ABSTRACT

SELM, KATHRYN RENEE. Climate Change Knowledge Perceptions and Household Adaptive Capacity. (Under the direction of Dr. Melissa McHale).

Addressing the challenges of global climate change will require a public that is knowledgeable and engaged, and policy actions that are scientifically informed. However, the perceptions people have of their knowledge and intelligence can complicate climate change educational efforts. In addition, governments struggle to adapt to climate change due to competing fiscal priorities and conflicting policies. Small governments prefer localized case studies to help make scientifically informed decisions regarding climate adaptation policies. In this research we examined two questions: whether gender and ethnicity predicted perceptions people had of their own climate change knowledge and whether a scale could be developed that captures the adaptive capacity of urban households.

In our first study, we developed a survey instrument to assess respondent’s self-perceived climate change knowledge (n = 200). Survey respondents were asked on a 5-point scale how strongly they agreed with the statement “I feel knowledgeable about climate change” (1 = strongly disagree, and 5 = strongly agree). We found women’s self-perceived knowledge to be unexpectedly higher than men among those with low levels of educational attainment, but were higher for men than women among those with high levels of educational attainment. In addition, minority respondents self-reported lower perceived climate change knowledge than white respondents. This study enhances our understanding of the gender gap previously identified in the literature about climate change knowledge perception, by suggesting gender differences may be contingent on educational attainment. Studies show that people who question their knowledge are often more knowledgeable than those who do
not, and may contribute to further knowledge seeking. Therefore, highly educated women and minorities, despite their negative self-perceptions, may still be more receptive to climate education efforts than white men.

In an attempt to better understand household adaptive capacity, which could mean more effective use of limited municipal resources, we also created a scale for measuring household adaptive capacity. We developed a survey instrument guided by four of the capitals that support human livelihoods: social, human, physical, and financial—and surveyed 200 households in Raleigh, NC, in the summer of 2015. We then used a principal components analysis to develop and test the scale for measuring adaptive capacity. Results suggested our household adaptive capacity scale is a valid and concise tool. Three major dimensions were present among the scale items: financial capital, political awareness, and access to resources. Together these three dimensions can be used to measure adaptive capacity among different households.
Climate Change Knowledge Perceptions and Household Adaptive Capacity

by
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BIOGRAPHY

Kathryn Selm was born and raised in the wilds of Western North Carolina where her family taught her a great appreciation for nature and compassion toward all living things. Her fascination with plants and love of scientific research led her to receive an undergraduate degree in biology with a research focus in botany from UNC Asheville. She received a distinction in undergraduate research for publishing a paper on beaver browse of the endangered shrub Virginia Spiraea. In order to further define her career interests she traveled around the United States for several years taking jobs in biology with the federal government, non-profits, and for profit sectors. These experiences taught her that many social and environmental justice issues are largely entwined, leading her to study urban ecology and natural resources at North Carolina State University. She hopes to utilize her education and experience to promote the responsible use of our natural resources and to limit the impacts of climate change and environmental degradation.
ACKNOWLEDGMENTS

I would like to thank Dr. Melissa McHale, who pushed me beyond my comfort zone and helped me find a voice. As a young female scientist I found her strong mentorship to be invaluable. My gratitude also goes out to my committee members—Dr. George Hess and Dr. Nils Peterson—for always keeping me honest and asking the tough questions. I would also like to thank the National Science Foundation and the US Environmental Protection Agency for their funding of this research. This study would not have been possible without my wonderful lab partner, Scott Beck, who I will never be able to thank enough. In addition, I would like to thank Dr. Fikret Isik for all his technical assistance and for teaching me to enjoy statistics. Last but certainly not least I would like to thank all the peers, students, and friends who braved the summer heat to help me administer door-to-door surveys. Thanks especially to my fellow graduate students and dear friends—Michael Drake and Emily Morris for their support and guidance throughout all stages of this research.
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Abstract

Education may encourage personal and collective responses to climate change, but climate education has proven surprisingly difficult and complex. Individual’s perceptions of knowledge and intelligence represent one factor that may impact willingness to learn about climate change. We explored this possibility with a case study in Raleigh North Carolina in 2015 (n = 200). Our goal was to test how gender and ethnicity influenced perceptions people had of their own climate change knowledge. Survey respondents were asked on a 5-point scale how strongly they agreed with the statement “I feel knowledgeable about climate change” (1 = strongly disagree, and 5 = strongly agree). Our survey instrument also included demographic questions about race, age, income, gender, and education, as well as respondent’s experience with natural disasters and drought. Our results supported an interaction between education and gender where women’s self-perceived knowledge was unexpectedly higher than men among people with low levels of educational attainment, but was higher for men than women among people with high levels of educational attainment. In addition, minority respondents self-reported lower perceived climate change knowledge than white respondents, regardless of educational attainment. This study enhances our understanding of the gender gap previously identified in the literature about climate change.
knowledge perception, by suggesting gender differences may be contingent on educational attainment. This could be the result of the stereotype-threat experienced by women and minorities, and exacerbated by the educational system. Because people who question their knowledge are often more knowledgeable than those who do not—highly educated women as well as minorities, despite their negative self-perceptions, may still be more receptive to climate education efforts than white men.

Introduction

Educational efforts are often promoted as antidotes to apathy and denial associated with environmental issues. Increased environmental knowledge has been shown to lead to growing concerns over the social and environmental impacts of climate change (Millfont 2012; Shi et al., 2016) that may also influence individual and collective action (Spence et al., 2011; Smith & Leiserowitz, 2014; Stevenson & Peterson, 2015). Despite the effectiveness of education as a tool to promote environmental action, achieving and fostering climate literacy is challenging for many reasons. Educational efforts are confounded by the complicated and highly variable nature of this environmental problem (Scheraga & Grambsch, 1998, Stevenson et al., 2014), along with successful media campaigns to foster skepticism among the public (Jacques et al., 2008; McCright & Dunlap, 2011).

Climate change literacy can also serve to further polarize certain individuals (Hamilton, 2011; Weber & Stern, 2011; Clayton et al., 2015). Kahan et al., (2012) found that scientific literacy and numeracy has opposite effects on climate change concern among those
with differing worldviews. They found that those who subscribe to a worldview that ties authority to conspicuous social rankings become less concerned about the risks of climate change with increasing scientific literacy and numeracy. Those with worldviews that favor less regimented forms of social organization and greater collective attention to the individual respond to climate change education with increasing concern. This gap is attributed to identity-protective cognition, wherein the holders of certain worldviews use and credit the information that is supportive of their own values and opinions (Kahan et al., 2007; Hamilton, 2011; Kahan et al., 2012; Howe & Leiserowitz, 2013).

Self-perceptions of knowledge represent a less studied factor that may also shape efficacy of climate education efforts. Perceptions of intelligence can determine how people engage with issues; for example, illusions of superiority can distort the way people filter and take-in information (Taylor & Brown, 1988, Waylen et al., 2004). Studies find that if people feel confident in their levels of knowledge, regardless of their assessed knowledge, they are unlikely to be motivated to acquire new information (Chaiken & Eagly, 1989; Sundblad et al., 2009; Gross & Latham, 2012); feelings of academic inferiority, on the other hand, can drive the search for further knowledge (Chaiken & Eagly, 1989; Kruger & Dunning, 1999; Gross & Latham, 2012). Alternatively, negative self-perceptions can have detrimental impacts; studies find low confidence is one contributing factor to the high attrition rates of women and minorities in science, technology, engineering, and math (STEM) fields (Elliott et al. 1996; Aronson & Inzlicht, 2004).
Negative cultural stereotypes can lead to these biased self-perceptions by inducing fear and anxiety—known as stereotype threat (Steele & Aronson, 1995). Stereotype threat undermines academic performance and can reduce one’s sense of agency (Aronson & Inzlicht, 2004; Liebow, 2016). Negative stereotypes exist in particular for women and minority groups. Both men and women perceive women to be less knowledgeable on the topics of politics (Morehouse & Osborne, 2009) and science (Grunspan et al, 2016), and studies find individuals with lighter skin are perceived to be more intelligent, regardless of their assessed intelligence (Hannon, 2014).

Few studies have explored the knowledge perceptions of women and minorities as it relates to climate change science. This is a critical gap within the climate change perceptions literature for several reasons. First, although women appear to be more ideologically receptive to climate change education than men (McCright & Dunlap, 2011; Whitmarsh, 2011), they may possess self-perceived limitations, intensified by educational attainment (Etkowitz et al., 2000; Miller et al., 2006; McCright, 2010), that could influence the way they engage with this increasingly important topic (Stoutenborough & Vedlitz, 2014; Schuld & Pearson, 2016). In addition, the demographics of America are shifting; the US Census Bureau (2012a) predicts the US will be a majority-minority country as early as 2043. This means that non-whites will be increasingly exposed to, and required to respond to, the impacts of climate change in America. Ensuring that these groups feel empowered to take on such a challenge is therefore important.
Our goal was to evaluate the self-perceptions of knowledge on climate change among various socio-demographic groups, particularly women and minorities. We tested whether the following: age, education, gender, experience with disaster and drought, race, and an interaction between gender and education, predicted the respondent’s self-perceived level of climate change knowledge. Because women may underestimate their comprehension of climate science (McCright, 2010), we anticipated that women would perceive a lower level of climate change knowledge than their male counterparts. We also expected that increasing educational attainment would further reduce the level of knowledge perceived by women, since increasing education may reduce confidence in knowledge among women (Etkowitz et al., 2000; Miller et al., 2006). Similarly, we hypothesized that minority respondents would self-report less knowledge on climate change than white respondents because previous research suggests racial minorities experience negative self-perceptions of intelligence (Aronson & Inzlicht, 2004).

Methods

Study Site

The socio-demographic composition of Raleigh, NC, makes it a suitable location for exploring the role of educational attainment in influencing people’s perceptions of their climate change knowledge. Raleigh is a city of relatively well-educated people; the percentage of the population with a bachelor’s degree or higher in Raleigh (48%), which is greater than the average for the state of North Carolina (28%) (US Census, 2015). In
addition, the relatively high racial diversity of Raleigh’s population (US Census, 2015) allows for generalizable results relevant to the future majority-minority demographics of the US.

**Survey Instrument**

We measured respondent’s self-perceived knowledge of climate change on a 5-point scale with the question “I feel knowledgeable about climate change.” Our survey instrument also included demographic questions about race, age, income, gender, and education, as well as respondent’s experience with natural disasters and drought. We measured education on an 11-point scale, ranging from no formal education completed (1) to a doctorate degree (11). Income was measured in $20,000 increments, ranging from less than $10,000 a year (below poverty) to more than $210,000 a year. The design of the survey instrument was guided by Dillman’s (2011) tailored design method. The final instrument was developed with pretesting among an equal number of respondents across five social vulnerability classes (n=20). Respondents were asked at the end of the survey to give feedback on the instrument. After evaluating this feedback, cognitive interviews were conducted with 5 participants to identify any alternative interpretations of survey questions. All research was reviewed and approved by the NC State University Institutional Review Board for the Use of Human Subjects in Research (Protocol Number 4087).
Sampling

We administered two hundred surveys door-to-door in Raleigh, NC, during the summer of 2015. To promote a representative sample of demographic groups, the sample locations were evenly stratified across five social vulnerability classes, ranging from high to low vulnerability, found in Cutter et al.’s 2006-10 (2003) social vulnerability index (SoVI) data set. The 2006-10 SoVI data set is a national index of social vulnerability, comprising 27 sociological characteristics that are aggregated into quintiles. Within the boundary of Raleigh’s city limits, we randomly selected forty households from each of the five SoVI levels using Hawth’s tools in ArcMap 10.x GIS software (Beyer, 2004). We started sampling from those houses selected with the GIS analysis and, if no one answered, we visited every other house within the SoVI boundaries until a participant agreed to be surveyed.

Data Analysis

We constructed a full ordinary least squares regression model in SAS version 9.4 software for Windows (©2013), for the dependent variable, “I feel knowledgeable about climate change.” We controlled for the following predictor variables: age, race, education, gender, past experience with any natural disasters and drought, and included an interaction term between education and gender. We collapsed the seven race categories into white and minority due to low response rates in several categories. Income was not included in the full model as it was collinear with education ($r = 0.45$).
Results

Overall, self-perception of climate knowledge was higher among women than men, countering our initial hypothesis (Table 1). However, education interacted with gender: highly educated women had a lower self-perception of climate change knowledge than less educated women, whereas highly educated men had a higher self-perception of climate change knowledge than less educated men (Table 1; Figure 1). Increasing educational attainment decreased (but reversed) the gap between the genders because self-perceived knowledge levels among women declined as their educational attainment increased. With all other variables held constant, women were around one point higher than men on the self-reported climate change knowledge scale at the lowest level of educational attainment, and around 0.6 points lower than men at the highest level of educational attainment. Minority respondents also perceived lower levels of knowledge about climate change than white respondents ($p = 0.02$).

Discussion

Our results contribute to literature on self-perceived climate knowledge by suggesting gender differences may be contingent on educational attainment. Women have been shown to underestimate their competence and intelligence in many fields, including climate change (McCright, 2010; Stoutenborough & Vedlitz, 2014), a phenomenon commonly referred to as the “gender confidence gap” (Seymour & Hewitt, 1997; Kissinger et al 2009). The confidence gap is often attributed to the high standards of perfection to which women hold
themselves (Hewitt et al., 1991; Sonnert & Holton, 1996), as well as their risk-aversion (Moore & Eckel, 2003; Borghans et al, 2009). However, our results suggest this gap exists primarily among those with higher education and is perhaps reversed between the genders among those with low education.

Multiple explanations for this interaction are possible. Negative stereotypes face women regarding their academic proficiency, especially in science, technology, engineering, and math (STEM) fields (Steele & Aronson, 1995; Shapiro & Williams, 2012). These negative stereotypes can elicit a disruptive and anxious state, known as stereotype-threat (Steele & Aronson, 1995; Kahan et al., 2011; Spencer et al., 2016), which can undermine academic performance and contribute to the high attrition rates of women in STEM fields (Elliott et al. 1996; Aronson & Inzlicht, 2004). These stereotypes can also influence the way women and young girls are treated in classrooms; some teachers are biased against women, particularly in math and the sciences (Riegle-Crumb & Humphries, 2012; Lavy & Sand, 2015), a phenomenon commonly referred to as expectation bias (Rosenthal & Jacobson, 1968; Dalkvist et al., 2014). These biases can further exacerbate the negative self-perceptions of female students (Hall & Sandler, 1982; Bernard, 1988), and become self-fulfilling prophecies, as these students are often sent on less ambitious tracks (de Boer et al., 2010).

The negative self-perceptions of knowledge held by educated women may actually be an indication of intelligence. Kruger and Dunning (1999) illustrated that the highest
performing individuals underestimate their abilities, while those who over estimate, but are incompetent, do not recognize their incompetence because they lack metacognition. The “Dunning-Kruger” effect, as it is known, is supported by the climate change literature, where women exhibit more scientifically accurate climate change knowledge than do men, yet underestimate their climate change knowledge more than men (McCright, 2010; Stoutenborough & Vedlitz, 2014).

One crucial implication of the “Dunning-Kruger effect” is that a low level of confidence in one’s own knowledge may actually be a driving force in the search for further information (Chaiken & Eagly, 1989; Gross & Latham, 2012). Highly educated women may therefore be well suited to learning about the complex and controversial topic of climate change. Climate change is a politically polarized topic in the US (Dunlap & McCright, 2008) and an intrinsically challenging phenomenon to understand (Weber & Stern, 2011); the impacts are spatially and temporally distant, and the causes are not directly observable (Moser, 2009; National Research Council, 2009). Understanding this complex phenomenon requires the critical thinking skills provided by higher education (Huber & Kuncel, 2016), a healthy skepticism of one’s own assumptions, and a drive to seek further knowledge—all qualities that highly educated women appear to possess.

Cultural exclusion, expectation bias, and limited representation of minorities in STEM majors (Litzler et al., 2014) likely all contributed to the low level of self-reported climate change knowledge among minority respondents. Minority groups are often culturally
excluded from rigorous scientific and environmental education (Finney, 2005) and many attend schools in low-income urban school districts, which are largely under-funded (Ayscue & Orfield, 2015). Additionally, minority respondents may have self-reported lower levels of knowledge due to cultural stereotypes of intellectual ability, similar to those that plague women. For example, Steele and Aronson (1995) found that black students only underperform compared to white students when they believe their intellectual ability is being tested. The biased expectations that teachers have of minority students can influence their pedagogical effectiveness, further driving the academic underperformance of minorities (Jacoby-Senghor et al., 2016). Future studies should explore the drivers of low perceived climate change knowledge among minorities and compare the levels of assessed climate change knowledge of minority groups to their levels of perceived knowledge.

Increasing climate change knowledge and self-perceptions of intelligence of minority groups is critical since we are projected to be a majority-minority country by 2043 (US Census Bureau (2012a). The lack of psycho-social support coupled with lower self-concept could have negative implications for the engagement of minorities in climate change advocacy and education. More culturally diverse communicators on the topic of climate science could help encourage engagement (Kahan et al., 2012, Brooms & Davis, 2017) as well as better k-12 environmental education programs in majority-minority schools. Studies have also found that one way to successfully fortify students against these ill effects is with social-psychological interventions, such as with praise to enforce an incremental theory of
intelligence (Mueller & Dweck, 1998) or through self-affirming writing assignments that aim to reduce negative stereotypes (Cohen et al., 2006, 2009).

**Conclusion**

This study enhances our understanding of the gender gap previously identified in the climate change knowledge perceptions literature (McCright, 2010, Stoutenborough & Vedlitz, 2014). Our results illustrate that the negative perceptions of climate change knowledge in women are a function of higher educational attainment, and at lower levels of education, women actually self-report more knowledge than men.

Although further research is required, previous studies find minorities have lower levels of assessed climate change knowledge (McCright, 2010), and a lack of psycho-social support—which can lead to less engagement with scientific topics (Swindle et al., 2001; Brooms and Davis, 2017). Together with our findings, these studies may indicate the need for educational and psychological intervention on behalf of minorities in order to increase climate change literacy and perceptions of intelligence.

However, efforts to enhance climate literacy among women and minorities should not be discouraged by the low level of perceived knowledge, because a lack of confidence in one’s own knowledge may encourage further knowledge seeking (Chaiken & Eagly, 1989). Encouraging knowledge-seeking behavior among women and minorities – who are less skeptical about climate change than white men (Whitmarsh, 2011) – could help to increase concern and policy action in the politically polarized United States.
Table 1. Predictors of perceived climate change knowledge. Education was coded on an 11-point scale from (1) no formal education completed to (11) doctorate degree. Gender was coded as 0=male and 1=female. Race was coded as 0=white and 1=minority. Drought and disaster were on a 5-point Likert scale ranging from (1) not at all affected to (5) very affected. Model Fit statistics: $R^2 = 0.089$, Adj $R^2 = 0.055$, $p = 0.01*$, RMSE = 0.92

<table>
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Figure 1. Effect of education on self-perceived climate change knowledge among women and men. Both regression lines predicting climate change knowledge were generated from the regression equation used to generate results in table 1—where demographic variables, as well as drought and disaster experience predict climate change knowledge. Error bars represent standard error. Y-axis starts at 3 as no respondents self-reported knowledge levels below 3.
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FINANCIAL CAPITAL, POLITICAL AWARENESS, AND ACCESS TO RESOURCES ARE INDICATORS OF ADAPTIVE CAPACITY IN URBAN HOUSEHOLDS

Abstract

Governments struggle to mitigate and adapt to climate change due to competing fiscal priorities and conflicting policies. Understanding household adaptive capacity, and how to strategically invest in increasing the resilience of the most vulnerable households, could mean more effective and efficient use of the limited funding in cities. We developed a scale for measuring household adaptive capacity with the use of a survey instrument guided by four of the capitals that support human livelihoods: social, human, physical, and financial. We surveyed 200 households in Raleigh, NC, and used a principal components analysis to develop and test the scale for measuring adaptive capacity. The results suggest the scale is a valid and concise tool. Three major dimensions were present among the scale items: financial capital, political awareness, and access to resources. Together these three dimensions can be used to measure adaptive capacity among different households. These findings are supported by similar work illustrating the value of income inequality and political awareness as indicators of adaptive capacity. Our results also demonstrate that complex relationships among the livelihood capitals may confound our ability to measure financial, physical, and human capitals separately. This framework for assessing adaptive capacity of households, with further refinement and testing, may be applied in other urban populations in the US.
Introduction

Adaptive actions, once popularly considered the “lazy” alternative to climate change mitigation, are now a primary focus of the Intergovernmental Panel on Climate Change’s (IPCC) strategy (Pielke et al., 2007; Prins & Rayner, 2007). The failures of large-scale mitigation are largely a function of international disagreements concerning responsibility, conflicting policies, and minimal funding (Aldy et al., 2010). In addition, mitigation to limit the amount of carbon emissions or enhance carbon sequestration and storage will not provide climate benefits, or produce noticeable results, for decades (Pielke et al., 2007). Therefore, adaptive actions are vital components of any climate change policy, regardless of future mitigation efforts.

Although both coordinated “bottom up” and “top down” strategies will be crucial in climate change adaptation (Hill & Engle, 2013; Bierbaum et al., 2014), adaptive efforts are often more successful at smaller scales (Brooks & Adger, 2005), with cities now widely recognized as important actors in responding to climate change (Rosenzweig, 2010). Cities, which are often hubs of innovation and economic activity, allow for a more comprehensive and context-specific response to climate change (Carter et al., 2015). Yet, cities have also been slow to act on climate change adaptation due to competing fiscal priorities (Carmin et al., 2012).

Controlling the cost of adaptive actions through the use of strategic and targeted initiatives is a priority for cities managing limited resources. Because the manner in which people adapt to stress can affect the costs and benefits of public policy (Kane & Shogren,
the adaptive capacity of individual households should be understood before municipal resources are allocated (Bierbaum et al., 2014; Araya-Muñoz et al., 2016). Large-scale governmental efforts to combat climate change that do not consider household-level actions and resources can actually undermine the inherent adaptive capacity of households (Dietz et al., 2009) or de-incentivize further protective measures taken by households (Barrett, 2006; Toole et al., 2016).

The factors that determine household level adaptability are poorly understood (Nhuan et al., 2016; Toole et al., 2016) as most studies that attempt to quantify adaptive capacity are performed at the national level (Adger & Vincent, 2005; Brooks et al., 2005), or at other large spatial scales (Araya-Muñoz et al., 2016), using indicators from secondary-data (Tinch et al., 2015). These attempts avoid the complexity of adaptive capacity in the pursuit of generalization and tend to overlook important regional variation (Adger & Vincent, 2005; Smit & Wandel, 2006; Toole et al., 2016). For instance, the factors that determine whether a rural farmer can adapt to climate effects will not be the same as those that affect a wealthy landowner or a single mother (Yohe & Tol, 2002; Brooks & Adger, 2005; Smit and Wandel, 2006; Engle, 2011).

The IPCC summarized the main determinants of adaptive capacity as economic resources, technology, information and skills, infrastructure, institutions, and equity (Smit et al., 2001; Engle, 2011). These attributes of adaptive capacity are included in the five capitals (social, human, physical, financial, and natural) that comprise the rural livelihoods.
framework (Ellis, 2000; Brown et al., 2010; Tinch, 2015). The five capitals have been used previously by researchers to capture the combination of resources utilized to reduce vulnerability (Farrington et al., 1999; Hammill et al., 2005, Park et al., 2012), and could also be used to link adaptive capacity to an existing conceptual framework that has been extensively researched (Tinch et al., 2015).

To capture the complexity of adaptive capacity and contribute to municipal adaptation planning efforts, we utilized the rural livelihoods framework to create an instrument to measure urban household-level adaptive capacity. We used Raleigh, NC, as a case study to develop and test a comprehensive measure of household adaptive capacity.

Methods

Study Site

Raleigh, North Carolina provides a good context for the development of an adaptive capacity scale for urban US households. Raleigh had the 21st largest numeric increase in population among the nation’s cities between 2010 and 2015 (Tippett, 2016), making it an ideal location for capturing a rapidly urbanizing population. Since the world’s population is becoming more urban (Davis 2003), results of this study will be more generalizable in the future. In addition, the Triangle Region of NC is a technology hub of highly educated people (US Census, 2015) that provides job growth, real estate expansion, and overall prosperity (Jones Lang LaSalle, 2014). These qualities are indicative of developed nations, which have been under-researched in the adaptive capacity literature (Toole et al., 2016).
**Survey Instrument**

Our survey instrument contained 19 capital-specific questions, each on a five-point scale. Physical, financial, social, and human capitals were assessed with several questions each. The capital-specific survey questions were drawn from capital definitions taken from several studies and tailored to households in an urban setting (Table 1). Natural capital is a traditional component of the rural livelihoods framework, because local natural resources often provide crucial support for rural households, especially in times of stress (Twine et al., 2003). Because traditional indicators of natural capital do not adequately address the livelihoods of urban households, we omitted them from the survey.

The design of the survey instrument was largely guided by Dillman’s (2011) tailored design method, and the survey was pretested before use. The instrument was reviewed and approved by the NC State University Institutional Review Board for the Use of Human Subjects in Research (Protocol Number 4087).

**Physical Capital**

Physical capital questions were focused on personal assets and resources rather than infrastructure, because the surveys were conducted in an urban setting where people typically have access to running water and electricity (Table 2, Questions 1-4). We included transportation, housing, and emergency supplies as physical capital (Baum 2008; Notenbaert et al., 2013). Access to transportation was considered physical capital, rather than financial, because Raleigh, NC, has a public transportation system that includes no-cost options.
Housing can be considered financial capital, because room or house rentals can provide monetary gains (Moser, 1998). However, good quality housing is also a valuable physical asset in the urban context (Nhuan et al., 2016). Emergency supplies are wholly tangible items that a household can possess to better cope with stress (Ellis, 2000).

**Financial Capital**

Financial capital questions focused on sustainable employment, because labor is an urban dweller’s most important asset in highly commoditized urban settings (Table 2, Questions 5-8; Moser, 1998). Questions also focused on market confidence (Ellis 2000; Gasper et al., 2011) and monetary savings and assets (IPCC, 2001; Tinch et al., 2015). Lastly, financial capital questions focused on the respondent’s assessment of their ability to secure, maintain, and utilize different financial assets (Ellis, 2000; Brown et al., 2010).

**Human Capital**

Awareness and knowledge (Frankhauser & Tol, 1997; Smit & Pilifosova, 2003) and health and well-being (Ellis, 2000; Lwasa, 2010; Gasper et al., 2011) fall within the definition of human capital. We included questions regarding awareness of natural disasters, political awareness, and access to affordable health care (Table 2, Questions 9-12).

**Social Capital**

Social capital questions were written to measure contacts and associations, also known as bonding social capital (Table 2, Questions 13-14; Pelling & High, 2005). Bonding
social capital can be described as the interpersonal relationships that are shared between individuals with a similar background—ethnic, religious or otherwise. We also measured social and civic engagement (Adger, 2003; Sander & Lee, 2014) using questions about social bonds, safety nets, and community and political activities.

**Sampling**

Two hundred surveys were administered door-to-door in Raleigh, NC, during the summer of 2015. To ensure a representative sample of demographic groups, the sample locations were evenly stratified across five social vulnerability classes, ranging from high to low vulnerability, found in Cutter et al.’s 2006-10 (2003) social vulnerability index (SoVI) data set. The 2006-10 SoVI data set is a national index of social vulnerability, comprising 27 sociological characteristics that are aggregated into quintiles. Within the boundary of Raleigh’s city limits, forty households were randomly selected from each of the five SoVI levels using Hawth’s tools in ArcMap 10.x GIS software (Beyer, 2004). We started sampling from those houses selected with the GIS analysis and, if no one answered, we visited every other house within the SoVI boundaries until a participant agreed to be surveyed.
Data Analysis

To limit the number of scale items, variables were removed that had correlations of $\leq 0.4$ between the combined scale (all values added) and each of the scale’s component variables (Dunlap et al., 2000). A principal components analysis enabled us to assess the 14 variables’ suitability for scale creation. We utilized the Kaiser criterion (Guttman, 1954) and extracted the factors with eigenvalues of 1.0 or greater and identified items that loaded at or above 0.3 within those factors (Spector, 1992). Cronbach’s alpha scores were used to assess the internal consistency of the 14-item scale, as well as the important factors identified with the principal components analysis. We created an additive scale with the 14 items after removing the missing observations, and assessed criterion validity for the 14-item scale. The measure of criterion validity, or how much the scale is related to outcomes it is supposed to measure (Zeller & Carmines, 1980), was determined by the scale’s significant correlations with well-defined and frequently utilized indicators of adaptive capacity: income, education, and renters’ insurance (Molua 2009; Harvatt et al., 2011; Safi et al., 2012). Statistical analyses were performed using SAS version 9.4 software for Windows (©2013).

Results

The 14 survey questions included in the scale exhibited internal consistency ($\alpha = 0.83$), which suggests that all the questions effectively measured adaptive capacity. The scale’s consistency was also reinforced by its criterion validity, whereby it was positively and significantly correlated with income ($r = 0.37$), education ($r = 0.38$), and having renters’
Results of the principal components analysis indicate three major factors underlying the scale—financial capital, political awareness, and access to resources (Table 2). These three factors met the Kaiser criterion and together explained around 56% of total variance. The first factor had the largest eigenvalue (4.6) and explained the most variance (33%). The items with the most influence on the scale (loadings ≥ 0.3) were those regarding financial resources and assets. Together, these items had a Cronbach’s alpha of 0.76, indicating their validity as a financial capital subscale. The second factor had an eigenvalue of 1.9, explained 13% of the variance, and highlighted items related to political awareness. Cronbach’s alpha for the second factor also met the internal consistency criteria with a rather large alpha (α = 0.92). The third factor, with an eigenvalue of 1.3, explained 10% of the variance, and highlighted resource access. The resource access items did not have as high internal consistency, with a borderline Cronbach’s alpha of 0.60.

Discussion

The increasing role of the private sector in modern society and economies around the world may help explain why financial capital was the strongest dimension within the adaptive capacity measure. Nhuan et al. (2016) had similar results when they quantified household level adaptive capacity in Vietnam. Taken together, these results suggest unequal wealth may play a role in adaptive capacity across a range of social, economic, and cultural
contexts globally (McKenzie, 2005). The high internal consistency of our financial capital subscale ($\alpha = 0.76$) could be partially explained by the more uniform and directly observable nature of financial resources, as compared to the more qualitative concepts found within human, physical, and social capitals (Tinch et al., 2015).

Political awareness, the second-strongest dimension of adaptive capacity identified in this study, illustrates the importance of governance in the measurement of adaptive capacity in US urban households. Governance indicators have been identified as important determinants of adaptive capacity at nearly all other spatial scales and locations: nationally (Brooks et al., 2005), in rural agricultural communities (Lockwood et al., 2016), and in several countries around the globe (Engle & Lemos, 2010; Nhuan et al., 2016). The universal importance of governance is justified because adaptation occurs within the bounds of regulatory systems and political jurisdictions (Lindseth, 2004; Næss et al., 2005) that influence the lives of nearly everyone in the world (Adger et al., 2005). Therefore, policymakers and stakeholders should engage the public across all scales and locations to contribute to a higher overall adaptive capacity.

Access to resources comprised items from human, physical, and financial capitals, which suggests that these three capitals may be interrelated. Similar relationships among these capitals have been found in rural studies conducted at refined spatial scales (Ellis, 2000; Lockwood et al., 2015). While the capitals are often treated as discretely measurable items at the national level (Tinch et al., 2015), these findings indicate that different
combinations of capitals may be required to measure adaptive capacity at the household level. Traditional livelihoods assessments at large spatial scales that cast household actions as voluntary and calculated, do so without gathering information on how people gain and utilize the capitals, and may not reflect the interdependencies of people needs and arrangements (Dijk, 2011).

Although social capital was not influential to the measurement of household adaptive capacity in this case study, the questions we developed may not have been sufficiently comprehensive. For instance, social capital has been shown to include many distinct dimensions that may be difficult to quantify (Van Beuningen & Schmeets, 2013). Alternatively, social capital can contribute less to adaptive capacity in populations that are more educated, as well as among those with a more individualistic culture (Guiso et al., 2004). Raleigh has both of these characteristics, with a high percentage of people with secondary degrees (US Census, 2015) and, as part of the United States, traditionally considered a more individualistic society (Han & Shavitt, 1994).

With further refinement, the tool presented in this study may help increase the adaptive capacity of cities by identifying economic disparity, refining areas of interest for city planners, and directing municipal investments to the most vulnerable residents. Investments in the economic welfare (e.g., employment availability and sustainability) and resource access (e.g., healthcare and public transportation) of households could improve the overall adaptive capacity of cities. Although long-term city plans often incorporate these
types of welfare and infrastructure projects, without a targeted approach, citywide socio-economic exclusion and income inequality could continue to increase (Lee, 2011). Our instrument could provide this targeted approach since it incorporates multiple measures of household welfare and economy that are rarely incorporated into publicly available data sets. While adaptation planning by cities is on the rise (Cruce, 2009), implementation is in its infancy because cities lack scientific guidance to justify expenses (Carlson & McCormick, 2015; Lehmann et al., 2015). Deeper and more context-specific understanding of adaptive capacity may also help identify approaches that increase resiliency and climate adaptation without high-cost infrastructure, such as through initiatives to increase political awareness and engagement

**Conclusion**

We developed and validated a tool to measure adaptive capacity among urban US households based on the rural livelihoods framework. The 14-item scale was a valid and concise instrument with three dimensions that can be treated as subscales: financial capital, political awareness, and access to resources. These three dimensions are consistent with previous characterizations of adaptive capacity (Smit & Pilifosova, 2003; Lockwood et al., 2015; Nhuan et al., 2016) and can guide future scale development efforts.

This work contributes to our understanding of resilience and illustrates that wealth inequality could be a consistent, global indicator of household-level adaptive capacity. While governance indicators, such as political awareness, have been identified as factors that
influence adaptive capacity at many spatial scales and locations (Brooks et al., 2005; Engle & Lemos, 2010; Lockwood et al., 2016), this study appears to be the first to demonstrate the importance of political awareness to the adaptive capacity of urban households in the US. By demonstrating the inter-relatedness of financial, physical, and human capitals that are traditionally measured separately, the results highlight the complexity of indicators required to assess household adaptive capacity.
Table 1. Definitions of the four capitals utilized in this study, adapted from Brown, 2010, Ellis, 2000, and Tinch, 2015.

<table>
<thead>
<tr>
<th>Capital</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Capital</td>
<td>Material goods and items produced by economic activity from other types of capital. It can include infrastructure, equipment and improvements.</td>
</tr>
<tr>
<td>Financial Capital</td>
<td>The level, variability and diversity of income sources, and access to other financial resources (credit and savings), that together contribute to wealth – its value is purely the ability to secure services of natural, human, social or manufactured capital.</td>
</tr>
<tr>
<td>Social Capital</td>
<td>The structures, institutions, networks, and relationships that enable individuals and societies to function effectively and facilitate cooperative action and the social bridging.</td>
</tr>
<tr>
<td>Human Capital</td>
<td>The skills, health, education, knowledge, civic engagement, political participation, and motivation of individuals that contributes to productivity and well-being.</td>
</tr>
</tbody>
</table>

Table 2. Principal components analysis of adaptive capacity scale items after removing scale items with low item-total correlations. Scale items are the survey questions that relate to the capitals indicated. The three factors were identified because they had eigenvalues ≥ 1.0 in the principal components analyses. The numbers in each cell are the loading factors in the principal components analysis. Loadings with an absolute value ≥ 0.3 are highlighted in bold.

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Capitals</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How confident are you that you have access to transportation whenever you need it?*</td>
<td>Physical</td>
<td>0.220</td>
<td>-0.123</td>
<td>0.325</td>
</tr>
<tr>
<td>2. How confident are you that you have the means (e.g. transportation, lodging, money) to temporarily leave the city?*</td>
<td>Physical</td>
<td>0.340</td>
<td>-0.151</td>
<td>-0.016</td>
</tr>
<tr>
<td>3. How confident are you that you have all the emergency supplies you would need for 72 hours after an emergency?*</td>
<td>Physical</td>
<td>0.201</td>
<td>0.238</td>
<td>-0.387</td>
</tr>
<tr>
<td>4. How confident are you that you would have access to all your basic goods and services if your primary means of transportation were not available?*</td>
<td>Physical</td>
<td>0.269</td>
<td>0.035</td>
<td>-0.497</td>
</tr>
<tr>
<td>5. How confident are you that you have access to transportation whenever you need it?*</td>
<td>Financial</td>
<td>0.309</td>
<td>-0.151</td>
<td>0.339</td>
</tr>
</tbody>
</table>
Table 2. continued

<table>
<thead>
<tr>
<th>Question</th>
<th>Factor</th>
<th>Mean 1</th>
<th>Mean 2</th>
<th>Mean 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>the ability to receive a formal loan? (e.g. bank)(^a)</td>
<td>Financial</td>
<td>0.313</td>
<td>-0.043</td>
<td>-0.100</td>
</tr>
<tr>
<td>6. How confident are you that you can always find a source of income when you need it?(^a)</td>
<td>Financial</td>
<td>0.287</td>
<td>0.019</td>
<td>-0.107</td>
</tr>
<tr>
<td>7. How confident are you that you could support your household on savings for at least 3 months without income?(^a)</td>
<td>Financial</td>
<td>0.356</td>
<td>-0.083</td>
<td>-0.136</td>
</tr>
<tr>
<td>8. How confident are you in your financial ability to move if you needed to?(^a)</td>
<td>Financial</td>
<td>0.356</td>
<td>-0.083</td>
<td>-0.136</td>
</tr>
<tr>
<td>9. How politically aware do you feel of your STATE government?(^b)</td>
<td>Human</td>
<td>0.169</td>
<td>0.602</td>
<td>0.172</td>
</tr>
<tr>
<td>10. How politically aware do you feel of your LOCAL government?(^b)</td>
<td>Human</td>
<td>0.150</td>
<td>0.620</td>
<td>0.201</td>
</tr>
<tr>
<td>11. How confident are you that you will be aware of any evacuation orders?(^a)</td>
<td>Human</td>
<td>0.212</td>
<td>0.188</td>
<td>-0.138</td>
</tr>
<tr>
<td>12. How confident are you that you have access to affordable healthcare?(^a)</td>
<td>Human</td>
<td>0.228</td>
<td>-0.022</td>
<td>0.468</td>
</tr>
<tr>
<td>13. How confident are you that if your dwelling were damaged, you would be able to stay with either family or friends?(^a)</td>
<td>Social</td>
<td>0.295</td>
<td>-0.223</td>
<td>-0.103</td>
</tr>
<tr>
<td>14. How confident are you that you have the ability to receive an informal loan? (e.g. family, friend)(^a)</td>
<td>Social</td>
<td>0.294</td>
<td>-0.199</td>
<td>0.153</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td></td>
<td>4.6</td>
<td>1.9</td>
<td>1.3</td>
</tr>
<tr>
<td>Percentage of variance</td>
<td></td>
<td>33</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Cronbach’s alpha</td>
<td></td>
<td>0.76</td>
<td>0.92</td>
<td>0.60</td>
</tr>
</tbody>
</table>

High loading variables in each factor are indicated in bold. \(^a\) Coding as follows: 5= *completely confident*, 3= *confident*, 1= *not at all confident*. \(^b\) Coding as follows: 5= *extremely aware*, 3= *somewhat aware*, 1= *not at all aware*
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