59ºF, and 57.2ºF and 55.1ºF respectively, for Stanwood. The much larger variation in nighttime lows between the first and second days in Everett lowers the average over the three-day period. In addition, three of the four Everett stations no matter the elevation showed a 6ºF difference in nighttime lows between the first and second night of the survey period, whereas all but one suburban/rural station had a 1°-3ºF difference in nighttime lows between the first and second night. This suggests there could be more variation in nighttime temperatures within the urban heat island.

At a finer scale, within the city of Marysville there was a difference of 3.5ºF between two stations 1.67 miles apart which differ by only 33 feet in elevation. Two stations in Everett less than one mile apart in distance, but differing by only 125 feet in elevation revealed a nearly 6°F difference in temperature. This highlights the need for a more detailed study of temperatures using a mobile unit to reveal if there are micro-hotspots within the built environment in both urban and suburban areas. This is especially true in Marysville, which is the fastest growing city in Snohomish County and is likely to become hotter as development continues.

Populations in Urban Heat Islands

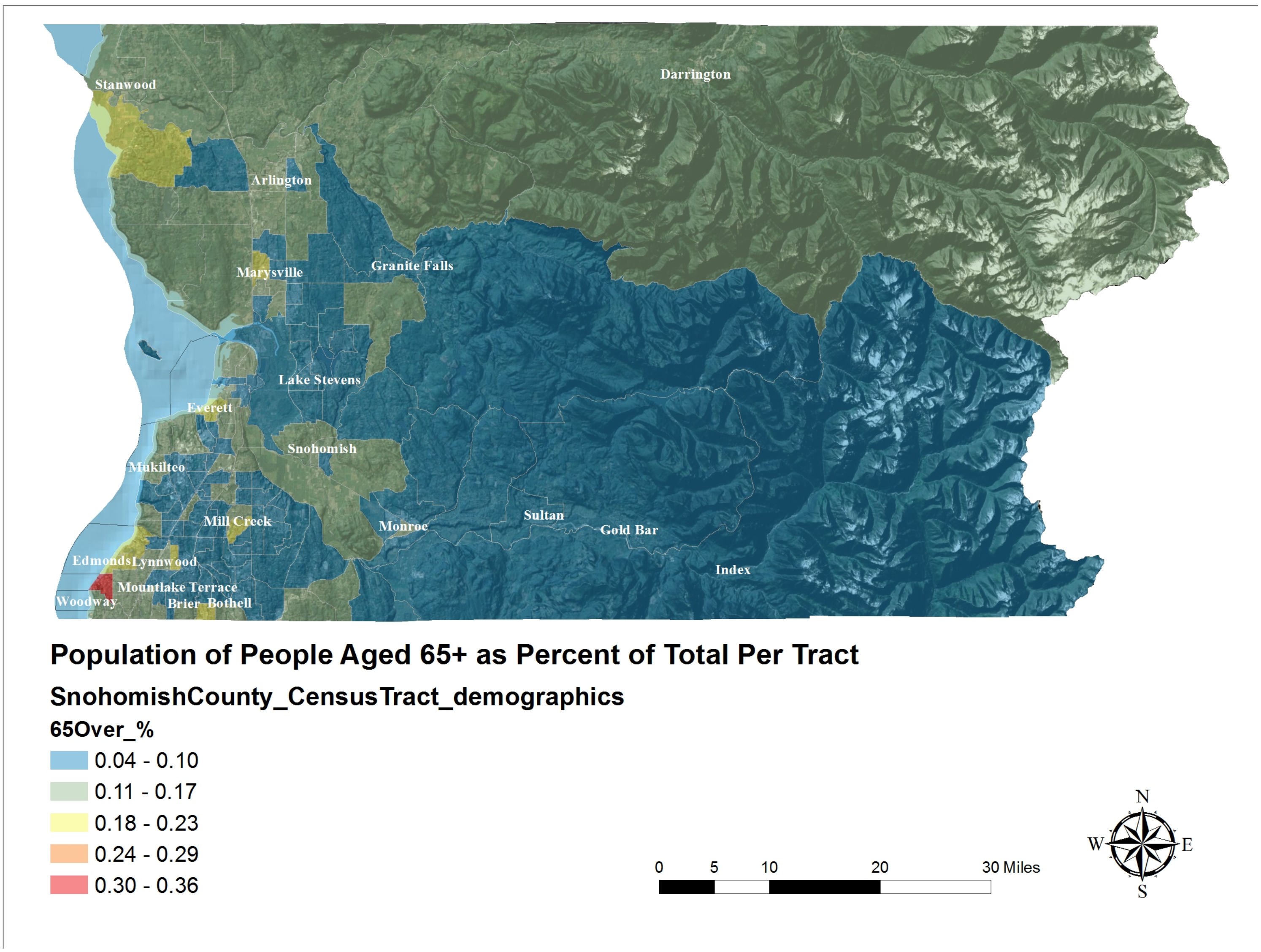

Figure 6 Population Density of People Aged 65+ Per Tract

The age group most at-risk, 65+ of any race, was found in areas with elevated temperatures. Overall this age group is 10% of the population of the county, yet there are numerous census tracts with higher concentrations than county average along the I-5 corridor and in the areas along the Puget Sound. Despite the relative cooling effects of living near water, the temperature map demonstrated these areas experience heat levels above background. In the most concentrated census tract of those aged 65+ between the cities of Edmonds and Woodway, this age group was as much as 36% of the population.

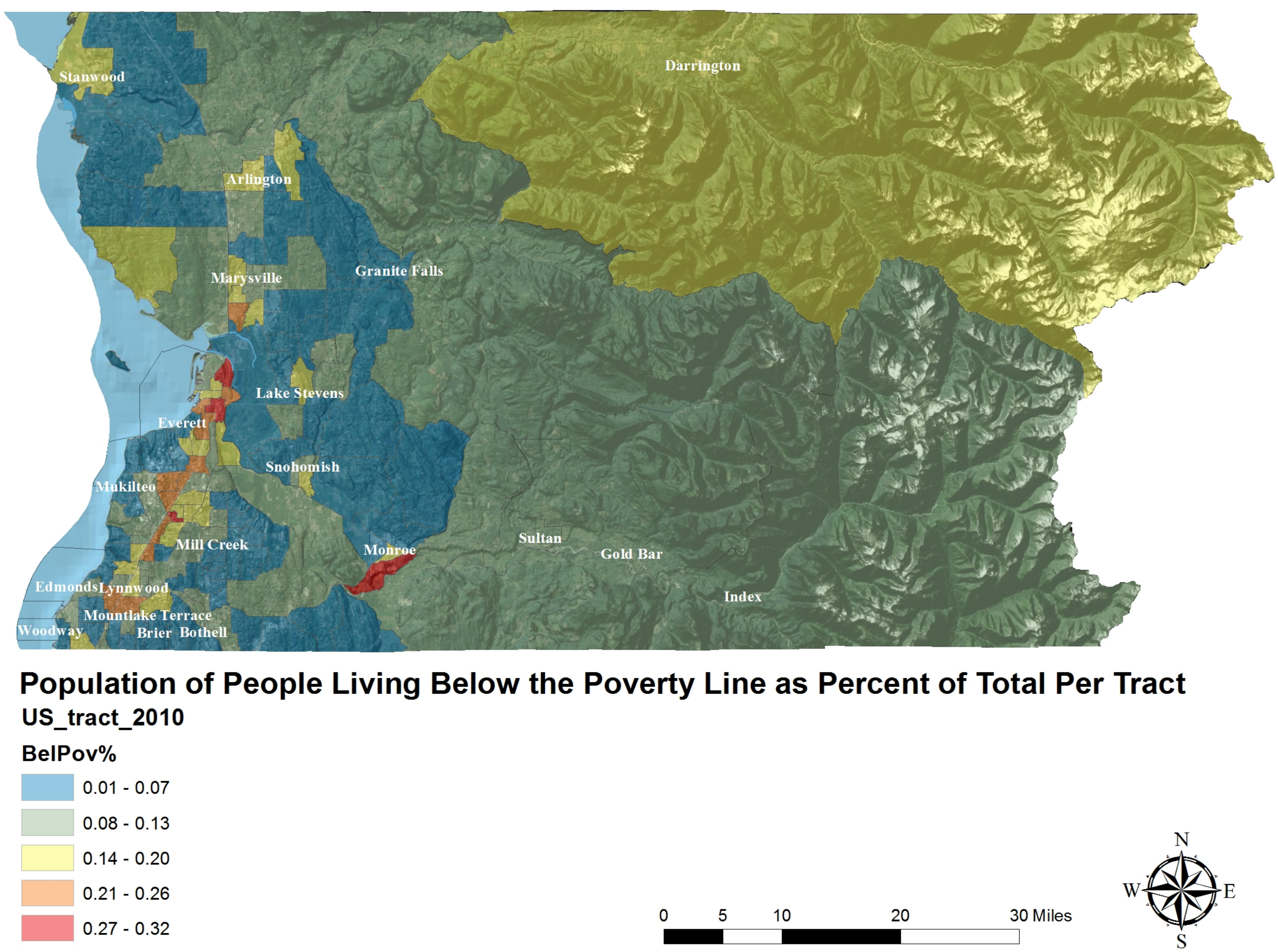

Figure 7 Population Density of People Living Below the Poverty Line Per Tract

The census tracts with the highest concentrations of people living below the poverty line were found in areas with UHIs, but there were some rural census tracts with between 14%-20% of the population living below the poverty line. However, as Johnson et al. (2009) point out, vulnerable rural populations are at lower risk during heat events when compared to urban populations due to the heat load of the urban environment.

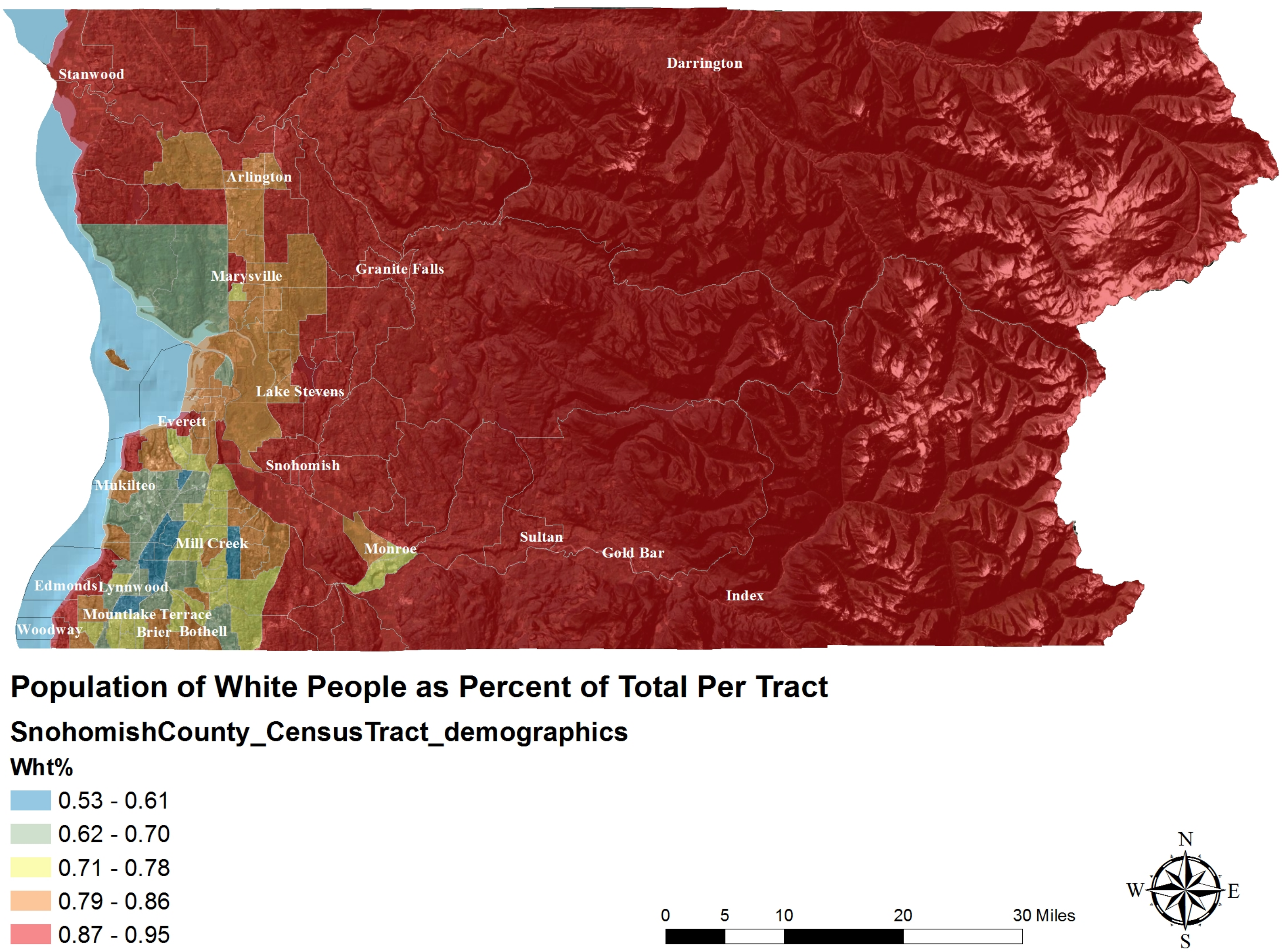

Figure 8 Population Density of White People Per Tract

At their lowest concentrations, white people represent 53%- 61% of the population in urban areas, yet are 78% of the overall population of the county. Based on U.S. Census reporting for white people, there is no way to measure what percent of this population is North African or Middle Eastern, so this number may be an overestimation of people who self-identify as white, or experience life as a white person.

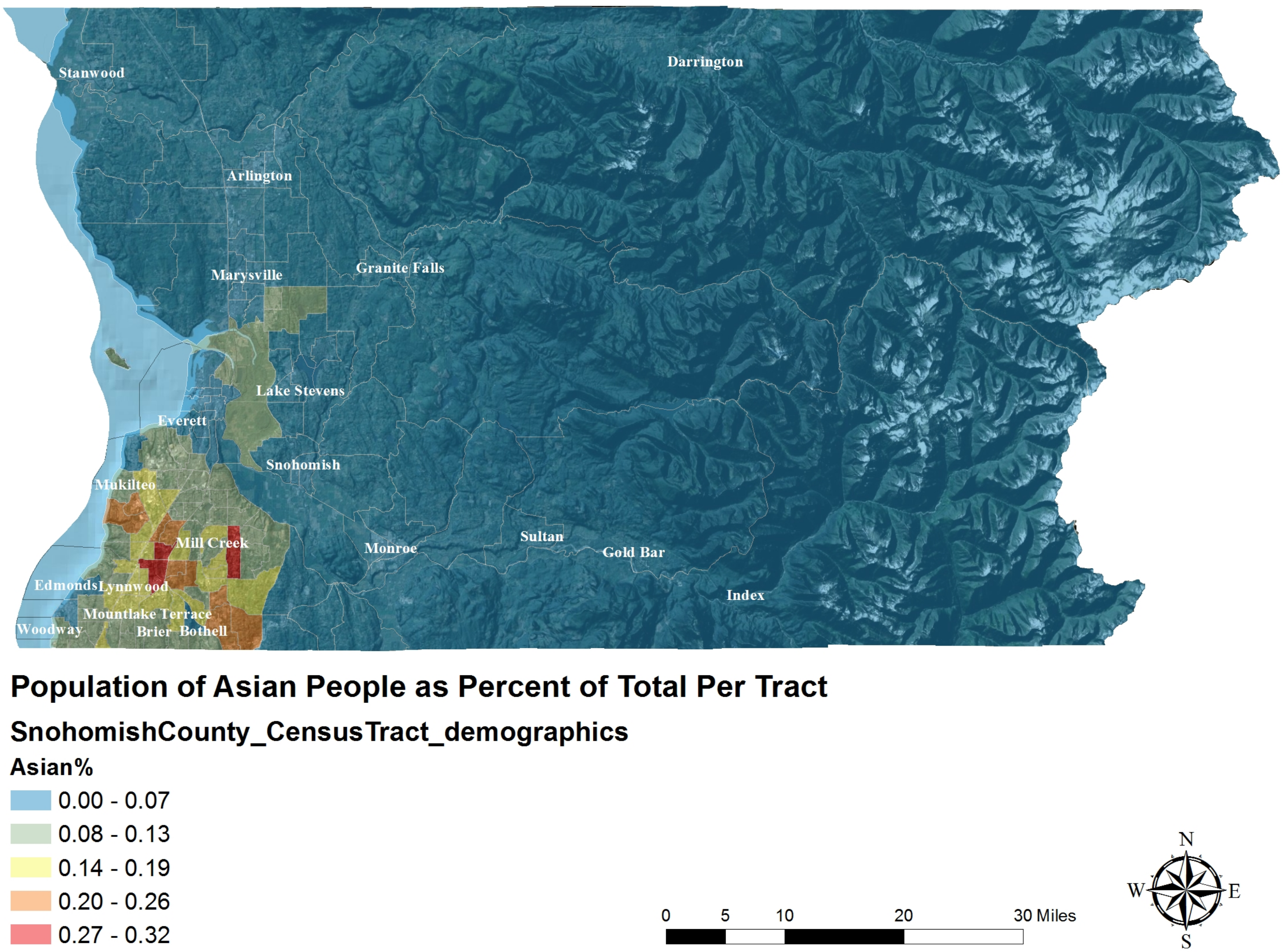

Figure 9 Population Density of Asian People Per Tract

Asian people are 9% of the population of the county, yet are between 14-32% of the population in many areas of the built environment where higher temperatures were revealed. One of the census tracts with the highest proportions of Asian people borders the I-5 corridor, and several with above average concentrations of Asian people border the area.

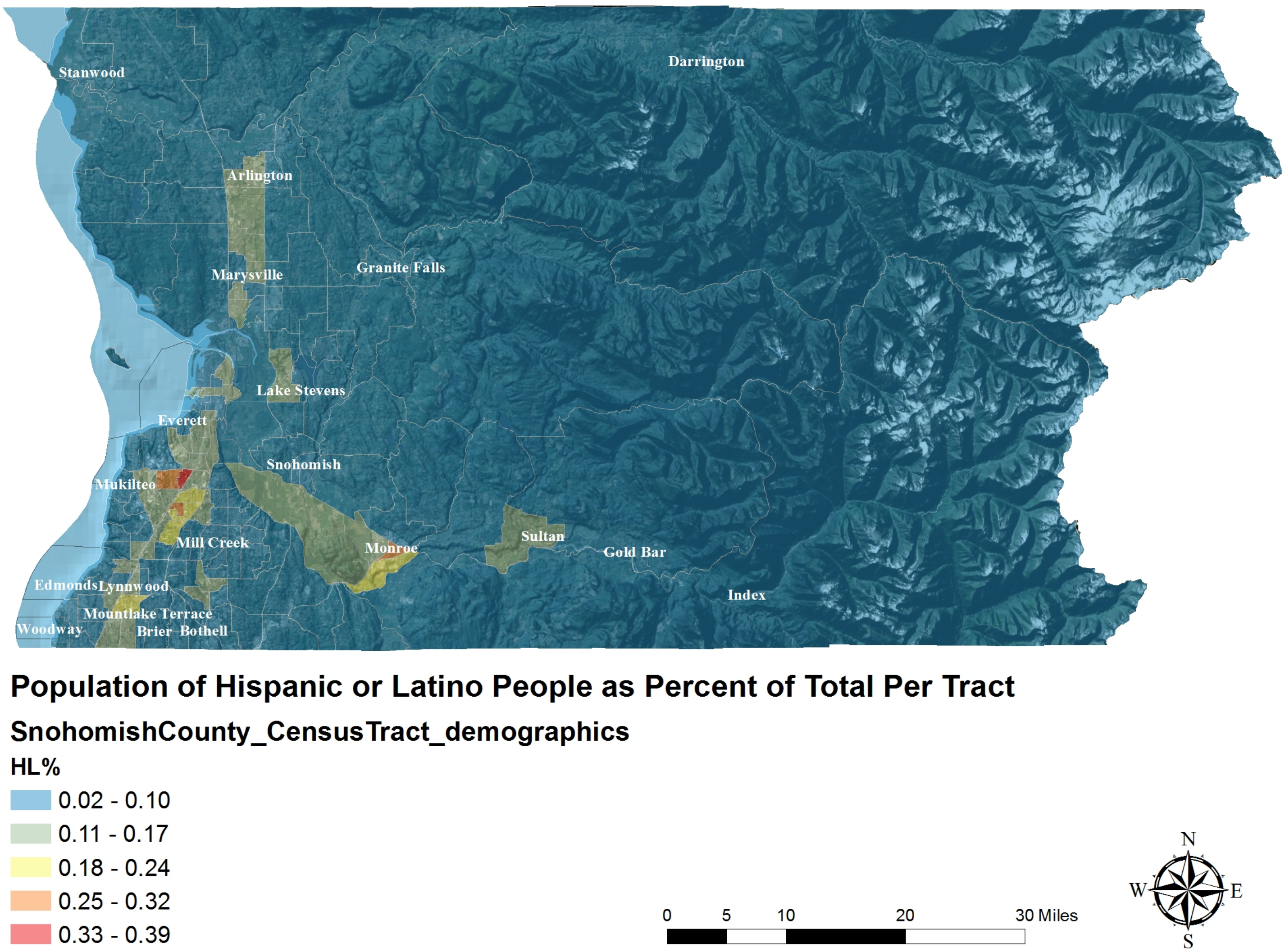

Figure 10 Population Density of Hispanic or Latino People Per Tract

Hispanic or Latino people are also 9% of the population, yet represent between 11% and 39% of the population in census tracts located in the urban environment, and of those tracts within the urban environment, almost all are along the I-5 Corridor.

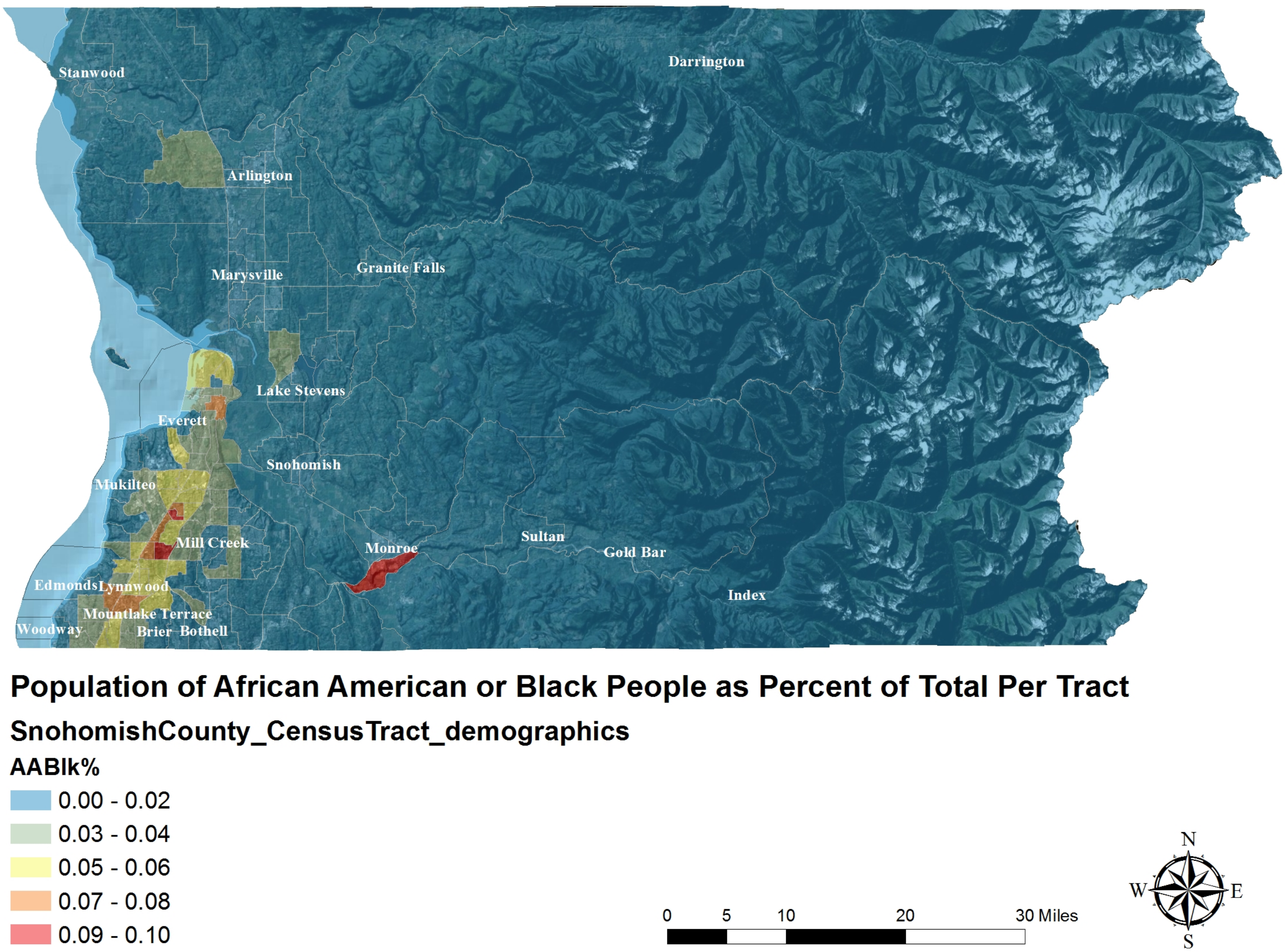

Figure 11 Population Density of African American or Black People Per Tract

African American or Black people are only 3% of the total population for Snohomish County, yet represent as high as 10% of the population in the most concentrated areas along the I-5 corridor. In fact, all but one of the highest density census tracts are bordering the freeway or adjacent to a tract bordering the freeway. In addition, this group has the highest number of individual census tracts with high concentrations of a single racial group, signaling greater levels of segregation into the specific areas of the built environment than for any other racial demographic analyzed.

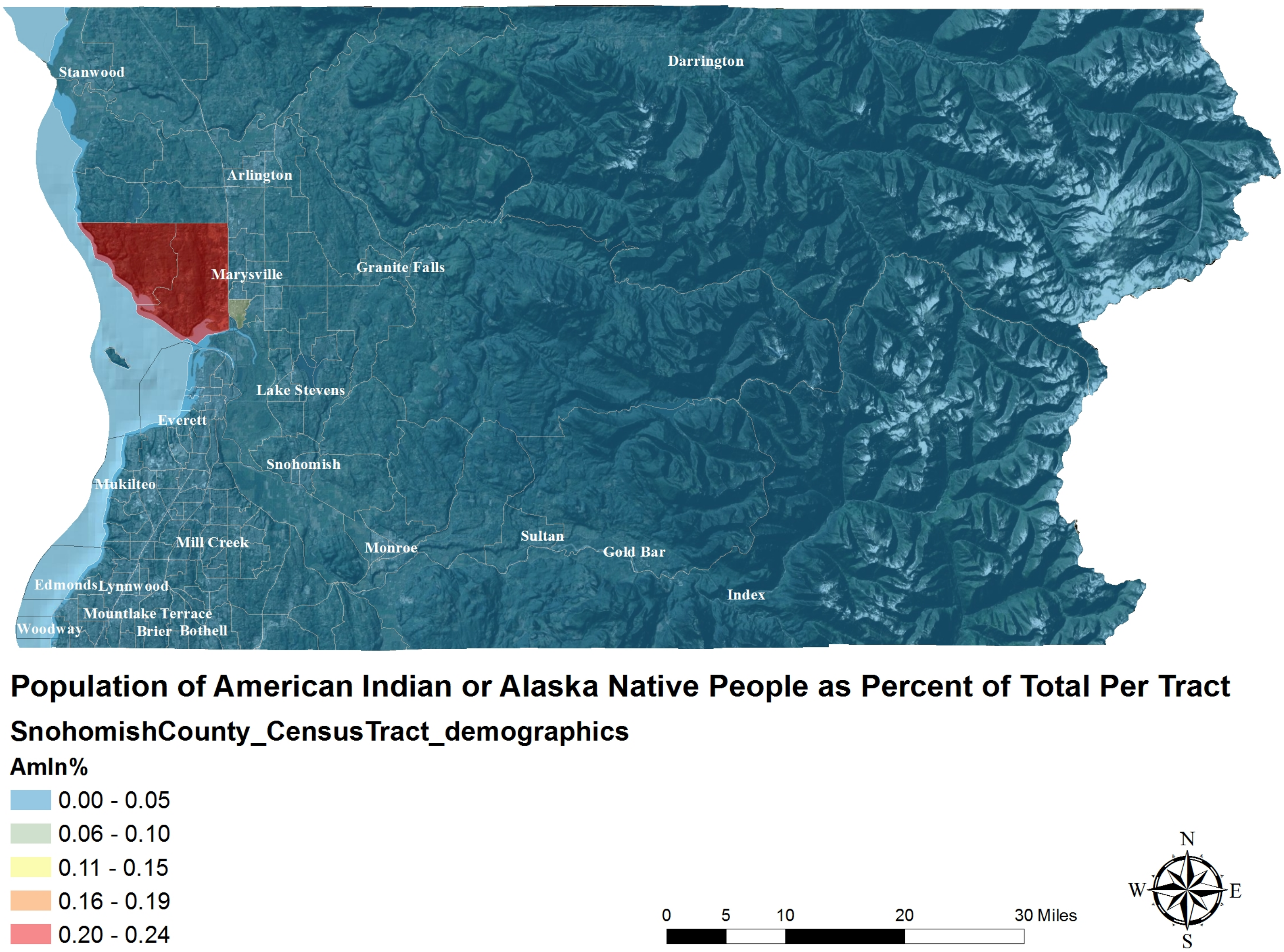

Figure 12 Population Density of American Indian or Alaska Native People Per Tract

American Indian or Alaska Native peoples are 1.5% of the county population, and almost exclusively represented in one area north of Everett, in and around the area where the Tulalip Tribes are located.

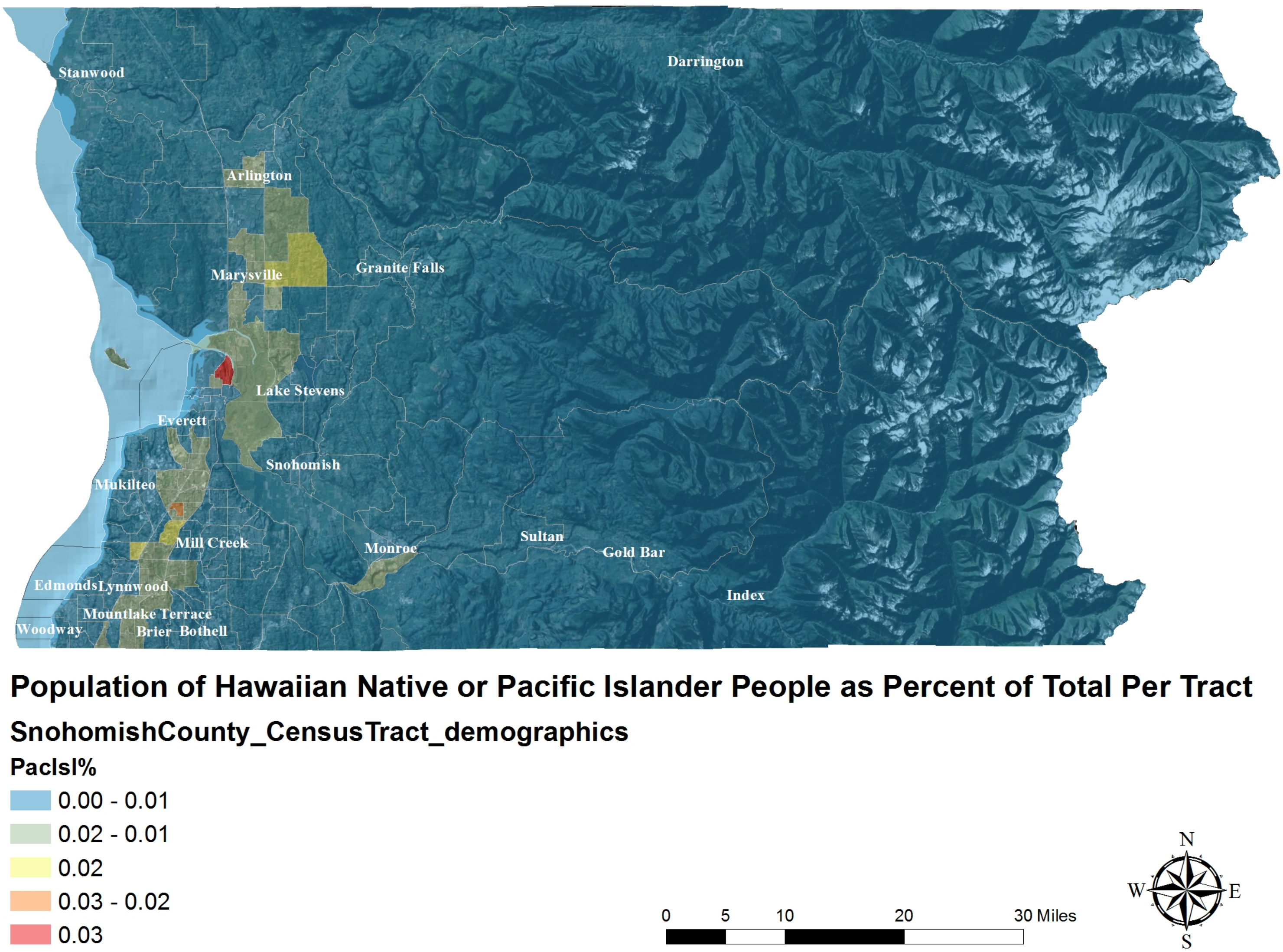

Figure 13 Population Density of Native Hawaiian or Other Pacific Islander Per Tract

Hawaiian or other Pacific Islander peoples are .05% of the population of the county. The highest density tracts are located along I-5, but are below county background.

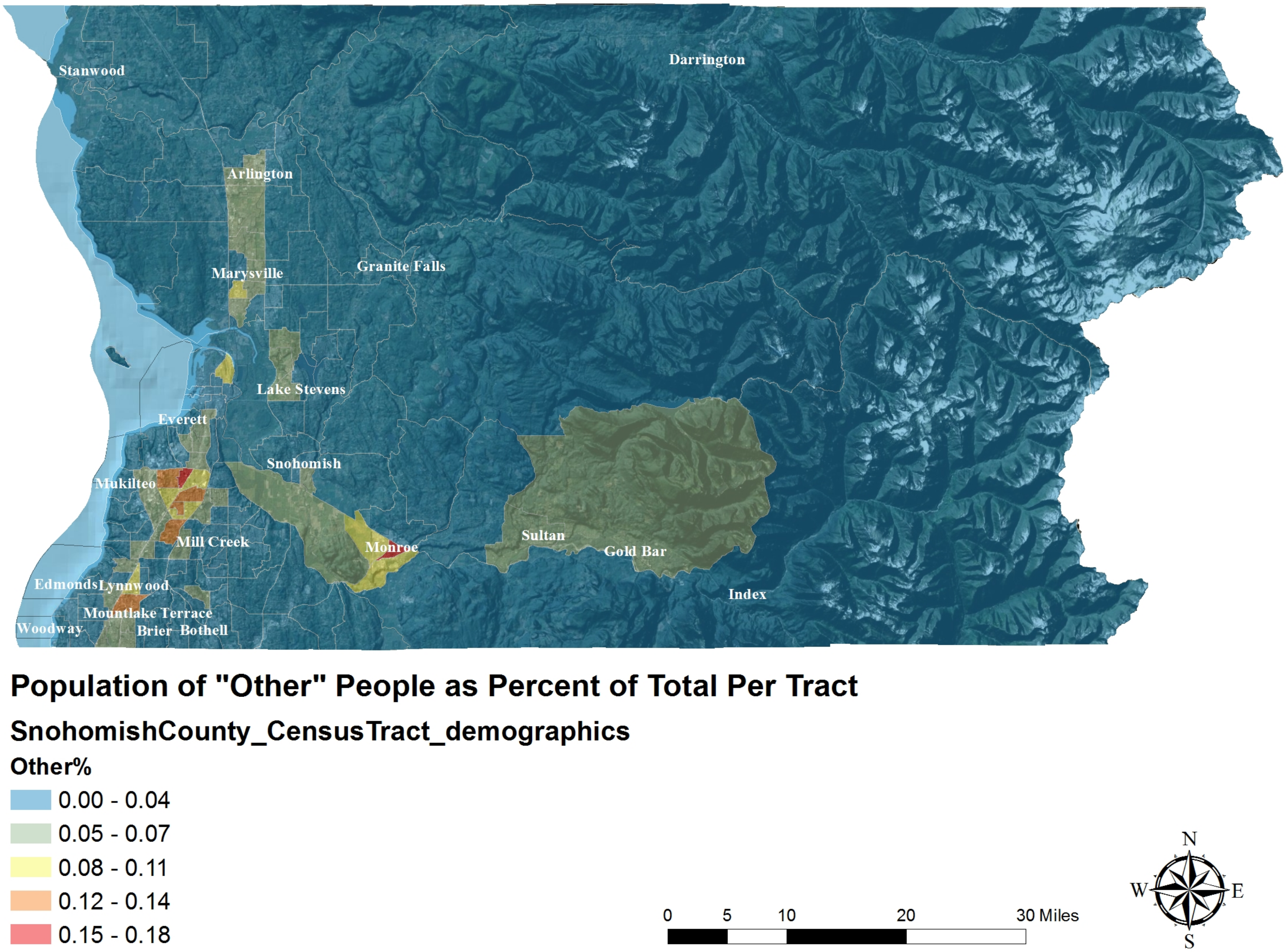

Figure 14 Population Density of Some Other Race Per Tract

People who chose the category of “other” for race represent nearly 4% of the county, and are also predominately living along the I-5 corridor in the built environment. This category of people includes anyone who doesn’t self-identify as White, African American or Black, Asian, American Indian/Alaska Native, or Hawaiian or Pacific Islander. According to Washington Community Action Network (2014), the United States Census includes members of one race or ethnicity into another category. For example, peoples of North African or Middle Eastern descent are counted in the “white” category, even though this may not be the lived experience of those peoples. This may account for the high percent of “other”. It also highlights the difficulty in mapping peoples as accurately as their lived experience would dictate, masking some settlement patterns.

Air Conditioners

The American Household Survey sampled 3,823 housing units in the Seattle Metropolitan Area, which includes the cities of Seattle, Bellevue, Redmond, Renton, Everett, Tacoma, Kent, Auburn and Lakewood. 26% of the population of this survey were calculated to own an air conditioner. Due to the fact only one Snohomish County city was included in the sample, it was impossible to state the percent of county residents who have this preventative measure, but this may be a similar rate for Snohomish County cities.

Chapter 5- Conclusion

To date, no other researcher has looked at urban heat islands in Snohomish County. This study was performed to fill this gap, and to create a starting point for public health and urban planning officials when considering issues such as social justice, equitable and fair housing, and climate change.

People of color, the poor, and the elderly are living in areas of Snohomish County where there are heat islands. There have already been heat events reported in this area in 2015 and 2016, the latter which is the subject of this study. As climate change progresses, heat events in Snohomish County will be more frequent, more severe, and longer lasting; like in the rest of the world.

As urbanization continues and cities in Snohomish County grow, there will be more heat islands, and thus more people at risk of the effects. The City of Marysville is the fastest growing city in Snohomish County and as of 2015 was the third fastest growing city in the state, behind only Seattle and Vancouver. Therefore, as Marysville grows it should be targeted for policy interventions and careful urban planning to mitigate for the changing climate. Other cities within the study area should be targeted for outreach and mitigation measures.

The City of Seattle publishes a list of cooling centers on their website: http://murray.seattle.gov/cooling-shelters-locations-announced-ahead-of-heat-wave/ -sthash.ZkktHMh2.dpbs, and it is advertised in newspapers, online, and on television prior to heat events. This type of policy could be adopted by the cities of Snohomish County.

The city of Vancouver, Canada has developed a heat emergency trigger system based on a threshold temperature they determined impacts mortality. The temperatures they identified were not extreme: two days of temperatures reaching 84ºF at the Vancouver Airport on the coast and 93ºF 40 miles inland at the Abbotsford Airport. Though daytime temperatures were not part of the final evaluation of this study, it was noted the temperatures identified in Vancouver as signaling a temperature threshold were similar to what people of Snohomish County experienced during the day in the heat events of August 18-20th, 2016. The trigger system is based on daytime highs, which is not how an atmospheric UHI is measured, but is correlated with morbidity and mortality during a heat event.

In 2010 the City of Tacoma, Washington adopted a new chapter in the comprehensive plan, called the Urban Forestry Policy Element. The vision is to increase the canopy cover from 19% (2009 levels) to 30% by 2030, partly to reduce the heat island effect. They are achieving this goal by increasing education and outreach, clarifying tree ownership and maintenance responsibilities, building and supporting partnerships, and coordinating planning and design of public infrastructure to include trees. This included changes to the city codes for new and updated developments. The city has also begun de-paving areas by ripping up excess sidewalk and planting trees. Trees that are planted are judged for their suitability to traffic, pollution, and drought (Ponnekanti, 2016).

Policy interventions that involve heat notification in other jurisdictions have not explicitly addressed language. When targeting intervention materials, language mapping will need to be performed to ensure intervention materials have the highest rates of success. The American Community Survey questionnaire includes language information and the U.S. Census bureau has a tool on their website revealing the location of people in Snohomish County who speak English, "less than well." The map reveals there are significant numbers of people whose first languages include Spanish, Russian, Polish, Persian, Arabic, Chinese, Japanese, Korean, Vietnamese, and Tagalog, as well as smaller populations of people speaking other languages such as German, Italian, Portuguese, and French.

Undocumented peoples may avoid filling out or being included in the census for fear of being targeted, punished, or deported. Undocumented people of color may therefore be under-represented in this study. Homeless people are not accounted for during the census, and are least likely to have access to outreach materials in the media warning of a heat event. Homeless shelters see a spike in use during heat events, and officials in Maricopa County, Arizona have begun to address the issue by creating maps of cooling centers and providing hydration stations (Koronowski, 2016). Similar programs could be adopted in Snohomish County.

Limitations of the study

This study was not designed to measure building age or conditions, which has been shown in other studies to impact health outcomes. In addition, the limited number of meteorological stations in the urban, suburban, and rural areas restricted finer analysis of heat, especially in the City of Stanwood. Lastly, the American Household Survey only includes one Snohomish County city in its survey, limiting understanding of air conditioner ownership in the study area.

Questions for future research

As with many studies, additional questions arise. For Snohomish County to create an effective heat-alert system, would thresholds be adopted from neighboring King County or would a county-specific threshold be measured based on local morbidity and mortality during a heat event? This study was also not designed to measure ozone. Is there a temperature level for ozone to begin to accumulate, given local topographic and geographic features? It was demonstrated in this study that temperatures vary greatly within cities such as Everett and Marysville. Is it worthwhile to measure micro-urban heat islands, or should county-wide tree planting and green roof measures be adopted like in the Cities of Tacoma and Portland? What measures can be taken to protect the homeless during a heat event, and how will those efforts be coordinated? Lastly, in this study building age and condition were not considered in areas where heat islands were found. Do these conditions increase a person's risk?

Appendices

Key Concepts

Vulnerable Populations have been defined in numerous ways. Regarding climate change and its myriad impacts, Cooley et al. define social vulnerability as the "susceptibility of a given population to harm from exposure to a hazard, directly affecting its ability to prepare for, respond to, and recover (2012)." A review of heat-health literature from around the world shows some variation in social vulnerability indicators. Consistent with most of the reviewed literature by this author are age, income, race and ethnicity. These four social indicators plus the presence of a single intervention variable were measured:

Category	Data source	Variable Definition
Age	U.S. Census (2010)	<65 ≥65
Race		White Black/African American Asian Native American/Native Alaskan Native Hawaiian or Pacific Islander Two or more races
Ethnicity		Hispanic Non-Hispanic
Income		Below the poverty line
Air Conditioner	U.S. Census American Housing Survey (2011)	Yes No

Figure 15 Measurements Used

Urban Heat Islands

Urban areas that experience higher temperatures than surrounding rural areas are called Urban Heat Islands (UHIs). *There is no agreed upon threshold level above* *background that indicates the presence of a heat island* (Calkins et al., 2016). This is likely due to variations in the “normal” heat levels experienced in each geographical area.

There are two types of UHIs: Surface and Atmospheric. According to the U.S. Environmental Protection Agency (EPA) they differ “in the ways they are formed, the techniques used to identify and measure them, their impacts, and to some degree, the methods available to mitigate them” (EPA 2008). Surface UHIs measure the temperature of surfaces such as soil, pavement, and roof tops. These temperatures contribute to the atmospheric temperature in the form of long-wave radiation (the release of heat from the earth), but is not the temperature people experience on their skin. Atmospheric UHIs measure the air temperature. “Atmospheric urban heat islands are often weak during the late morning and throughout the day and become more pronounced after sunset due to the slow release of heat from urban infrastructure (EPA 2008).”

The following table demonstrates the differences between the two:

Feature	Surface UHI	Atmospheric UHI
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (Most intense UHI conditions)	More spatial and temporal variation: • Day: 18 to 27 F (10 to 15 C) • Night: 9 to18 F (5 to 10 C)	Less variation: • Day: -1.8 to 5.4 F (-1 to 3 C) • Night: 12.6 to 21.6 F (7 to 12 C)
Typical Identification Method	Indirect measurement: • Remote sensing	Direct measurement: • Fixed weather stations • Mobile traverses
Typical Depiction	Thermal image	Isotherm map Temperature graph

Figure 16 Definition and Measurement of Surface UHI and Atmospheric UHI

Source: Reducing Urban Heat Islands: Compendium of Strategies

When measuring Atmospheric UHIs, it is common to compare ambient temperature using meteorological stations at one or more fixed points within the urban and adjacent rural area. Martin-Vide et al., (2015) argue it is important the “rural reference” not differ from the urban one by more than 30 meters, or 98.4 feet in altitude and 800 meters or 2,624 miles in distance from the sea. In addition, they stress the importance of measuring temperature during the night, when atmospheric UHIs are most pronounced and detectable.

Extreme Heat Events

Jackson et al. (2010) defined heat events as one or more consecutive days of the humidex above calculated thresholds. Isakson et al. (2016) calculated the humidex threshold for King County, Washington at 96.2ºF. Humidex is a measure of the combined effect of heat and humidity on human physiology, in other words, how hot it “feels”. The equation to calculate humidex is:

Humidex=T+5/9*(v-10)

Where T= air temperature (Celsius),

v= vapor pressure = (6.112x10^(7.5*T/(237.7 +T))* H/100, H= humidity (%)

Urban Effect

“Temperature measured at the urban point is a function of the climate of the region it is located, plus the effect of local geographic factors and urbanization, whereas the temperature at the non-urban point of the regional climate itself and the effect of local geographic factors (Martin-Vide et al., 2015)." The urban effect is therefore the temperature difference between the two, assuming two other factors are considered: elevation of the two points must be within approximately 30 meters, and distance from the coastline between the two points must not differ more than 800m.

Works Cited

Akbari, Hashem, Surabi Menon, Arthur Rosenfeld. 2008. "Global Cooling: Increasing World-Wide Urban Albedos to Offset CO2." *Climatic Change* 95 (3-4). doi: 10.1007/s10584-008-9515-9

Aniello, Cathy, Ken Morgan, Arthur Busbey, Leo Newland. 1995. "Mapping Micro-Urban Heat Islands Using Landsat TM and a GIS." *Computers & Geosciences.* 21:8:965-969

Associated Press. "Heat Wave Causes 5 Deaths in Roseville, Fire Chief Says." *CBS Detroit*. July 22, 2016.

Barbash, Fred and Travis M. Andrews. "'100 Percent Avoidable': Hiker Deaths Mount in Blazing Arizona Heat Wave." *The Washington Post,* June 22, 2016.

Bell, Michelle L., PhD, Aidan McDermott, PhD, Scott L. Zeger, PhD, Jonathan M. Samet, MD, Francesca Dominici, PhD. 2004. "Ozone and Short-Term Mortality in 95 US Urban Communities, 1987-2000." *JAMA*. 292(19) 2372-2378. doi:10.1001/jama.292.19.2372.

Buchin, Oliver, Marie-Therese Hoelscher, Fred Meier, Thomas Nehls, Felix Ziegler. 2016. "Evaluation of the Health-Risk Reduction Potential of Countermeasures to Urban Heat Islands." *Energy and Buildings.* 114:27-37. http://dx.doi.org/10.1016/j.enbuild.2015.06.038

Cadot, Emmanuelle, Victor G. Rodwin, Alfred Spira. 2007. "In the Heat of the Summer: Lessons from the Heat Waves in Paris.: *Journal of Urban Health.* 84(4):466-468. doi: 10.1007/s11524-007-9161-y

Calkins, Miriam M., Tania Busch Isaksen, Benjamin A. Stubbs, Michael G. Yost, Richard A. Fenske. 2016. "Impacts of Extreme Heat on Emergency Medical Service Calls in King County, Washington, 2007-2012: Relative Risk and Time Series Analyses of Basic and Advanced Life Support." *Environmental Health.* 15:13. Doi:10.1186/s12940-016-0109-0

Centers for Disease Control and Prevention. "Heat-Related Deaths After an Extreme Heat Event- Four States, 2012, and United States, 1999-2009." *Morbidity and Mortality Weekly Report*. June 7, 2013. 62(22): 433-436 https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6222a1.htm

—— "Climate Change and Extreme Heat Impacts."
——"Extreme Heat Prevention Guide" https://www.cdc.gov/disasters/extremeheat/heat_guide.html

Census.gov https://www.census.gov/programs-surveys/ahs/about/methodology.html

Chong, Jia-Rui, "California's 2006 Heat Wave was Much Deadlier Than Previously Reported, Researchers Say," *Los Angeles Times*, July 21, 2009.

City of Chicago. "Chicago's Urban Forest Agenda" https://www.cityofchicago.org/content/dam/city/depts/doe/general/NaturalResourcesAndWaterConservation_PDFs/UrbanForestAgenda/ChicagosUrbanForestAgenda2009.pdf

—— Green Alley Program.
https://www.cityofchicago.org/city/en/depts/cdot/provdrs/street/svcs/green_alleys.html

City of Tacoma. Tree Planting.
http://www.cityoftacoma.org/cms/one.aspx?objectId=35885

Clickondetroit.com. “Roseville Suffers 5 Heat-Related Deaths in Last 3 Days.” July 22, 2016. www.clickondetroit.com

Climate Central. “”Heat Islands” Cook U.S. Cities Faster Than Ever.” *Scientific American.* August 22, 2014.

Cooley, Heather, Eli Moore, Matthew Heberger, Lucy Allen. 2012. “Social Vulnerability to Climate Change in California.” Pacific Institute.

Dematte, Jane E., MD, Karen O’Mara, DO, Jennifer Buescher, BS, Cynthia G. Whitney, MD, MPH, Sean Forsythe, MD, Turi McNamee, MD, Raghavendra B. Adiga, MD, I. Maurice Ndukwu, MD, MPH. 1998. “Near Fatal Heat Stroke During the 1995 Heat Wave in Chicago.” *Annals of Internal Medicine.* 129 (3) 173-181.

Donovan, Geoffrey H., PhD, David T. Butry, PhD, Yvonne L. Michael, ScD, Jeffrey P. Prestemon, PhD, Andrew M. Liebhold, PhD, Demetrios Gatziolis, PhD, Megan Y. Mao. 2013. “The Relationship Between Trees and Human Health.” *American Journal of Preventative Medicine* 44(2):139-145. http://dx.doi.org/10.1016/j.amepre.2012.09.066

Ebi, Kristie L. Thomas J. Teisberg, Laurence S. Kalkstein, Lawrence Robinson, Rodney F. Weiher. 2004. “Heat Watch/Warning Systems Save Lives.” *Bulletin of the American Meteorological Socity* August: 1067-1073.

Environmental Protection Agency (EPA). 2014. “Keeping Your Cool: How Communities Can Reduce the Heat Island Effect.” Publication Number 430F14041

—— 2012. “Cool Pavements” *Reducing Urban Heat Islands: Compendium of Strategies. Draft.* https://www.epa.gov/heat-islands/heat-island-compendium*.*

——2008. “Green Roofs.” *Reducing Urban Heat Islands: Compendium of Strategies. Draft. https://www.epa.gov/heat-islands/heat-island-compendium.*

——2008. “Urban Heat Island Basics.” *Reducing Urban Heat Islands: Compendium of Strategies. Draft. https://www.epa.gov/heat-islands/heat-island-compendium.*

—— 1992. “Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing.”

EPA.gov. Ozone Pollution. https://www.epa.gov/ozone-pollution

—— “Using Trees and Vegetation to Reduce Heat Islands.”
https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands

Fuhrmann, Christopher M., Margaret M. Sugg, Charles E. Konrad II. 2016.

"Impacts of Extreme Heat Events on Emergency Department Visits in North Carolina." *Journal of Community Health.* 41:146-156. doi:10.1007/s10900-015-0080-7

Gago, E.J., J. Roldan, R. Pacheco-Torres, J. Ordóñez. 2013. "The City and Urban Heat Islands: A review of Strategies to Mitigate Adverse Effects." *Renewable and Sustainable Energy Reviews*. 25: 749-758.

Gray, K. A. and Finster, M. E. 1999. "The Urban Heat Island, Photochemical Smog, and Chicago: Local Features of the Problem and Solution." Evanston, IL: Northwestern University.

Hamlet, Alan F., Se-Yeun Lee, Kristian E.B. Mickelson, Marketa M. Elsner. 2010. "Effects of Projected Climate Change on Energy Supply and Demand in the Pacific Northwest and Washington State." *Climatic Change* 102 (1) 103-128. doi: 10.1007/s10584-010-9857-y

Harmon, Katherine. "How Does a Heat Wave Affect the Human Body?" *Scientific American*. July 23, 2010 https://www.scientificamerican.com/article/heat-wave-health/

Henderson, Sarah B., PhD, and Tom Kosatsky, MD. 2012. "A Data-Driven Approach to Setting Trigger Temperatures for Heat Health Emergencies.", *Canadian Journal of Public Health.* 103(3) 227:230.

Hewitt, Virginia, Eric Mackres, Kirk Shickman. 2014. "Cool Policies for Cool Cities: Best Practices for Mitigating Urban Heat Islands in North American Cities." American Council for an Energy-Efficient Economy and Global Cool Cities Alliance.

Holthaus, Eric. "French Toast: Temperatures Surge as Historic Heat Wave Hits Western Europe. *The Slatest*. July 1, 2015.

Humes, Karen R., Nicholas A. Jones, and Roberto R. Ramirez. 2011. "Overview of Race and Hispanic Origin, 2010." *US Census Briefs* https://www.census.gov/prod/cen2010/briefs/c2010br-02.pdf

Isaksen, Tania Busch, Richard A. Fenske, Elizabeth K. Hom, You Ren, Hilary Lyons, Michael G. Yost. 2016. "Increased Mortality Associated with Extreme-Heat Exposure in King County, Washington, 1980-2010." *International Journal of Biometeorology*. 60:85-98. doi:10.1007/s00484-015-1007-9.

Isaksen, Tania Busch, Michael G. Yost, Elizabeth K. Hom, You Ren, Hilary Lyons, Richard A. Fenske. 2015. "Increased Hospital Admissions Associated with Extreme-Heat Exposure in King County, Washington, 1990-2010." *Reviews on Environmental Health.* 30(1):51-64. doi:10.1515/reveh-2014-0050

Isaksen, Tania Busch, Michael Yost, Elizabeth Hom, Richard Fenske. 2014. "Projected Health Impacts of Heat Events in Washington State Associated with Climate Change." *Reviews on Environmental Health.* 29(1-2): 119-123, doi:10.1515/reveh-2014-0029.

Jackson, J. Elizabeth, Michael G. Yost, Catherine Karr, Cole Fitzpatrick, Brian K. Lamb, Serena H. Chung, Jack Chen, Jeremy Avise, Roger A. Rosenblatt, Richard A. Fenske. 2010. "Public Health Impacts of Climate Change in

Washington State: Projected Mortality Risks Due to Heat Events and Air Pollution." *Climatic Change.* 102: 159-186. doi:10.1007/s10584-010-9852-3.

Jesdale, Bill M., Rachel Morello-Frosch, Lara Cushing. 2013. "The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation." *Environmental Health Perspectives*. 121:811-817. http://dx.doi.org/10.1289/ehp.1205919

Johansson, Erik. 2006. "Influence of Urban Geometry on Outdoor Thermal Comfort in a Hot Dry Climate: A Study in Fez, Morocco." *Building and Environment*. 41: 1326-1338. doi:10.1016/j.buildenv.2005.05.022

Johnson, Daniel P., Jeffrey S. Wilson, George C. Luber. 2009. "Socioeconomic Indicators of Heat-Related Health Risk Supplemented with Remotely Sensed Data." *International Journal of Health Geographics.* 8 (57). doi:10.1186/1476-072X-8-57.

Kenny, Glen P. PhD, Jane Yardley MSc, Candice Brown BSc, Ronald J. Sigal MD MPH, Ollie Jay PhD. 2010. "Heat Stress in Older Individuals and Patients with Common Chronic Diseases." *CMAJ*. 182(10) 1053:1060. doi:10.1.503/emaj.081050

Kleerekoper, Laura, Marjolein van Esch, Tadeo Baldiri Salcedo. 2012. "How to Make a City Climate-Proof, Addressing the Urban Heat Island Effect.", *Resources, Conservation and Recycling*. 64:30-38. doi:10.1016/j.resconrec.2011.06.004

Knowlton, Kim, Miriam Rotkin-Ellman, Galatea King, Helene G. Margolis, Daniel Smith, Gina Solomon, Roger Trent, Paul English. 2009. "The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits." *Environmental Health Perspectives*. 117(1) 61-67. doi:10.1289/ehp.11594

Koronowski, Ryan. "Climate Change's Growing Impact on People Experiencing Homelessness." *Think Progress.* June 29, 2016 https://thinkprogress.org/climate-changes-growing-impact-on-people-experiencing-homelessness-219e2b8ba90d

Martin-Vide, Javier, Pablo Sarricolea, M. Carmen Moreno-Garcia. 2015. "On the Definition of Urban Heat Island Intensity: The "Rural" Reference." *Frontiers in Earth Science.* 3 (24) 1:3. doi:10.3389/feart.2015.00024

Matthews, Tony. 2012. "Heat Islands: Understanding and Mitigating Heat in Urban Areas." *Australian Planner.* 49:4,363-364 doi:10.1080/07293682.2011.501742

Meehl, Gerald A. and Claudia Tebaldi. 2004. "More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century." *Science.* 305:994-997

Memon, Rizwan Ahmed, Dennis Y.C. Leung, Liu Chunho. 2007. "A Review on the Generation, Determination, and Mitigation of Urban Heat Island." *Journal of Environmental Sciences.* 20:120-128.

NCSU.edu. Evapotranspiration. http://climate.ncsu.edu/edu/k12/.evapo

New York Times. "St. Louis Bears Brunt of Heat Wave as U.S. Toll Rises." July 24, 1983.

Nowak, David J., Satoshi Hirabayashi, Allison Bodine, Eric Greenfield. 2014. “Tree and Forest Effects on Air Quality and Human Health in the United States.” *Environmental Pollution*. 193:119-129 http://dx.doi.org/10.1016/j.envpol.2014.05.028

Office of Financial Management. 2016. “State of Washington 2016 Population Trends.”

Oke, T.R. 1973. “City Size and the Urban Heat Island.” *Atmospheric Environment.* 7: 769-779.

O’Neill, Marie S., Antonella Zanobetti, and Joel Schwartz. 2005. “Disparities by Race in Heat-Related Mortality in Four US Cities: The Role of Air Conditioning Prevalence.” *Journal of Urban Health: Bulletin of the New York Academy of Medicine.* 82(2): 191-197. doi:10.1093/jurban/jti043

Ponnekanti, Rosemary. “Tacoma’s Challenge: Making City of Destiny More a City of Trees.” *The News Tribune.* January 2 2016. http://www.thenewstribune.com/news/local/article52605380.html

Reid, Colleen E., Marie S. O’Neill, Carina J. Gronlund, Shannon J. Brines, Daniel G. Brown, Ana V. Diez-Roux. 2009. “Mapping Community Determinants of Heat Vulnerability.” *Environmental Health Perspectives.* 117(11) 1730:1736

Roux, Ana V. Diez. 2004. “The Study of Group-Level Factors in Epidemiology: Rethinking Variables, Study Designs, and Analytical Approaches.” *Epidemiologic Reviews*. 26:104-111. doi:10.1093/epirev/mxh006.

Rubin, Bonnie Miller and Jeremy Gorner. “Deadly Heat Wave Struck Chicago 20 Years Ago This Week,” *Chicago Tribune,* July 15, 2015

Ryu, Young-Hee, Jong-Jin Baik, Sang-Hyun Lee. 2013. “Effects of Anthropogenic Heat on Ozone Air Quality in a Megacity.” *Atmospheric Environment.* 80:20-30. http://dx.doi.org/10.1016/j.atmosenv.2013.07.053

Salamanca, F., M. Georgescu, A. Mahalov, M. Moustaoui, M. Wang. 2014. “Anthropogenic Heating of the Urban Environment Due to Air Conditioning.” *Journal of Geophysical Research: Atmospheres.*119: 5949-5965. doi:10.1002/2013JD021225.

Schwartz, Joel. 2005. “Who is Sensitive to Extremes of Temperature? A Case-Only Analysis.” *Epidemiology*. 16(1): 67-72. doi:10.1097/01.ede.0000147114.25957.71

Semenza, Jan C., Daniel J. Wilson, Jeremy Parra, Brian D. Bontempo, Melissa Hart, David J. Sailor, Linda A. George. 2008. “Public Perception and Behavior Change in Relationship to Hot Weather and Air Pollution.” *Environmental Research.* 107:401-411. doi:10.1016/j.envres2008.03.005.

Shahmohamadi, P., A.I. Che-Ani, I. Etessam, K.N.A. Maulud, N.M. Tawil. 2011. “Healthy Environment: The Need to Mitigate Urban Heat Island Effects on Human Health.” *Procedia Engineering*. 20: 61-70. doi:10.1016/j.proeng.2011.11.139

Smargiassi, A., M.S. Goldberg, C. Plante, M. Fournier, Y. Baudouin, T. Kosatsky.

2009. "Variation of Daily Warm Season Mortality as a Function of Micro-Urban Heat Islands." *Journal of Epidemiological Community Health* 63: 659-664. doi:10.1136/jech.2008.078147

Snohomish County Area Plan on Aging https://snohomishcountywa.gov/DocumentCenter/View/7176

Stone, Brian Jr. 2007. "Urban and Rural Temperature Trends in Proximity to Large US Cities: 1951-2000." *International Journal of Climatology*. 27: 1801-1807. doi: 10.1002/joc.1555

Stott, Peter A., D.A. Stone, M.R. Allen. 2004. "Human Contribution to the European Heatwave of 2003." *Nature* 432 (2) 610-613

Taha, Haider. 1997. "Urban Climates and Heat Islands: Albedo, Evapotranspiration, and Anthropogenic Heat." *Energy and Buildings* 25: 99-103

Trust for Public Land https://www.tpl.org/green-alleys - sm.00007fhmtioezeq0t5q2iv6hdrtwn

Uejio, Christopher K., Olga V. Wilhelmi, Jay S. Golden, David M. Mills, Sam P. Gulino, Jason P. Samenow. 2011. "Intra-Urban Societal Vulnerability to Extreme Heat: The Role of Heat Exposure and the Built Environment, Socioeconomics, and Neighborhood Stability." *Health & Place*. 17: 498-507. doi:10.1016/j.healthplace.2010.12.005

Vandentorren, S. P. Prein, A. Zeghnoun, L. Mandereau-Bruno, A. Croisier, C. Cochet, J. Ribéron, I. Siberan, B. Declercq, M. Ledrans. 2006. "August 2003 Heat Wave in France: Risk Factors for Death of Elderly People Living at Home." *European Journal of Public Health.* 16 (6) 583-591. doi:10.1093/eurpub/ck1063

Washington Community Action Network. 2014. "Facing Race, Washington's Racial Equity Agenda" http://washingtoncan.org/wordpress/wp-content/uploads/2013/12/FINAL-Facing-Race-report.pdf

Weber, Stephanie, Natasha Sadoff, Erica Zell, Alex de Sherbinin. 2015. "Policy-Relevant Indicators for Mapping the Vulnerability of Urban Populations to Extreme Heat Events: A Case Study of Philadelphia." *Applied Geography*. 63:231-243. http://dx.doi.org/10.1016/j.apgeog.2015.07.006

Whipple, Heidi, Jason Garver, Hilary Ahearn. "Promoting Equitable Climate Resilience in King County: Mapping Communities Vulnerable to Extreme Heat." Professional Master's Program in GIS, University of Washington, 2016

Wolf, Kathleen L. 2005. "Trees in the Small City Retail Business District: Comparing Resident and Visitor Perceptions." *Journal of Forestry*. 103:8:390-395

Wolfe, MI, R. Kaiser, MP Naughton, MC Mirabelli, SS Yoon, R. Hanzlick, AK Henderson. 2001. "Heat-Related Mortality in Selected United States Cities, Summer 1999." *American Journal of Forensic Medical Pathology* Dec 22(4): 352-357.

Wood, Anthony R. “Three Heat Related Deaths Reported in Philly”. *The Philadelphia Inquirer.* July 11, 2016.