Appalachian STATE UNIVERSITY BOONE, NORTH CAROLINA

Climate, Environment, And Public Health In Western North Carolina

By: **Maggie Sugg, Lauren Andersen, Elizabeth Shay,** Jennifer Schroeder Tyson, and Jennifer Runkle

Abstract

The frequency and severity of extreme weather events are expected to increase in the context of a changing climate. Populations across the globe are vulnerable and already experiencing the health effects of a changing climate. Western North Carolina (WNC) is no exception. The last decade was the warmest ever on record. This past year, 2019, broke historical records in North Carolina, and temperature anomalies in WNC largely drove this pattern. The indirect and direct effects of climate on human health are complicated and modulated by underlying social vulnerabilities that enhance the severity and sensitivity of population exposure to climate hazards. In this paper, we discuss the complex pathways through which climate hazards impact health in WNC and the on-going efforts among the academic and public health community to address these emerging climate-related health threats. Specifically, we highlight the changing patterns in (1) temperature-related disease, (2) vector-borne disease, (3) natural hazards, (4) mental health impacts and the (5) built environment. Lastly, we identify important research needs and partnerships required to motivate effective and meaningful engagement with the public and policymakers around the regional impacts of climate change on human health, potential solutions, and co-benefits of resilience planning in WNC.

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The frequency and severity of extreme weather events are expected to increase in the context of a changing climate. Populations across the globe are vulnerable and already experiencing the health effects of a changing climate. Western North Carolina (WNC) is no exception. The last decade was the warmest ever on record. This past year, 2019, broke historical records in North Carolina, and temperature anomalies in WNC largely drove this pattern. The indirect and direct effects of climate on human health are complicated and modulated by underlying social vulnerabilities that enhance the severity and sensitivity of population exposure to climate hazards. In this paper, we discuss the complex pathways through which climate hazards impact health in WNC and the on-going efforts among the academic and public health community to address these emerging climate-related health threats. Specifically, we highlight the changing patterns in (1) temperature-related disease, (2) vector-borne disease, (3) natural hazards, (4) mental health impacts and the (5) built environment. Lastly, we identify important research needs and partnerships required to motivate effective and meaningful engagement with the public and policymakers around the regional impacts of climate change on human health, potential solutions, and co-benefits of resilience planning in WNC.

Introduction

The influences of extreme weather and climatic events are significant and varied, with both indirect and direct public health impacts. Climate change is projected to change the frequency, severity, duration, and locations of these extreme events, thereby placing populations at risk for new or elevated exposure to climate stressors such as higher temperatures, heavy rainfalls and floods, and droughts[1]. In North Carolina, average summer temperatures have been the warmest on record over the last 14 years, and the number of very warm nights is increasing at a higher rate than warm days[2]. Projections suggest that North Carolinians will experience historically unprecedented warming by the end of the 21st century, increasing the intensity of heatwaves. Although there is no clear signal for precipitation, projections highlight significant increases in annual perception with the potential for precipitation to be concentrated in heavier rainfall events with more prolonged periods of drought.

Climatic events act as a threat multiplier by which existing health conditions and underlying social stressors (such as unemployment, stigmatization, poverty) work in combination with environmental stressors, such as urbanization, air pollution, and loss of urban tree canopy, to increase a population's vulnerability to climate exposures. Other subpopulations who are generally vulnerable to a wide range of health insults are also most at risk for climatic changes; these include the young, the elderly, and pregnant women[1].

In this paper, we discuss the complex pathways through which climate hazards impact health in WNC and the on-going efforts among the academic and public health community to address these emerging climate-related health threats. Specifically, we highlight the changing patterns in (1) temperature-related disease (2) vector-borne disease, (3) natural hazards, (4) mental health impacts, and the (5) built environment. Lastly, we identify important research needs and partnerships required to motivate effective and meaningful engagement with the public and policymakers around the regional impacts of climate change on human health, potential solutions, and co-benefits of resilience planning in WNC.

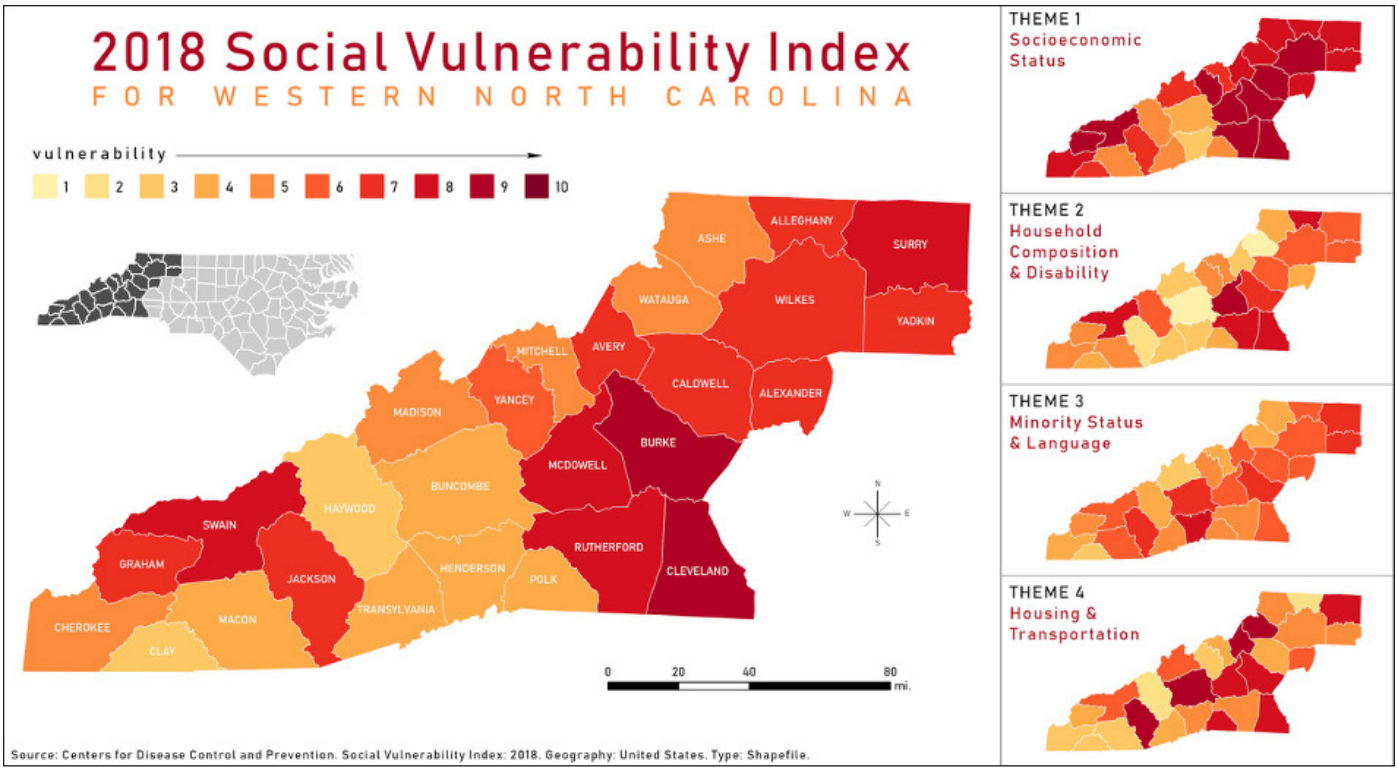

Figure 1. The 2018 social vulnerability index for WNC, USA.

The WNC region encompasses 27 counties in NC[4]. The region is an important source of water for major cities like Charlotte and Atlanta and a popular destination for outdoor recreation, including camping, hiking, biking, and winter sports, due to the landscape and presence of federal areas, such as the Blue Ridge Parkway and Great Smoky Mountains National Park. The region is divided by the Blue Ridge Escarpment into two physiographic provinces—the Blue Ridge and the Piedmont. The Blue Ridge Escarpment and associated elevation gradient drive temperature and precipitation variability throughout WNC. For example, precipitation ranges from less than 40 inches annually in Buncombe County to more than 100 inches in neighboring Transylvania County[5]. Variability in the physical landscape across WNC contributes to complex and frequently unpredictable weather patterns across the region.

According to the 2010 Census, 60.8% of the population in WNC is classified as rural, which is above the state (35.6%) and national (21.0%) values[6]. The large rural population is characterized by health challenges, such as lower life expectancy and higher rates of chronic disease and mental illness, driven in part by a lack of access to quality healthcare[7]. These health challenges are further exacerbated by economic hardship in many communities across the region. The poverty rate for the region is 16.9% with values as high as 27.2% in Watauga County, 13% higher than the rate for the United States8. Similarly, WNC's overall median household income in 2018 ($42,710) is below the state ($52,413) and national ($60,293) averages. Within the region, inequality is pronounced, with a difference of over $16,000 between the highest ($52,815 in Henderson County) and lowest ($36,525 in Graham County) median incomes[9].

As a result of economic disparities, there is great variation across WNC in the Social Determinants of Health (SDOH)—conditions in the social environment in which people are born, live, learn, work, and play that affect a wide range of health, functioning, and quality-of-life outcomes and risks[7]. The metropolitan locales, such as Asheville in Buncombe County, have greater access to goods and services and therefore greater capacity for resilience. In contrast, smaller communities must adapt with fewer resources. A variety of indices have been developed to measure the relative vulnerability of communities for the purpose of improving emergency response. The Center for Disease Control and Prevention's Social Vulnerability Index (SVI) ranks counties nationwide based on four themes: 1) socioeconomic status, 2)

household composition and disability, 3) minority status and language, and 4) housing type and transportation. Across WNC, SVI values are high, especially in the northern and eastern portions of the region (CDC 2018) (Figure 1). While the higher values are predominantly driven by socioeconomic variables, themes 2 and 4 also influence vulnerability in many counties. The varying drivers of vulnerability across the region highlight the need for local-scale responses.

TEMPERATURE-RELATED IMPACTS

Heat is the number-one weather-related killer in the United States[10]. In NC, heat-related illnesses, like heat syncope, heat exhaustion and in the most severe cases heat stroke, are responsible for at least 2000 emergency department visits per year[11]. Heat-related illness (HRI) in NC has a distinct pattern, with the most rural locations experiencing the highest heat-related illness rates, and urban locations experiencing the lowest rates of heat-related illness[12]. The patterns of HRI in NC contrasts with much of the literature that demonstrates urban locations due to their higher population and hotter temperatures (urban heat island effect) typically exhibit greater HRI risk. Although HRI in the mountains of WNC are low compared to other regions of the state, HRIs peak at lower temperatures well-below National Warning Service heat advisory and heat warning thresholds. Heat can also trigger other health outcomes, with significant increases in NC emergency department visits for conditions like cardiovascular and cerebrovascular diseases, and respiratory diseases (e.g., hemorrhagic stroke, hypotension, aneurysm, COPD, bronchitis, emphysema) [13].

In the mountains of NC, occupationally exposed grounds workers may perceive themselves at higher risk for heat strain; however, the overall risk is still low compared to other populations in the southeastern United States[14]. Nonetheless, they do experience physiological heat strain events, despite workplace adaptive measures in the summer including shifting the work schedule to the early morning hours and access to air-conditioned vehicles and buildings. A partnership between academics, students, and grounds workers have sought to enhance understanding around this issue by providing workers with personalized monitors and information on individual-level temperature exposure, heart rate and geo-locational changes to decrease occupational exposure to extreme heat[14-18].

Unlike other regions in the southeastern US, western North Carolinians are vulnerable to cold extremes, as well. Health impacts from cold temperatures can also occur at climatologically normal cool conditions whereby elevates health risks may occur in response to prolonged exposure[19]. Research has found that populations in the southeast US are more vulnerable to cold temperature due to adaptive measures and poor acclimation. Preliminary mapping has identified significant clustering of hypothermia in the far western part of the NC among adolescent males and the elderly[20]. Further research is needed to understand the underlying vulnerabilities and exposure risk for WNC populations to cold extremes.

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Vector-Borne Diseases

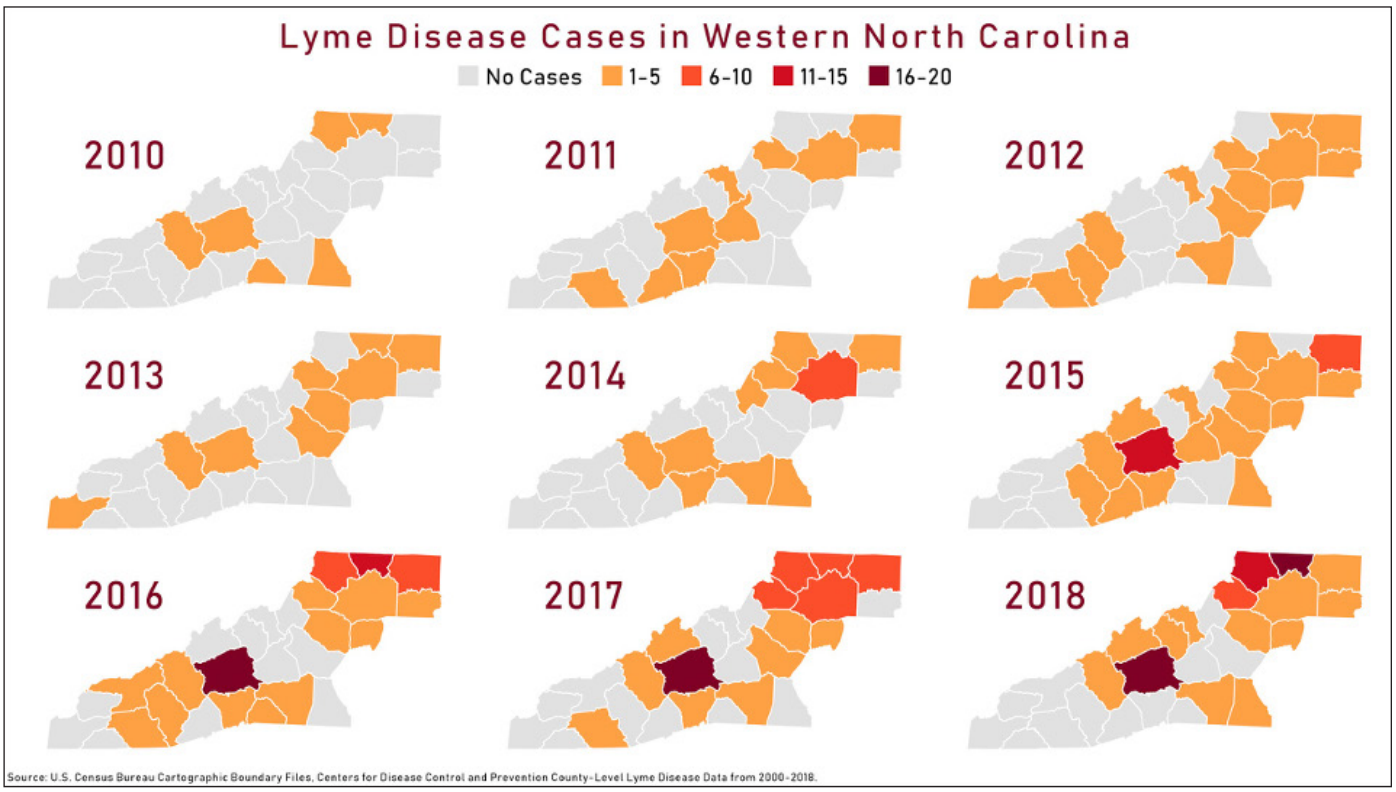

Figure 2. The 2010-8 Lyme disease cases in WNC.

Climate exerts a more indirect effect on vector-borne disease on WNC, with temperature and precipitation affecting the life cycle of vectors and the behavior of the human population. In NC, the most common vector-borne disease are associated with ticks, which carry diseases including Rocky Mountain Spotted Fever, ehrlichiosis, Lyme disease, and Southern Tick-Associated Rash Illness (STARI), although mosquito-borne diseases also occur, with less frequency (e.g., La Crosse Encephalitis, West Nile Virus, Eastern Equine Encephalitis) [21].

Previous investigations have reported the marked southward propagation of Lyme Disease from 2000 to 2014, southwest along the Appalachian Mountains with new disease clusters in the southern Virginia mountain region and expansion into WNC (Figure 2)[22]. AppHealth Care's State of the Community's Health Reports highlight Lyme Disease as an emerging issue for the area[23].

The main vector for Lyme Disease, Ixodes scapularis (commonly referred to as the deer tick or black-legged tick) is highly dependent on climate patterns, specifically in regard to temperature and water stress. Optimal climate conditions are crucial for I. scapularis to regulate off-host mortality. The distribution of I. scapularis has been forecasted to shift from the southern United States to the central United States in the future due to increasing temperatures[24]. Ticks are likely to thrive with increasing temperatures because of their long development in surface layers of the soil[25]. Lyme Disease is a zoonotic disease, spread between animals and humans, and is crucially connected to environmental factors[26]. As a result, the recent emergence of LD in North America has been shown to be linked to environmental change[24]. The most common host of I. scapularis is the white-footed mouse (Peromyscus leucopus), but other transmitters, such as deer, rodents, and even acorns, have also been identified[27-28]. The white-footed mouse is expanding northward due to milder winters[27,29]. Milder winters and earlier spring snowmelt could be driving white-footed mouse presence earlier in the year, indicating an increasing temporal range suitable for Lyme Disease[27]. New and existing vector-borne diseases remain an important contributor to morbidity among NC residents and more research is needed to understand which vectors and geographic locations within the state will be most impacted by future climate stressors[30].

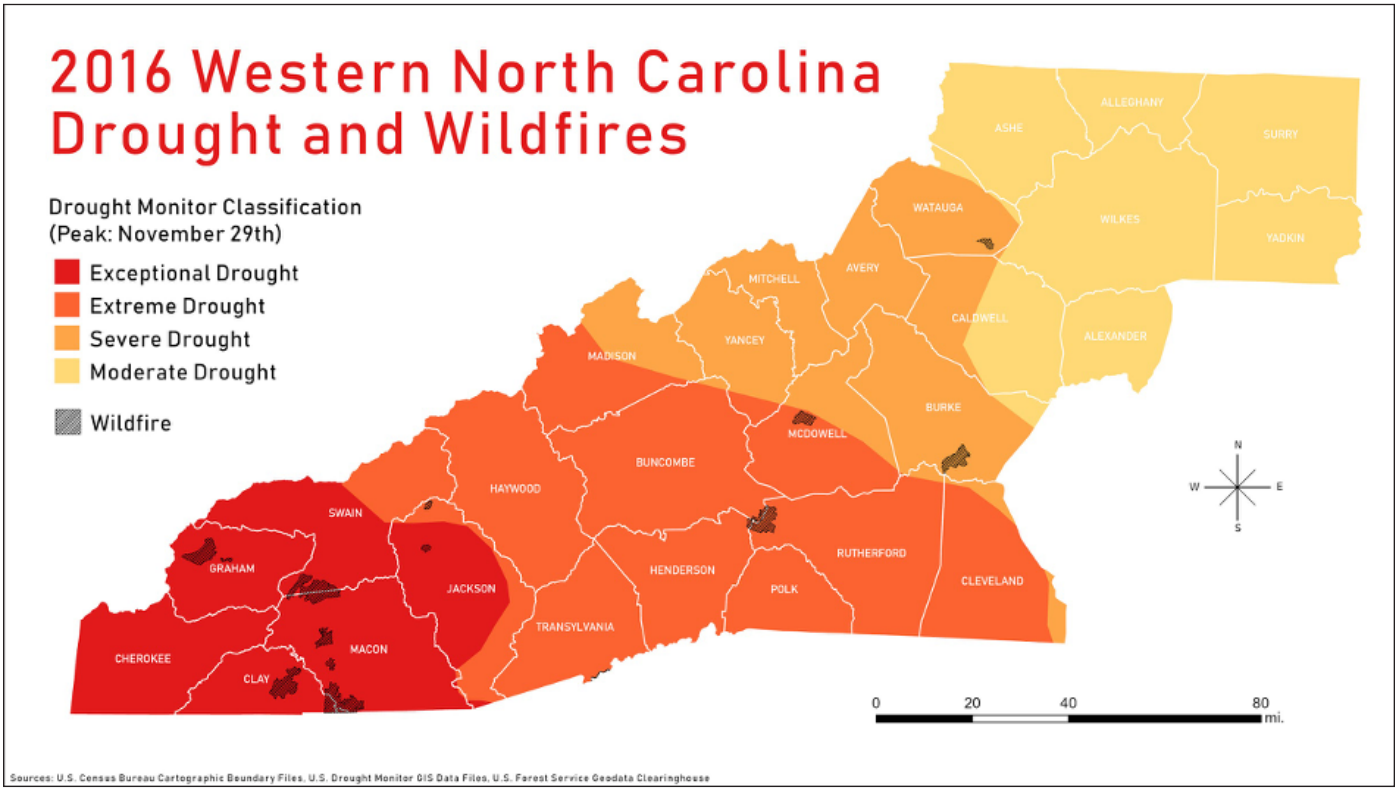

Figure 3. The 2016 drought and wildfires in WNC.

The WNC region is regularly impacted by extreme weather events like flooding, landslides, drought, and wildfire. In the future, climate changes may amplify these extreme events, increasing the frequency and/or intensity of droughts and floods and the potential for natural hazards like wildfires and landslides.

In 2004, tropical cyclones Ivan and Frances hit the region, resulting in the largest 24-hour rainfall in United States history to occur in WNC (near Grandfather Mountain with a measurement of 22 inches in 24 hours). Heavy rainfall events not only result in damage and injuries from flash flooding, but can also amplify the risk for landslides, a significant hazard in mountainous regions. Moreover, a combination of thin soils, steep slopes, and frequent precipitation increase the susceptibility of WNC to landslide events[31-32]. In 2004, the precipitation from Ivan and Frances resulted in approximately 400 landslide events across WNC that resulted in $200,000,000 in damage and the deaths of 11 individuals[33]. These events are not unusual to WNC, with heavy rains and subsequent landslides reported during earlier storms in 1916, 1940, and 1977 [31].

In 2016, WNC experienced an intense drought that began in March and worsened through late November, with all counties in the region experiencing moderate, severe, extreme or exceptional drought conditions[34]. From October through December, numerous wildfires occurred throughout WNC, burning approximately 60,000 acres (Figure 3) [35]. The wildfire outbreak was supported by a combination of ideal physical characteristics favorable to wildfire growth, accumulating fuel loads resulting from historical fire suppression practices, and extremely dry conditions caused by a severe drought. The wildfires were unprecedented for Appalachia, resembling wildfires occurring in California. The impacts of the drought and subsequent wildfires were far-reaching. During the wildfires, outdoor recreational activities - a significant source of revenue for WNC - ceased due to health concerns about the diminished air quality[36]. As precipitation becomes increasingly variable in the future, the risk of lengthy periods of drought and subsequent wildfire outbreaks, such as the one in 2016, also increases.

MENTAL HEALTH IMPACTS

Suicide is an ongoing public health crisis, with rates

increasing nearly 13% in NC from 1999 to 2016[3]. Most troubling, the incidence of suicide among adolescents is also increasing, with suicide as the second leading cause of death and nearly doubling over the previous decade[37]. The WNC region has an elevated risk of mental health impacts, particularly among adolescents, with spatially significant clustering of suicide in all WNC counties from 1999 to 2017 [38]. Elevated risk for suicide among rural populations in the U.S. is well-established. Suicide rates in most rural settings are nearly double those found in urban locations, and this gap is widening among adolescents[39]. Several possible explanations for this have been proposed, including limited availability of mental health services in rural regions, low acceptability of professional help-seeking (e.g., stigma), social isolation, socioeconomic factors, and access to lethal means[39].

The impacts of climate and natural hazards from mental health are unclear. Previous work by the authors has noted a strong relationship between temperature and crisis events, or events in which adolescents seek out the support of a crisis counselor in other areas of the country such as Chicago, IL and New York City, NY[40]. Preliminary results among the co-authors have also found a significant relationship with high temperature and emergency department visits from mental health conditions in WNC. Similar trends have been noted worldwide with elevated temperature being associated with increases in emergency room visits and/or hospitalizations for mental health illness in numerous countries including Australia, China, Canada, and Taiwan[41-45].

Research demonstrating physiological pathways for the association between temperature and mental health is evolving. One possible mechanism is an overactive temperature-response in the brown adipose tissue, which impairs heat tolerance and results in an intensification of anxiety, suicidal ideations and/or suicidal occurrence[46-47]. While brown adipose tissue is found in all humans, this mechanism might be particularly relevant to adolescents who have higher volumes of this tissue compared to adults[48]. High temperatures may also result in higher rates of hospitalizations among individuals who frequently use mental-health-related drugs, such as psychotropics[49]. Further research efforts are needed to understand the pathway between temperature and mental health conditions.

Although research is lacking in WNC, there is a strong relationship between mental health and natural hazards. In Eastern NC, a significant increase in crisis response, particularly for conditions like stress and anxiety and suicidal thoughts, were observed following Hurricane Florence, a tropical cyclone that devastated the eastern NC coast with heavy precipitation in 2018 50. Similar hurricane-related impacts have been felt in WNC resulting in multi-million-dollar disasters from the 2004 hurricanes (Ivan and Frances) and Hugo (1989), and these extreme events could be more intense under a warmer climate regime[1].

BUILT ENVIRONMENT

Decades of research into the relationship between transportation infrastructure and mobility has shown that individual and household travel choices (including number of trips, origins and destinations of trips, routes, and travel mode choice) respond to transportation infrastructure capacity and quality, as well as to the cost (in time and money), convenience, safety, and comfort of transportation services[51-52]. The reverse relationship—the environment shaping the built environment—also is observed, in terms of impact of both recurrent and extreme weather events (flooding, landslides, drought, wildfire, ice storms, hurricanes, and more) on the built environment, and increasingly onerous costs to maintaining and sometimes rebuilding transportation infrastructure in an era of heat (buckling pavement), flooding (erosion, scouring, building damage, human injury and death), sea level rise (loss of property, buildings, roads, and natural landscape), and other events that are increasingly frequent and severe with a changing climate[53].

Beyond transportation infrastructure, other features of the built environment are threatened by climate change, and offer rich targets for policy and technological innovation that prepare for the climate of the future. Harlan and Ruddell summarize a range of environmental strategies with the potential to address climate impacts, ranging from land uses (including urban gardens and forests, and water management tools) and transportation (supporting public transportation and non-motorized modes—walking and cycling), to more energy-efficient and climate-ready building materials and design, to effective communications (public messaging) and innovation in operations and systems[54]. The transition

to sustainable infrastructure needed to assure that society will both survive and thrive will require attention to the complexity of urban ecosystems and substantive shifts in planning and decision-making[55]. The intertwining of built and natural environment not only presents challenges (in studying, measuring, and addressing problems relating to climate stressors), but also offers the potential of co-benefits when acting on one identified component with attendant impacts on others. Indeed, Younger et al. argue that the human and environmental health impacts of transportation, buildings, and land use, including forestry and agriculture, can be tackled in ways that produce better outcomes across sectors and address sociodemographic inequities, such as those relating to access to mobility services and active travel modes, and the distribution of risks and benefits of pollution, green space, healthy and resource-efficient buildings[56].

The built/natural environment relationship manifests differently across landscapes. Rural regions are characterized by a variety of engineered landscapes, ranging from low-density scattered habitations and small-scale economic activity, to small towns with varying degrees of compactness and intensity of land uses, to cities in otherwise rural counties. In general, rural populations have a higher share of residents who are older, sicker, and poorer[57-59]. The very characteristics that attract some people to remain in—or move to—rural communities, such as lower taxes and less crowding, also make some aspects of rural life more challenging, given scarce resources and underdeveloped economies60. Rural regions have less concentrated goods and services, so people must travel farther to access retail outlets including groceries and pharmacies, medical care, education, recreation, public services, and other key resources. Non-drivers who don't own or cannot drive a vehicle may rely on scheduled fixed-route transit where it is offered, or demand-responsive services if they qualify, for example, for medical appointments. A study of transportation disadvantage in five rural NC counties employed key informant interviews and non-expert resident focus groups, along with mapping of risk factors, to probe the mismatch between travel demand to access key destinations and mobility options available to them[61-62]. Their findings affirmed earlier research on vulnerable populations (specifically, old and young, low-income, physical mobility-limited, English proficiency, and vehicle access), while also producing insights into which residents experience transportation disadvantage, and the formal and informal coping mechanisms adopted by rural residents with limited mobility options.

The sparsely populated rural landscapes of WNC pose specific challenges related to the built environment and environmental challenges related to a changing climate. The ruralness of the region, where a few major cities stand out in a region of many small towns and hamlets, with many residents living an hour or more from the closest metropolitan region, makes the population particularly dependent on road travel for both routine needs (groceries, banks, public buildings) and for infrequent destinations (airports or major retail centers) and acute needs (e.g., medical care). Travel in the region, with its rugged terrain and widely separated destinations, has long been disrupted by events such as flooding, wildfires, landslides, and ice storms, which may force travelers onto long detours or otherwise complicate already onerous travel conditions. The new wrinkle in this travel landscape is the increasing frequency and severity of such events, exacerbated by uncertainty and by communications and coordination challenges in a sparsely populated region that also hosts many seasonal residents and visitors[36]. Emergency management personnel and regional health districts are challenged to provide information about climate-related risks to the population, which may involve decisions and public messaging about preparing for and recovering from both acute events such as flooding or landslides, or serious chronic conditions such as dangerous air quality during prolonged wildfires.

DISCUSSION AND CONCLUSION

WNC is a complex region undergoing rapid changes as a result of biophysical (e.g., climate and land cover changes) and socioeconomic factors (e.g., inequality, economic growth) that produce an array of interactions that elevates the risk and vulnerability of the population. Specifically, the distinctive mountain landscape, with limited road networks and steep terrain, can present particular transportation and economic challenges that are exacerbated by the risk of extreme events (e.g., storms, droughts), and uncertainty about frequency, duration, and severity of these events under a new climate regime.

The unique geography and challenges of WNC are further altered by the underlying populations, which vary in social vulnerability and resilience across the entire area. Although the impacts of climate change are often focused on coastal communities, where hurricanes and sea-level rise will have direct impacts, inland locations like WNC also face unique stresses to climate change, which will amplify current health disparities and environmental health risk.

In general, higher temperatures will increase the threat of heat-related illnesses, particularly among the occupationally exposed, those with underlying medical issues, and rural populations in WNC[14,20]. Threats from high temperatures can impact heat-related illness and exacerbate other illnesses including cardiovascular and cerebrovascular illnesses[13]. High temperatures can also increase the risk of mental health illnesses and crisis events[40]. Regional WNC public health agencies, hospitals, and emergency preparedness staff should prepare for increases in health effects during extreme heat events and for the resources to treat patients. Moreover, programs that alleviate heat stress, such as cooling centers and resources for building weatherization, are needed for the population to address rising temperatures.

Changes in temperature and precipitation will also indirectly affect the distribution of vectors, like ticks, which spread disease such as Lyme disease. As predicted by research disease diffusion models, Lyme disease is spreading into Northern WNC and will likely impact all of WNC in the decades to come. The distribution of other vectors, and the corresponding vector ecology (e.g., bite frequency, geographic distribution) will increase with higher temperatures and alter the incidence of these diseases among residents of WNC.

Extreme weather events (e.g., drought, heavy precipitation) are a normal climatological occurrence in WNC, and communities should be prepared for natural hazardous events like landslides, flash flooding, and wildfires. Building infrastructure situated in at-risk geographic locations, should be developed with caution and account for the potential of such climate and weather extremes.

The environmental impacts from climate change are multifaceted, and include other health stressors like air quality and waterborne disease, which will likely interact with climate stressors discussed in this paper, like higher than average temperatures, precipitation extremes, and weather-related disasters are expected to also impact WNC. Although beyond the scope of this paper, these topics are important and should be considered among the health and climate impacts of WNC residents.

In the future, WNC communities will need to identify ways to adapt to a changing climate that addresses existing health disparities and the risk of emerging and reemerging diseases. This paper provides stakeholders with a current overview of the regional impacts of climate change on human health for the purpose of identifying vulnerability and improving resilience in WNC. Due to the highly variable nature of hazards in mountain environments, policymakers should conduct local-scale assessments of vulnerability and allocate resources to increasing awareness of risks and access to health services. Proactive action to address threats to human health will enable communities to prosper in the midst of a changing climate and may also serve to reduce inequities and enhance economic vitality across the region.

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