

Going Beyond Mere Distance for Geographic Disparities to Lung Cancer Screening: Using the
Enhanced Two-Step Floating Catchment Area Method in Washington State

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A thesis

submitted in partial fulfillment of the
requirements for the degree of

Master of Public Health

University of Washington

2023

Committee:

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Program Authorized to Offer Degree:

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Population Health

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Abstract

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Early detection of lung cancer reduces cancer mortality; yet uptake for lung cancer screening has been limited in Washington state. Geographic disparities contribute to low uptake but do not wholly explain gaps in access for underserved populations. Other factors such as having an adequate workforce to meet population demand and the capacity of accredited clinics must also be considered. Therefore, we used the enhanced two-step floating catchment (E2SFCA) model to evaluate how geographic accessibility in addition to availability of lung cancer screening imaging centers contribute to disparities. We used available data on radiologic technologist volume at each American College of Radiology accredited clinic to estimate each site's capacity to meet potential population demand. Spearman rank correlation coefficients of the spatial access ratios (SPARs) were compared with the 2010 Rural-Urban Commuting Area (RUCA) codes and Area Deprivation Index (ADI) quintiles to identify characteristics of patients

with greater and lesser levels of access. A total of 549 radiologic technologists were identified across the 95 ACR accredited clinics. We observed that 92% of the eligible population had proximate access to any ACR accredited clinic. However, when we incorporated the E2SFCA method, we found significant variation of access for eligible populations. The inclusion of the availability measure attenuated access for all eligible populations. Furthermore, we observed that rural areas were substantially correlated and areas with greater socioeconomic disadvantage were modestly correlated with lower access. The E2SFCA models demonstrated that capacity is an important component to access for lung cancer screening and how geographic access and availability jointly contribute to disparities in access to lung cancer screening.

Introduction

Lung cancer is the leading cause of cancer death in Washington state.¹ In 2011, the National Lung Screening Trial found that low dose computed tomography reduced lung cancer mortality by 20% for high-risk populations.² Since 2013, the United States Preventive Task Force (USPTF) has recommended lung cancer screening for high-risk populations.³ In 2021, in an effort to reduce racial and gender disparities related to screening guidelines, USPTF lowered the age threshold to 50 years old and reduced the pack-year history to 20.⁴

Lung cancer screening remains underutilized, and in 2021, only 7 percent of high-risk populations were screened for lung cancer in Washington State.⁵ Adherence to lung cancer screening is associated with residing in proximity to lung cancer imaging facilities.⁶ National evaluations of access to lung cancer imaging facilities have demonstrated that there are wide spatial variations at the county and state levels, with greater access in densely populated counties.^{4,6-9} Evaluation of spatial accessibility plays a critical role in understanding how the distribution of health care delivery systems may influence utilization for populations at risk.

Important components of spatial accessibility include population needs, number of healthcare providers, and the geographic characteristics of health care services (such as the location or distance to), and travel impedance for populations to reach healthcare providers.¹⁰ Spatial accessibility to lung cancer screening imaging centers have been evaluated largely by number of physical locations of lung cancer screening facilities to populations (similar to provider-to-population ratios)^{4,9,11-15}; distance to the nearest lung cancer screening facility^{16,17}; and average distance to lung cancer screening.¹⁸ Although these measures provide important context for health services research, geographic access is only one measure. A spatial accessibility method that has been growing in popularity and has become more broadly used in

medical geography research is the enhanced two-step floating catchment area (E2SFCA) method. This method not only combines the measures of proximity and number of healthcare providers to define accessibility, negates the assumption that patients only visit healthcare providers within a defined catchment area, but also provides easily interpretable ratios of relative access between the healthcare providers and populations.

E2SFCA method has previously measured spatial accessibility to cancer care facilities as well as cancer screening imaging centers for breast cancer and colorectal cancer.¹⁹⁻²¹ To the best of our knowledge, this type of methodology has never been used to evaluate spatial access to lung cancer screening. Therefore, our aim for this study is to create a more comprehensive model that evaluates spatial accessibility to lung cancer screening to help better explain limited uptake to lung cancer screening in Washington state.

Methods

Data Sources

We used 8 data sources to measure variation of spatial access to lung cancer screening. After consultation with the University of Washington's Human Subject Division, IRB approval was deemed not necessary because of our use of publicly available data for the analysis.

In October 2022, we downloaded the accredited lung cancer screening sites from the American College of Radiology Registry (ACR) website. The ACR Lung Cancer Screening Registry monitors and evaluates the quality of lung cancer screening and is the only CMS approved registry for lung cancer screening.^{4,22} The facilities were geocoded using the “*tidygeocoder*” package.²³ 83 of the 95 sites were geocoded successfully, and the remaining screening centers were manually geocoded using the Census Bureau geocoding service.²⁴

We obtained the radiologic technologist workforce data from the Washington Health Workforce survey. This survey is designed to collect information related to the composition of the Washington Health workforce and is to be completed during a provider's license renewal—a biennial requirement for radiologic technologists.²⁵ In March of 2023, we downloaded de-identified survey responses of the radiologic workforce for the past four years and matched their addresses to the accredited lung cancer screening sites. Our inclusion criteria included radiologic technologists who work in diagnostic radiology, oncology, and other settings not specified. We excluded radiologic technologists who primarily worked in emergency departments, retirement homes, and education. We selected radiologic technologists rather than radiologists because technologists play pivotal roles in the physical screening process and can be used as a proxy measure for patient throughput at the screening facilities.²⁶

We measured the potential patient volume per census block group using the number of adults aged between 50 to 79 years old from the 2015- 2019 American Community Survey 5-year estimates using the Census Bureau's application programming interface (API).²⁷ Census block groups that had a population of 0 were excluded from the study. Since smoking prevalence data does not exist at the census block group level, we used the County Health Rankings Model of current smoking percentages and applied it to the age range to construct theoretical eligible population for lung cancer screening. The County Health Rankings uses Behavioral Risk Factor Surveillance Systems measures to construct current smoking percentages.²⁸

We used Mapbox API to obtain car-based travel times.²⁹ The Mapbox API created isochrones between each census block group and accredited lung cancer screening imaging facilities.

To assess socioeconomic status, we used 2015-2019 area deprivation index (ADI) values from the “*sociome*” package.³⁰ ADI values are derived from American Community Survey 5-year estimates and uses income, education, employment, and housing quality measures to rank neighborhoods by socioeconomic disadvantage. We constructed quintiles based on Washington state. Additionally, we used the 2010 Rural and Urban Commuting Area codes from the United States Department of Agriculture to assess the impact of rurality on the spatial access measures.³¹

Spatial access measures

The E2SFCA was originally developed by Luo and Qi to improve the basic two-step floating catchment method.³² A key improvement to the original method first proposed by Radke and Mu³³ was the incorporation of a distance decay function into its calculation of spatial access by adding penalties in a Gaussian weighting scheme to differentiate the travel times to the health care facilities and census block group centroids. An important component of the analysis is setting the size of the catchment area that has a reasonable patient travel time. We designated the maximum catchment size to be car-based 60-minute driving time with subzones from 0-15, 15-30, and 30-60 minutes. Populations that were outside of 60-minute catchment areas to ACR accredited screening facilities were considered to not have access. As the name suggests, the E2SFCA has two steps.

The first step measures the availability of radiologic technologies by weighted facility-to-population ratios. We weighted the radiologic technologists by the number of locations they listed in the Washington Health Work Force survey. For example, if a radiologic technologist listed two facilities, that technologist contributed to each facility with a weight of 0.5. Then, we summed the total weighted radiologic technologists at each facility to create an availability score

for each facility. We assigned a score of 0.25 to facilities that did not indicate any radiologic technologist survey responses. Each ACR facility score was then divided by estimated patient population within the catchment area. Estimated patient populations were calculated as the number of 50-79 years olds within the census block group and their subzones with respect to the ACR accredited facility, determined by friction-of-distance coefficient (β). Potential patient populations within 0-15 minutes were weighted more heavily with β equal to 0.93, 15-30 minutes less heavily with β equal to 0.75, and 30-60 minutes β equal to 0.33.

The second step measures the accessibility of the ACR facilities for each potential patient population and factors in the availability that was calculated in the first step. Each of the facilities is given a travel time weight relative to the location of each potential patient population, using the same friction-of-distant coefficients, and is weighted similarly as the patient populations in the first step. The spatial access scores were multiplied by 1,000 to represent the weighted ACR facility per 1,000 adult residents before calculating the spatial access ratio scores (SPARs). For ease of interpretation, we calculated SPAR values by normalizing the spatial access scores. SPAR values can be interpreted as weighted facility-to-population- ratios. Any SPAR value greater than 0 indicates there is at least one ACR accredited facility within a 60-minute drive of each census block centroid. SPAR values greater than 1 are interpreted to have greater access than the regional average while SPAR values less than 1 is considered to have less access.³⁴

Statistical Analysis

Using a common method for geographic disparities in lung cancer screening, we first measured access by measuring proximity of ACR accredited screening facilities by 15, 30, and 60-minute car-based drive times determined by each census block group. We then used the

E2SFCA method and compared differences of availability of accredited ACR facilities to their respective weighted technologist capacity in two models. The first model held the availability measure constant while the second model was weighted by the number of total radiologic technologists per facility. We considered the two lowest Jenks natural break categories as relatively low access, two middle categories as moderate, and the remaining two categories having high access for both models. Based on previous literature, we identified potential intervention areas by six-categories Jenks natural breaks for E2SFCA SPAR values, RUCA codes, and additionally included ADI quintile values.³⁵ We used Spearman rank correlation coefficient tests to compare SPAR values for each of the census block groups with their corresponding ADI values and RUCA codes. Potential intervention areas were defined if they met our criteria (1) census block groups with the lowest natural break of SPAR values, (2) census block groups that are within RUCA codes of 1,2, or 10, and ADI quintile values with the highest disparity scores. We used R v. 4.2.2 (Vienna, Austria) for all statistical analyses, and for data visualization we used ArcGIS Pro v. 3.0.3 in addition to R. All figures were projected in NAD83/UTM zone 10N.

Results

The study area included 4,752 out of 4,783 census block groups with a total 50 to 79 years old population of 2,284,552 and an estimated smoking population of 324,892 (see the Appendix for map of the study area). The population is serviced by a total of 549 radiologic technologists at the 95 ACR accredited clinics. The median number of radiologic technologists per ACR facility was 4 (IQR = 5), with clustering of technologists in the most populated parts of the state, including the Puget Sound area and the Columbia River Basin areas (Figure 1).

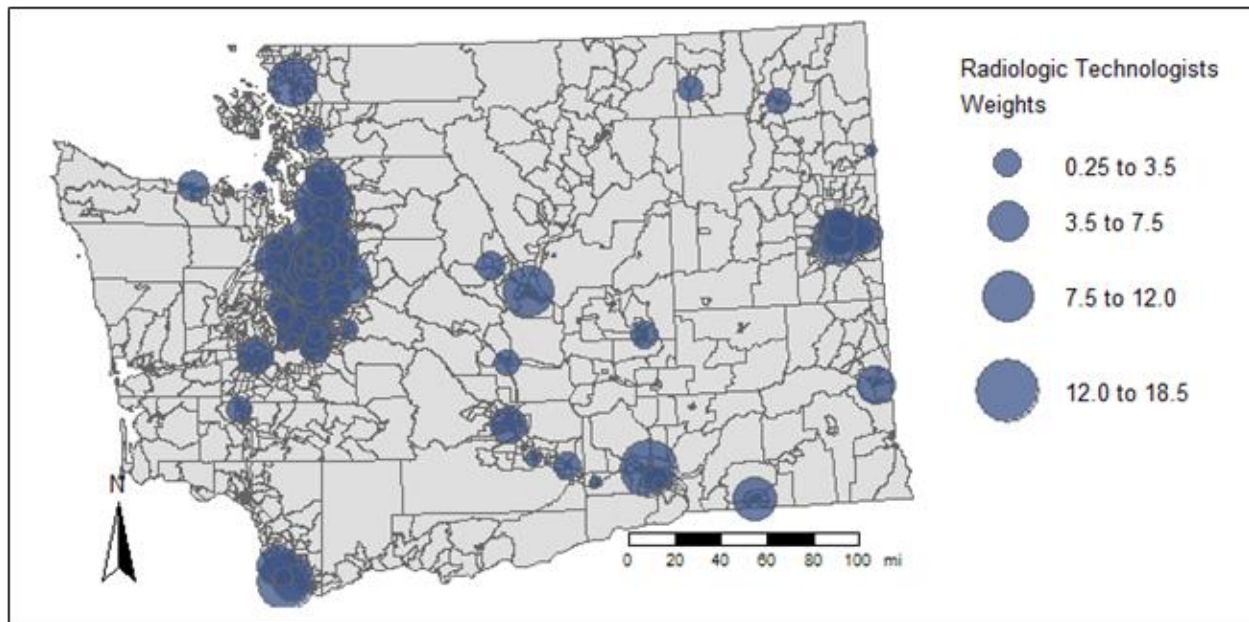


Figure 1: Weight sums and locations (N =95) of radiologic technologists in Washington State

Among the smoking population aged 50-to-79-years old, 68% of the population has access within 15 minutes, 85% of the population has access within 30 minutes, and 92% of the population has access within 60 minutes to any ACR accredited facility. Notably, 5% of the population did not have access to ACR accredited facilities. Proximate access to lung cancer screening did not vary substantially by smoking population and total population (see Table 1).

Access to ACR* Facilities N, (%)	Smoking Population (N = 324,892)	Total Population (N = 2,284,552)
0 – 15 minutes	219,428 (68%)	1,620,299 (71%)
0 - 30 minutes	275,943 (85%)	1,999,471 (88%)
0 - 60 minutes	297,725 (92%)	2,116,085 (93%)
> 60 minutes	17,064 (5%)	99,193 (4%)

*ACR, American College of Radiology

Table 1: Proportion of smoking population and total population counts that have physical access within -15, -30, and -60 car-driving minutes to any ACR accredited lung cancer imaging facilities.

When we incorporate the E2SFCA method, spatial accessibility changes significantly. In Model 1, the overall median value is 0.89 (IQR = 1.50). However, with the addition of the

availability measure based on the weighted ACR accredited facilities in Model 2, the median SPAR value decreases by 22 % (SPAR = 0.69, IQR =1.49). Table 2 presents the differences of E2SFCA SPAR values between Model 1 and Model 2 for populations that were defined as low, moderate, and high access while Figure 2 presents the visual differences of E2SFCA SPAR values between Model 1 and Model 2.

SPAR Values	Model 1 SPAR values	Model 2 SPAR values
Washington State, Median, (IQR)	0.89 (1.50)	0.69 (1.49)
Limited Access, (% Population)	0.63 (54%)	0.82 (60%)
Moderate Access, (% Population)	1.51 (20%)	1.80 (26%)
High Access, (% Population)	2.69 (26%)	2.89 (14%)

Table 2: Proportion of Smoking Population (N = 324, 892) that have relative limited, moderate, and high access to ACR lung cancer screening imaging facilities between Model 1 and Model 2

The differences between Model 1 and Model 2 indicate that inclusion of availability measure attenuated access for all populations. When weighting access by radiologic technologist values, the proportion of the population considered to have high access decreases by 12%. Even though the range of SPAR values increases in the second model, SPAR values decrease in metropolitan areas in the Puget Sound area, particularly in more socially disadvantaged areas. Inset maps of the Puget Sound area for both Model 1 and Model 2 are in the appendix.

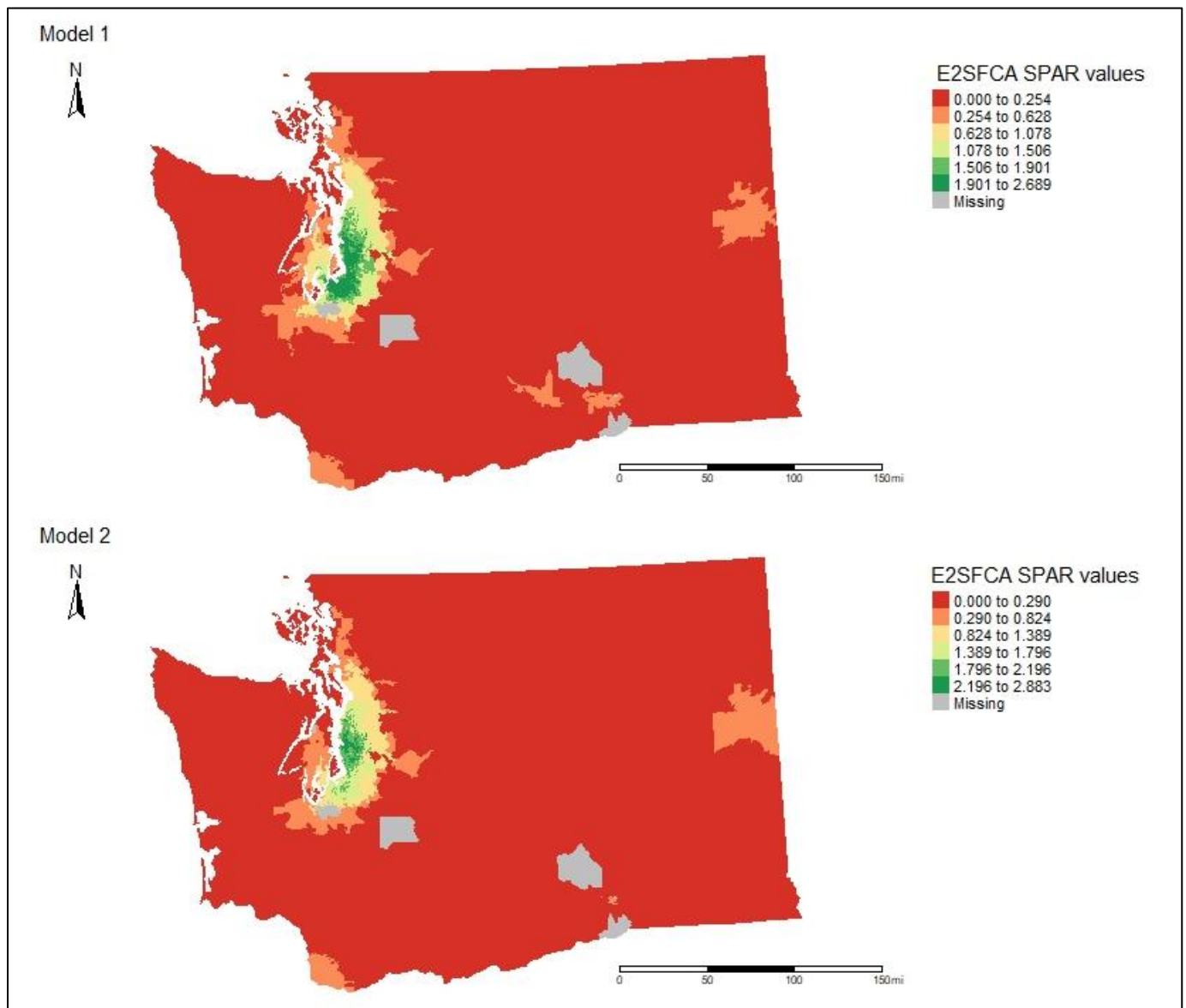


Figure 2: Jenks natural breaks map of E2SFCA with capacity of radiologic technologists held constant on top (Model 1), and the bottom map of Jenks natural breaks maps of E2SFCA with capacity by the weighted ACR accredited facilities (Model 2). Green denotes areas with better access while red denotes areas with worse access to lung cancer screening. Missing data refers to areas that did not have census block group populations and were excluded from the analysis.

The correlation between spatial accessibility and RUCA codes was substantial with $Rho = -0.63$, $p\text{-value} < 0.001$ (see Table 2). There was a significant drop in weighted Mean SPAR values for RUCA Codes 3 through 10. Furthermore, the correlation between spatial accessibility and ADI values was moderate $Rho = -0.37$, $p\text{-value} < 0.001$ (see Table 3). SPAR values steadily

decreased as rurality and ADI quintiles increased, indicating that populations in rural areas and those with more socioeconomic disadvantage experience worse access. The RUCA codes have a stronger association with SPAR values than the ADI values, which may be partially due to the equal distribution of the population for the ADI quintiles. Maps with the RUCA codes and ADI values for the study area are in the appendix.

RUCA Codes	Smoking Population	Total Population	Weighted Mean SPAR values (SD)
1 Metropolitan area core: primary flow within an UA	223,917	1,656,504	1.25 (0.76)
2 Metropolitan area high commuting: primary flow 30% or more to a UA	44,250	293,282	0.51 (0.46)
3 Metropolitan area low commuting: primary flow 10% to 30% to a UA	2,234	12,961	0.07 (0.08)
4 Micropolitan area core: primary flow within an UC of 10,000 to 49,999 (large UC)	20,764	124,678	0.10 (0.08)
5 Micropolitan high commuting: primary flow 30% or more to a large UC	6,088	35,175	0.04 (0.04)
6 Micropolitan low commuting: primary flow 10% to 30% to a large UC	2,139	11,967	0.10 (0.07)
7 Small town core: primary flow within an Urban Cluster of 2,500 to 9,999 (small UC)	9,494	55,160	0.03 (0.04)
8 Small town high commuting: primary flow 30% or more to a small UC	1,824	10,318	0.03 (0.03)
10 Rural areas: primary flow to a tract outside a UA or UC	14,182	84,507	0.04 (0.06)

Rho = -0.63, *p*-value < 0.001

Urban Area, UA

Urban Cluster, UC

Table 3: Weighted Mean SPAR values by RUCA codes. Code 9 was not present in the dataset and therefore is not shown.

Area Deprivation Index Quintiles (2015-2019)	Smoking Population	Total Population	Weighted Mean SPAR values (SD)
1 (Lower)	58,053	487,925	1.59 (0.66)
2 (Mid-Lower)	75,030	533,799	1.09 (0.76)
3 (Middle)	71,492	482,454	0.85 (0.77)
4 (Mid-Upper)	66,538	430,987	0.76 (0.76)
5 (Upper)	53,704	348,948	0.71 (0.77)

Rho = - 0.37, *p*-value < 0. 001

Table 4: Weighted Mean SPAR values by ADI quintiles. 2 census block groups were not present in the dataset and were excluded from the analysis. To interpret the index, the lower value corresponds to the lowest level of disadvantage in Washington state while the upper value corresponds to the highest level of disadvantage.

Based on our intervention criteria, we identified 277 census block groups that could be targeted to improve access to lung cancer screening imaging facilities. The targeted intervention areas included a total population of 100,910 residents and smoking population of 16,995 residents (see figure 3).

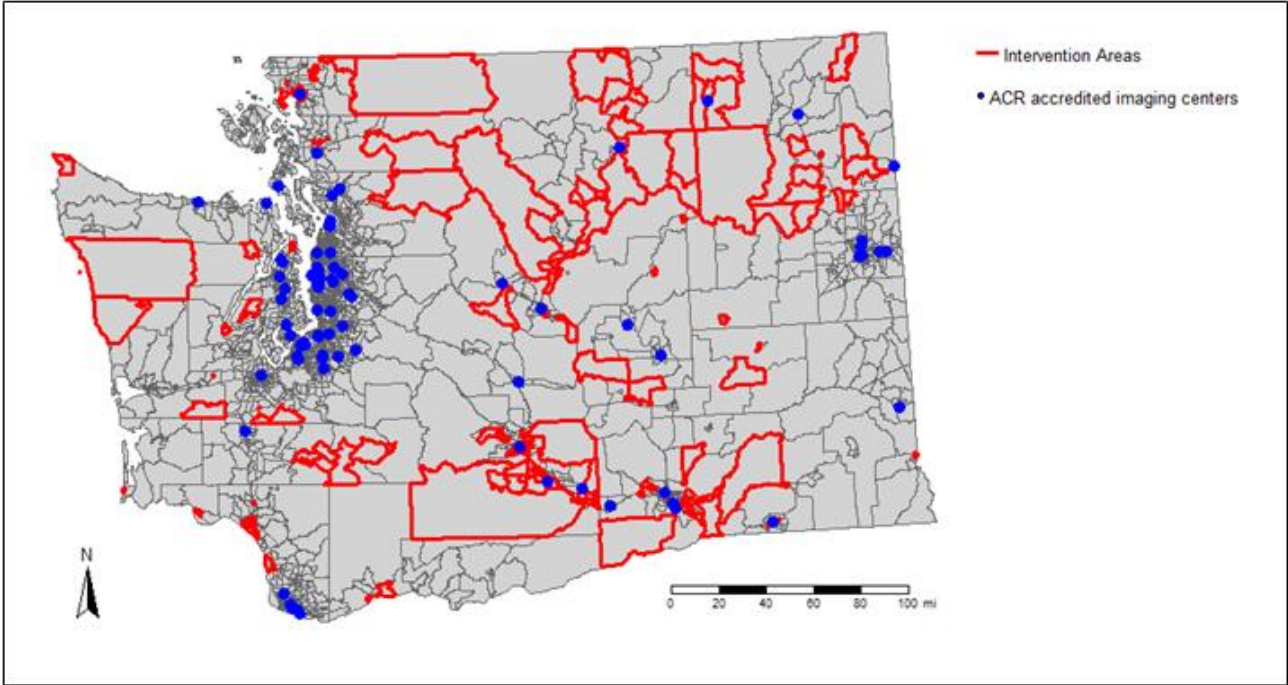


Figure 3: The identified areas of intervention are outlined in red (N = 277). The blue figures are the ACR accredited imaging centers (N = 95).

Discussion

We constructed a novel model incorporating geographic distance and availability to measure access to lung cancer screening in Washington State. Using a common geospatial method for determining access to lung cancer screening, we established that the majority of eligible residents live within 60 minutes car-based drive time to any ACR accredited lung cancer screening facility. However, when we incorporated the E2SFCA method, the models showed significant spatial variation for eligible populations. With the inclusion of the availability measure, our models indicated that there may be a misalignment between potential patient demand and lung cancer screening access in not only rural areas but also in metropolitan areas in Washington state. Similar to published literature on geographic disparities for lung cancer screening, our study also determined that rural and socioeconomically disadvantaged areas face greater disparities. Lastly, we identified areas where potential interventions could be focused on reducing disparities related to lung cancer screening.

A distinct challenge to widespread uptake of lung cancer screening is that the disease distribution for lung cancer is proportionate to the social disadvantage for the most at-risk populations.³⁶ The burden of lung cancer is higher in populations that have higher tobacco use, lower socioeconomic status, lower educational attainment, residence in geographically remote or rural areas, and have historically been marginalized.³⁶⁻³⁸ Similar to our findings, previous studies have established that rural populations are at a greater disadvantage to accessing lung cancer screening imaging facilities.^{4,9,12,18,39,40} Yet, few studies have evaluated the capacity of these lung cancer screening facilities and the radiologic workforce being able to meet population demand which may further explain limited uptake for lung cancer screening.^{41,42} Our models indicate that

capacity at current lung cancer screening imaging facilities may be inadequate to meet population demand and may help explain low uptake in Washington state.⁴¹

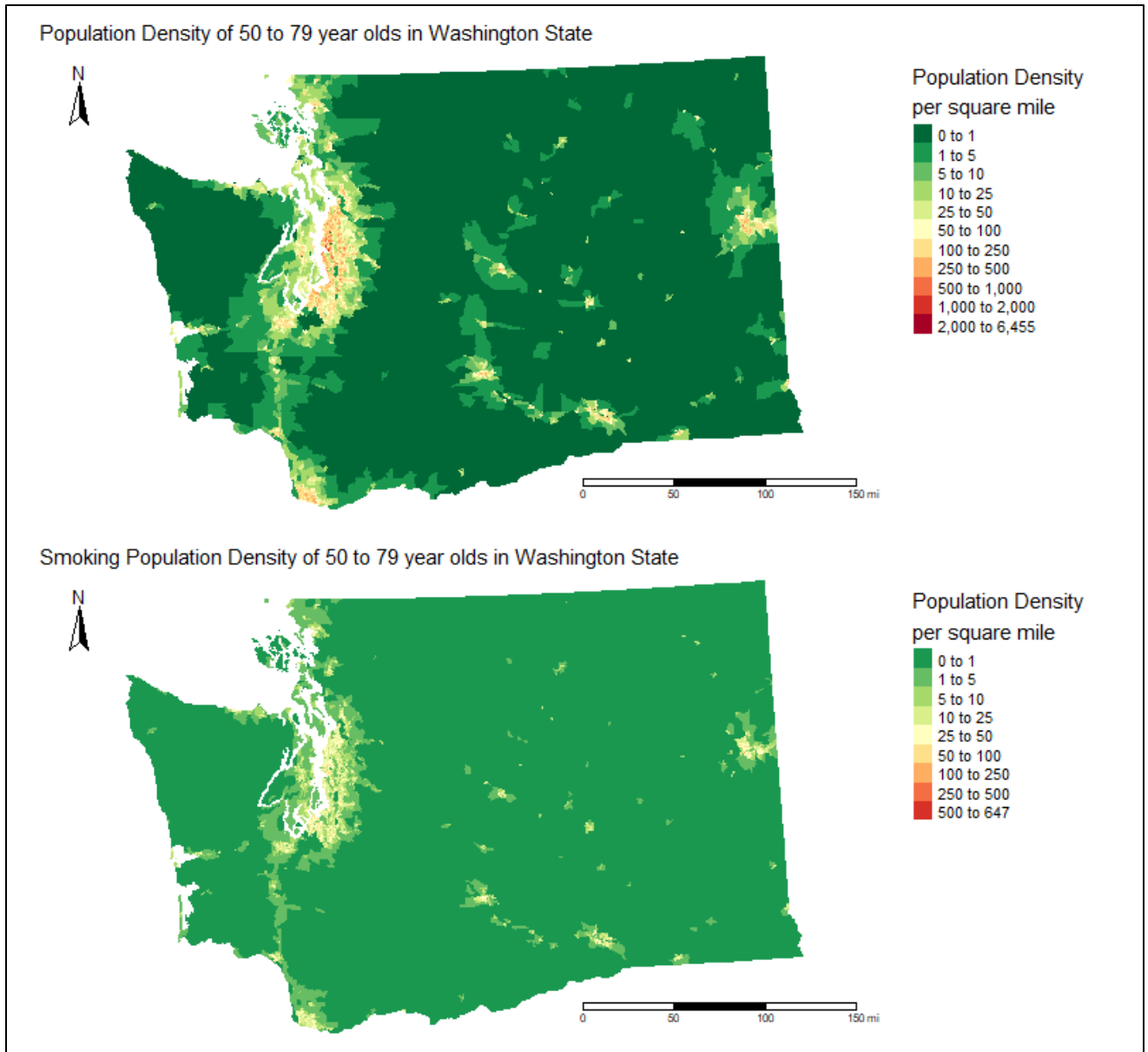
With the USPTF updated guidelines, populations eligible for screening have increased significantly.⁴³ Capacity of the radiological workforce is often limited in areas characterized by high risk for lung cancer.⁴¹ Therefore, considerations of increasing capacity of current screening facilities must be considered that best fits population needs without overburdening local health systems. Notably, many of the intervention areas identified were located on federal and state recognized tribal lands. Lung cancer is one of the leading causes of cancer mortality for American Indians and Alaska Natives.⁴⁴ For American Indian and Alaska Native communities located on reservations and other rural communities, the development of mobile CT units may be able to address geographic barriers and allow for more patients to be reached without placing the burden of rural health systems to develop high quality lung cancer screening programs.^{45,46} Furthermore, in metropolitan areas, increased availability such as increased opportunities to make evening or weekend appointments should be evaluated for accredited screening facilities. Moreover, radiologic technologists play a crucial role in patient throughput and improving CT capacity. Therefore, more training opportunities for radiologic technologists should be considered for improving screening workflow processes at existing clinics.

This study has several limitations. Since the study relied on publicly available data, the eligible population for lung cancer screening guidelines was difficult to determine and likely overestimated. The age population was not fully captured for the age requirements of 50-to-80 years old, and smoking data was not available at the census block group level and was constructed using county-wide estimates. Since the Washington Health Workforce survey is an open survey, radiologic technologists that did not need to renew their license within the past four

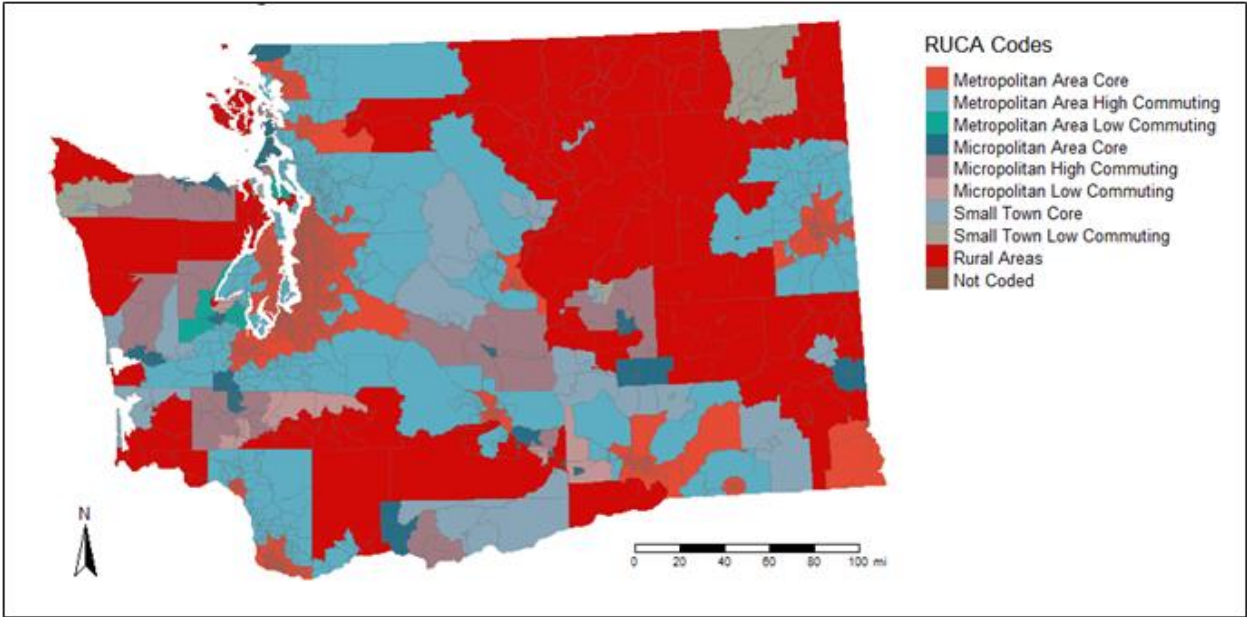
years may have not been included in the study, likely underestimating the total number of radiologic technologists. Even though lung cancer screening CT scan volume is not readily available data, it should be considered in future research for measuring availability of the clinics and patient throughput. Furthermore, other lung cancer screening programs may exist outside of the ACR registry in addition to other lung cancer screening programs outside the state of Washington likely underestimating the total number of lung cancer screening centers utilized by eligible populations. Furthermore, this study assumed that populations had access to personal vehicles to travel to these clinics.

Despite these limitations, this study provides the first state-wide evaluation of ACR accredited imaging centers with the updated age requirements utilizing the E2SFCA method. This study also assessed areas of lower and greater access with the inclusion of the RUCA codes and ADI values. Moreover, our study identified areas for tailored interventions such as improving capacity of current ACR accredited screening facilities or the implementation of mobile CT units in those geographic areas. While geographic access to care is important, it is only one dimension of access. Further research is warranted that incorporates capacity of imaging centers being able to meet population demand in addition to exploring solutions that address low lung cancer screening uptake such as utilizing mobile lung cancer screening units, training more radiologic technologists, or by increasing availability at existing screening facilities.

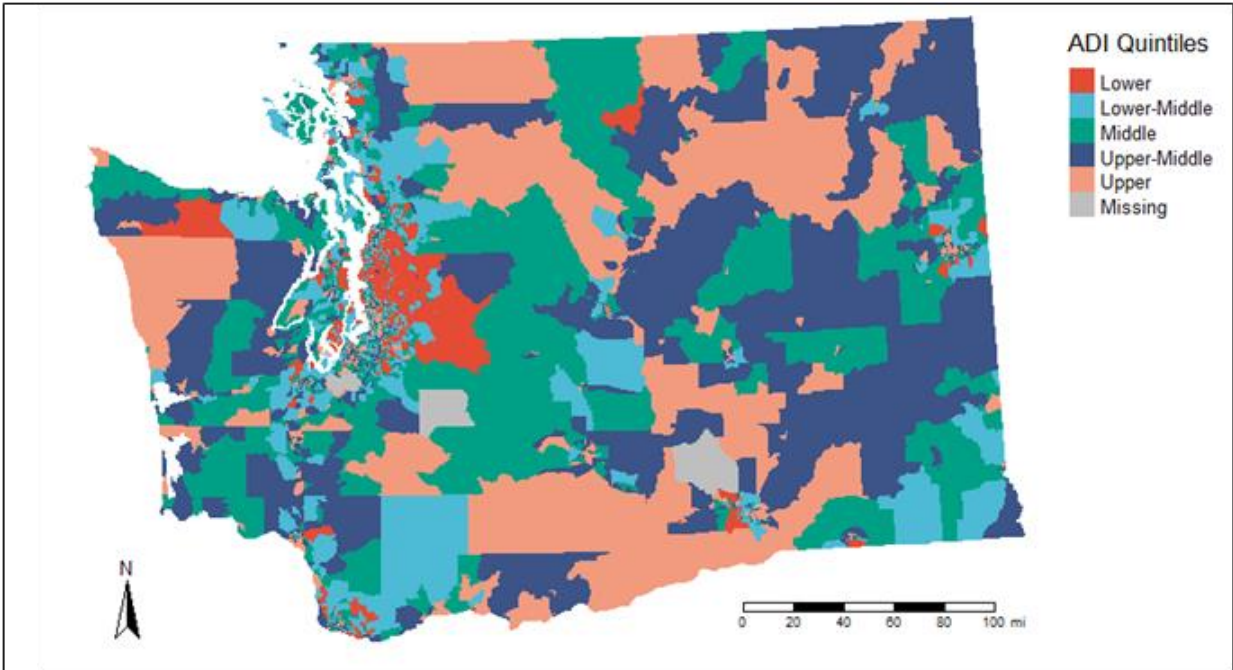
Appendix



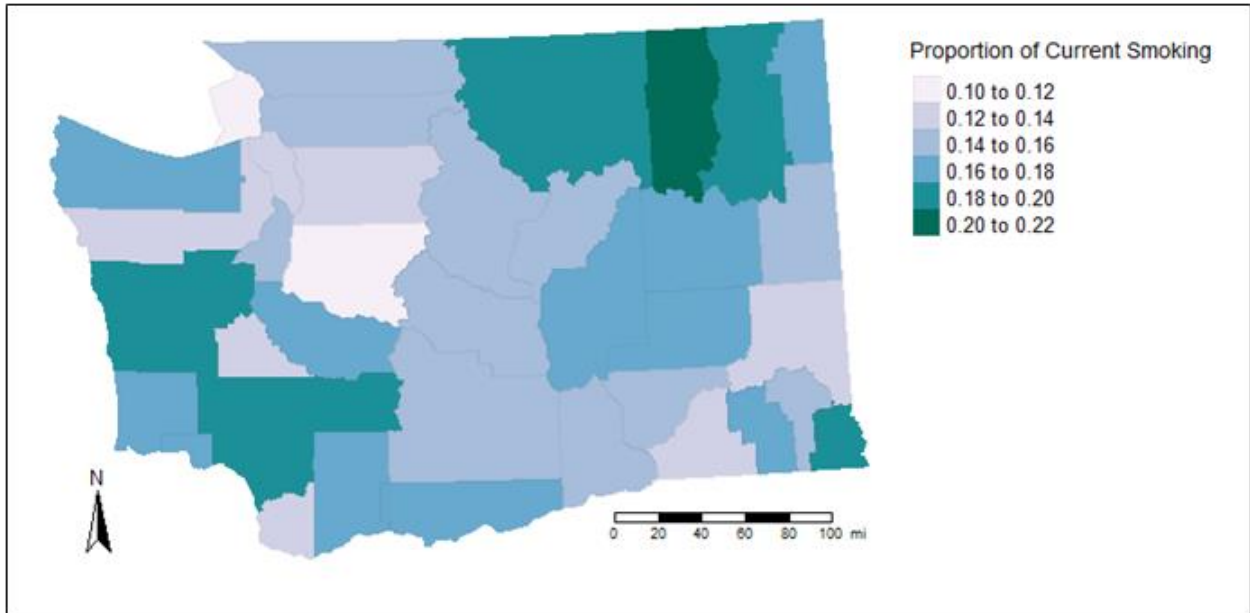
Supplemental Figure 1: Population Density maps of the total population aged 50-to-79 years old and total population with smoking status.



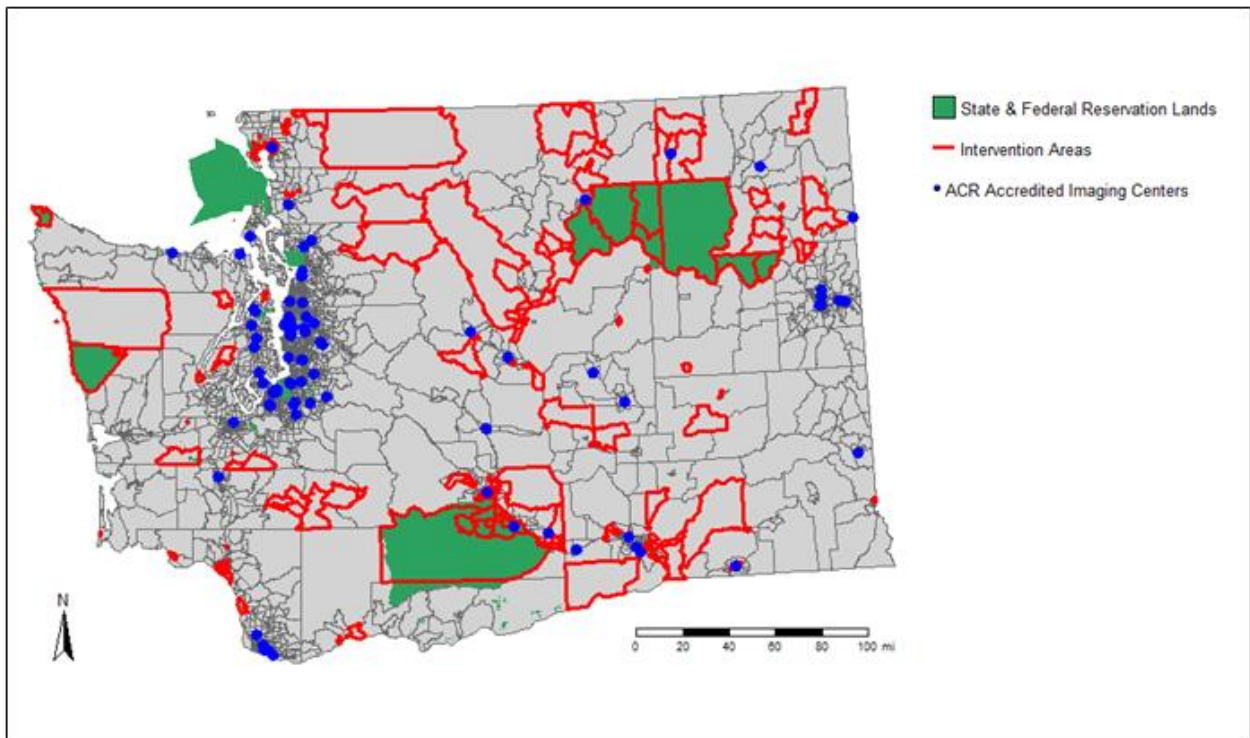
Supplemental Figure 2: Rural and Urban Commuting Codes of Washington State.



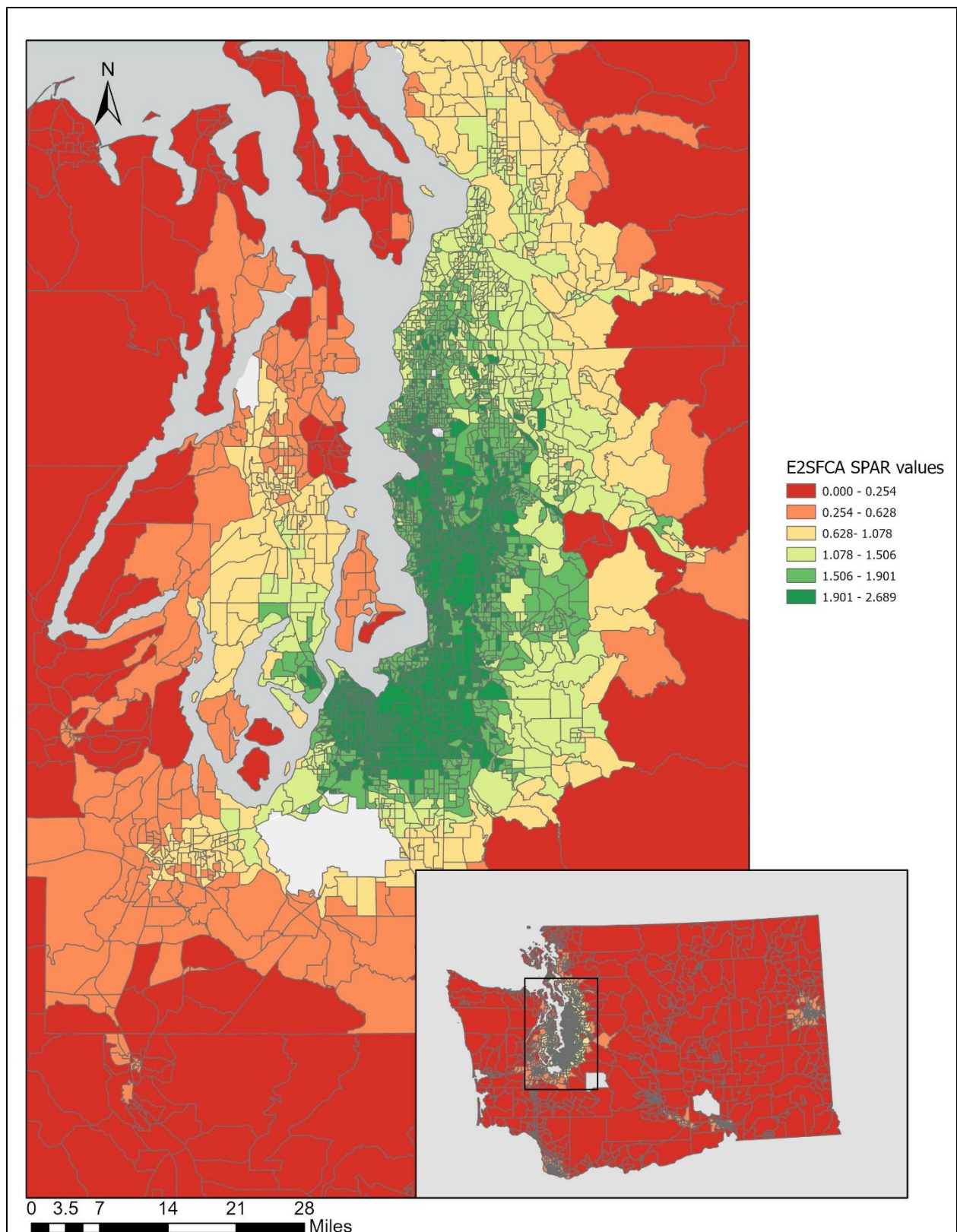
Supplemental Figure 3: Area Deprivation Index Quintiles of Washington State.



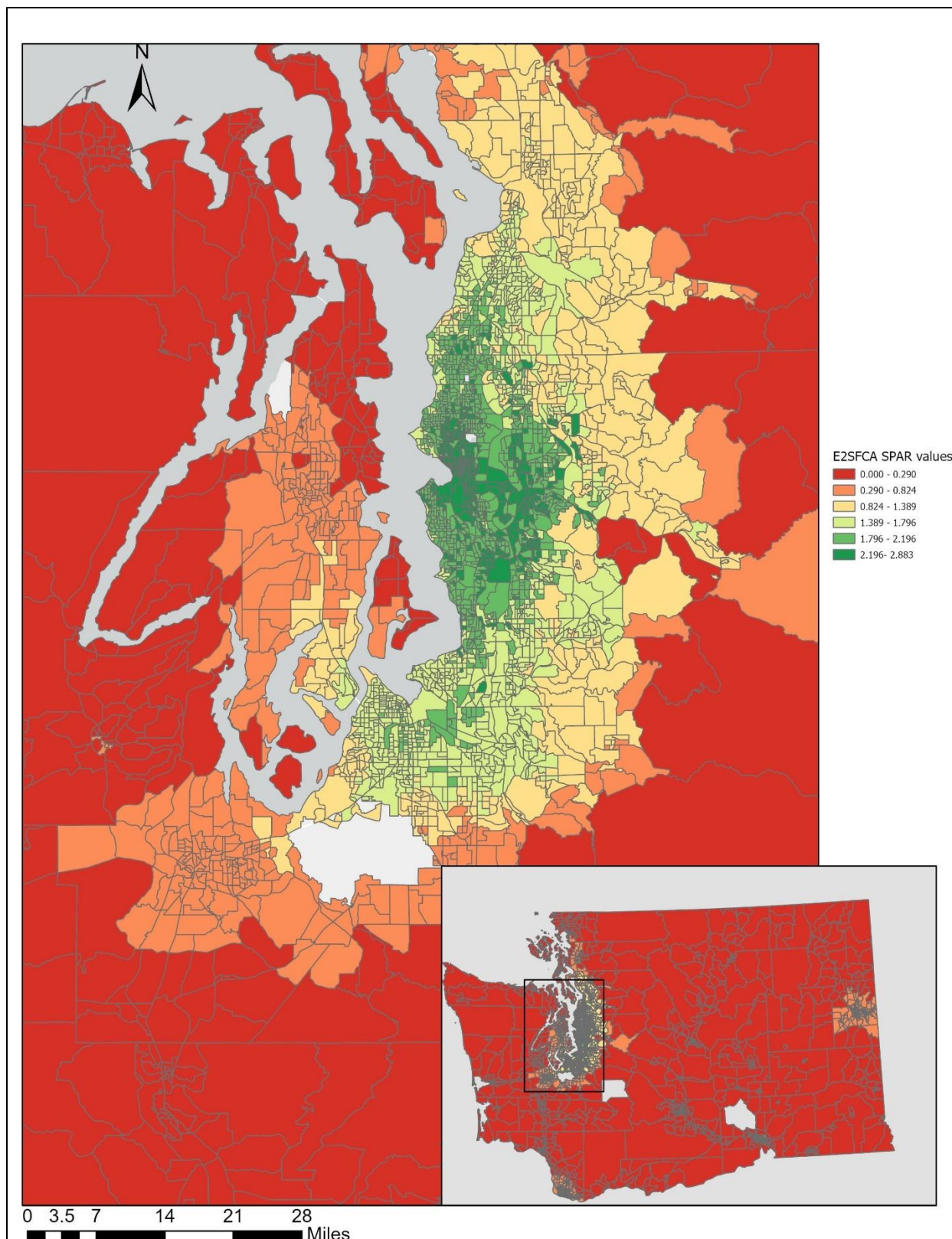
Supplemental Figure 4: County Rankings Proportion of Current Smoking in Washington State.



Supplemental Figure 5: Identified Intervention Areas overlaid with American Indian State and Federal Reservation Lands.



Supplemental Figure 6: Model 1 Inset Map of the Puget Sound Area. The light grey areas indicate missing values.



Supplemental Figure 7: Model 2 Inset Map of the Puget Sound Area. The light grey areas indicate missing values.

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