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Exploring the role of forest resources in reducing community vulnerability to the heat effects of climate change

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ABSTRACT

While the growing literature on forest ecosystem services has examined the value and significance of a range of services, our understanding of the health-related benefits of ecosystem services from forests is still limited. To characterize the role of forest resources in reducing community vulnerability to the heat effects of climate change, a general index of heat vulnerability (HEVI) was developed through Principle Components Analysis (PCA) and subsequently used within ANVOA and Poisson regression to assess the relationship between the amount and type of forest resources (species, management regime, spatial pattern) and a county's vulnerability to the heat effects of climate change. Results of the ANOVA showed significant differences in the extent and characteristics of forests among counties experiencing different levels of heat vulnerability. The Poisson regression using county heat mortality as the dependent variable found forest characteristics to have a significant influence on heat mortality when other determinants of vulnerability were controlled. A negative and significant relationship was specifically found between forest area and heat related mortality, which supports the hypothesis that the extent of forest coverage helps to alleviate vulnerability associated with heat effects. These findings have important implications for understanding the role of forest ecosystem services in reducing a community's vulnerability to the heat effects of climate change. Findings will also be useful in guiding land use planning and preserving desirable forest characteristics to help communities adapt to climate change.

1. Introduction

The emerging literature on ecosystem services has quantified and evaluated a variety of services from forests, including provisioning, regulatory, economic, and cultural benefits (Farber et al., 2002; Costanza et al., 2006; Vihervaara et al., 2012; Amacher et al., 2014). However, as climate change is expected to increase human exposure to heat and consequently vulnerability to the negative health effects of heat ("heat effects"), investigations of the characteristics and benefits of health-related ecosystem services derived from resources that mitigate heat, e.g., forests, is warranted (Myers et al., 2014). Increased heat effects are predicted to increase a community's vulnerability due to increased heat-related morbidity and health care costs, as well as energy consumption. The incremental increase in temperature associated with climate change acts at such a slow rate that the dangers associated with the overall trend are often unappreciated. However, the Center for Disease Control and Prevention (2009) advises that extreme heat events are responsible for more deaths annually than any other natural disaster in the United States. Further, the Intergovernmental Panel on Climate Change (IPCC, 2007) warns that the world will observe increased heat waves in the future. Considering the significance of heat vulnerability as a public health issue (Luber and McGeehin, 2008), there is a need for research to explore more carefully the links between forest cover and heat mitigation.

The literature on social vulnerability[1] indicates that the resiliency of human life and community structure depend both on the socioeconomic characteristics of households and features associated with the natural environment (Reid et al., 2009; Wilhelmi and Hayden, 2010; Uejio et al., 2011). Indeed, a growing number of empirical studies suggest human health benefits for urban residents living proximal to city trees and other green spaces (Donovan et al., 2011). Likewise, the literature on public health suggests that human communities in areas with less green space are more vulnerable to the heat effects of a warming planet (Reid et al., 2012). In terms of mitigation, however, ecological studies have also demonstrated that vegetation can help alleviate heat in urban areas (Akbari et al., 1997; Susca et al., 2011); and economics studies have characterized the value of residential energy savings related to forest vegetation (Donovan and Butry, 2009; Pandit and Laband, 2010). However,

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[1] Social vulnerability here refers to marginalization, characterized by the lack of ability to assertively navigate social systems or to move progressively towards higher living standards in terms of material wealth and influence (Gaither et al., 2011, p.27).

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whether and to what extent forest resources can be managed to increase the resiliency of local communities to the health effects of climate change remains almost unknown (Wilhelmi and Hayden, 2010). So far, studies on community vulnerability to natural disasters and risks have focused mostly on flood and wildfire (Cox et al., 2006; Zahran et al., 2008; Poudyal et al., 2012). The recognition of community vulnerability to climate-induced temperature increases is a relatively new phenomenon. As such, it has only recently started to receive attention from the social and economic sciences (Reid et al., 2012).

A handful of studies have examined community vulnerability in the context of green or vegetated areas in general. For example, Reid et al. (2009) showed non-vegetative areas (i.e. built up areas) to be an important component of vulnerability at the census tract level. Uejio et al. (2011) examined the relationship of heat-related mortality and morbidity with heat exposure, socioeconomic conditions, and the built environment for census block groups (CBG) in Philadelphia, PA and Phoenix, AZ. They found that heat mortality and heat distress incidents were higher in CBGs with low housing value, and higher proportion of black residents in Philadelphia, and in CBGs with sparse and less healthy vegetation in Phoenix. A similar study by Harlan et al. (2006) examined the correlation of heat index with population characteristics, environmental characteristics, and coping resources, respectively, in eight Phoenix neighborhoods. Results showed that neighborhoods with high housing density, sparse vegetation, and no open space had higher heat index ratings. Yet, these studies did not assess how vulnerability may be related to variations in characteristics of forest vegetation.

Variations that could determine a forests' ability to counteract heat effects include the extent of forest coverage, species composition, difference in major management regime, and the spatial pattern of forest patches. The tree physiology and landscape ecology literature suggests that a community's vulnerability to heat may also depend on the amount and composition of forests in the surrounding area. For instance, forest canopy density determines the amount of shade and cooling ability (Akbari et al., 1997). The species of a forest can also influence shade provision and therefore aid in cooling. Deciduous (hardwood) and mixed (deciduous and evergreen) species canopies typically contain larger leaves and wider canopies, and therefore offer wider shaded area than their evergreen counterparts (Akbari et al., 1997). The larger leaves and higher amount of shade per tree provides the potential for equivalent shading of forests with lower density.

Policy makers may be interested in knowing how factors that are beyond an individual's control, such as existing natural resources and community land use practices, could be used effectively to mitigate climate effects and what kind of low-cost options might be available for local communities to cope with the negative outcomes related to increasing temperatures. For example, some communities face more intense ambient temperatures due to the greater density of the built environment, and the lack of vegetation. This phenomenon, which is characteristic of many urban areas, is known as the Urban Heat Island Effect (UHI) (Environmental Protection Agency, 2014). Communities facing the intense effects of UHI may benefit from appropriate land use planning and urban tree management if they know whether and what kind of forest characteristics might help the community mitigate the negative effects of heat stress. Two otherwise identical communities may experience or have the ability to withstand different levels of heat stress simply because of the difference in the way forests and other green vegetation are managed. For example, if increasing canopy coverage could reduce the vulnerability of poor communities in treeless urban areas, community or urban forestry programs could be a favorable policy intervention. Therefore, understanding whether and what kind of roles forests of different characteristics play in reducing the heat effects of climate change not only increases our understanding of the full benefits of forest ecosystem services but also sheds light on the feasibility of expanding forestry programs as a means of climate mitigation and adaptation.

To fill this gap in knowledge, our study examined whether and how communities with different forest characteristics (i.e. amount of forest, species composition, management regime, and spatial configuration) might have different levels of vulnerability to the heat effects of climate change. We anecdotally know that increases in vegetation help mitigate heat (Akbari et al., 1997; Rosenfeld et al., 1995), but our goal is to understand (after controlling for all other factors) whether the species composition (e.g. deciduous, evergreen), broader management regime (protection, production), and spatial configuration (i.e. aggregate vs. fragmented) would significantly correlate to heat-related health outcomes of affected communities (i.e. an observable indicator of community vulnerability to heath effect). We hypothesize that increases in forest cover will significantly decrease the community's vulnerably to heat effects, but the contribution will vary across the type of dominant forest species, the way forests are managed, and the way they are distributed across the landscape.

2. Conceptual framework

The IPCC definition recognizes climate vulnerability as a multidimensional concept measuring "the degree to which geophysical, biological, and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" (IPCC, 2010). Vulnerability has been previously identified using socio-economic, demographic, and hazard specific indicators to estimate the resilience of a human population to the heat effects of climate change prior to an extreme heat event (Cutter et al., 2003; Cox et al., 2006; Reid et al., 2009). That is, different communities will possess different capabilities of coping with heat based on differences in their levels of exposure, sensitivity, and adaptive capacity (Wilhelmi and Hayden, 2010; Eq. (1)).

$$\text{Vulnerability} = f(\text{exposure}, \text{sensitivity}, \text{adaptive capacity}). \quad (1)$$

This model is referred to as a "vulnerability framework" where, conceptually, vulnerability is a function of the level of exposure, sensitivity, and adaptive capacity of a community (IPCC, 2014). In the case of heat effects from climate change, exposure encompasses the climate-related risks in regard to both longer term and episodic climate changes that a community experiences. Sensitivity is the predisposed risk associated with both the social and demographic characteristics of a community, and adaptive capacity is the ability of a community to adapt to or recover from stresses created by extreme heat (Wilhelmi and Hayden, 2010). The influences of extreme heat may be place-specific and path-dependent, meaning that the vulnerability of a community will depend on both the physical and social characteristics of place (e.g. the surrounding environment specific to the community), and the series of attributes and/or actions that make community members sensitive to extreme heat (e.g. lack of household financial resources and information, age, and physical ability).

In a recent work, Myers et al. (2014) presented a schematic of the complex relationships between altered environmental conditions and public health. The framework essentially shows that population-level vulnerability is affected by various social and infrastructure barriers that could either buffer or eliminate the impacts of an altered environment. We extend Myer's et al.'s thesis to posit that the characteristics of natural surroundings, including amount of forestland, species composition of a given forest, and the forest's spatial arrangement could make a difference in a proximal community's resiliency. If certain characteristics of forest and natural vegetation correlate positively with lower heat vulnerability within the landscape, such natural assets may be considered adaptive resource to offset the heat effects.

There are two primary approaches to operationalizing community vulnerability (Zahran et al., 2008). The first is a generic index approach using a combined index of vulnerability, where a large set of socio-demographic data, economic conditions, and other known risk factors are combined to represent the exposure, sensitivity, and adaptive

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