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ORIGINAL PAPER

Linking residential saltwater intrusion risk perceptions to physical exposure of climate change impacts in rural coastal communities of North Carolina

Abinash Bhattachan[1,2] · **Matthew D. Jurjonas**[3] · **Priscilla R. Morris**[4] · **Paul J. Taillie**[1] · **Lindsey S. Smart**[1,2] · **Ryan E. Emanuel**[1,2] · **Erin L. Seekamp**[3]

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Abstract
The salinization of freshwater-dependent coastal ecosystems precedes inundation by sea level rise. This type of saltwater intrusion places communities, ecosystems, and infrastructure at substantial risk. Risk perceptions of local residents are an indicator to gauge public support for climate change adaptation planning. Here, we document residential perspectives on the present and future threats posed by saltwater intrusion in a rural, low-lying region in coastal North Carolina, and we compare the spatial distribution of survey responses to physical landscape variables such as distance to coastline, artificial drainage density, elevation, saltwater intrusion vulnerability, and actual salinity measured during a synoptic field survey. We evaluate and discuss the degree of alignment or misalignment between risk perceptions and metrics of exposure to saltwater intrusion. Risk perceptions align well with the physical landscape characteristics, as residents with greater exposure to saltwater intrusion, including those living on low-lying land with high concentrations of artificial drainages, perceive greater risk than people living in low-exposure areas. Uncertainty about threats of saltwater intrusion is greatest among those living at higher elevations, whose properties and communities are less likely to be exposed to high salinity. As rising sea levels, drought, and coastal storms increase the likelihood of saltwater intrusion in coastal regions, integrated assessments of risk perceptions and physical exposure are critical for developing outreach activities and planning adaptation measures.

Keywords Rural coastal regions · Climate adaptation · Climate change exposure · Residential risk perception · Sea level rise impacts

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✉ Abinash Bhattachan
abhatta9@ncsu.edu

Extended author information available on the last page of the article

1 Introduction

Sea level rise and the associated impacts of saltwater intrusion pose a substantial threat to coastal populations, economic activity, coastal infrastructure, and ecosystems (Nicholls et al. 2007; Nicholls and Cazenave 2010; Nicholls 2011; Cazenave and Cozannet 2014). As the threat looms, coastal regions are becoming increasingly managed and engineered to support growing populations and associated infrastructure (Nicholls et al. 2007; Nicholls and Cazenave 2010). At the same time, substantial resources are invested in planning for and recovering from flooding and other damages from coastal hazards (Nicholls et al. 2007; Nicholls 2011; Hallegatte et al. 2013).

Public support for policy and infrastructure decisions often depend on recognizing that a threat exists; as such, risk perceptions of local residents can influence climate change adaptation planning (Kettle and Dow 2014; Lee et al. 2015; Kearney and Bell 2019). Psychological factors, such as uncertainty about climate change impacts and trust in science, affect risk perceptions (Corner et al. 2014; Kettle and Dow 2016); however, little research exists to document how physical landscape characteristics may align with, inform, or influence risk perceptions. An important first step in this work involves juxtaposing local residents' risk perceptions about specific climate impacts with landscape variables that portend those impacts. To this end, we document the risk perceptions of rural coastal residents about saltwater intrusion and analyze spatial relationships between risk perceptions and landscape variables commonly associated with saltwater intrusion.

To establish a case for understanding risk perceptions in rural coastal regions, we begin by describing processes related to sea level rise and saltwater intrusion, with specific emphasis on coastal North Carolina (our study region). We then review links between climate change adaptation planning, policy responses, and outreach, highlighting the fact that rural coastal regions receive much less scholarly attention than more densely populated coastal areas. After describing survey methods and geospatial analyses, we present results and discuss spatial relationships between landscape variables and perceptions of saltwater intrusion risk in our study region. We use results to inform policy and outreach recommendations that aim to improve awareness of saltwater intrusion risks in rural coastal areas and build support for climate change adaptation planning in regions similar to our study area.

1.1 Sea level rise, climate change response, and rural coastal regions

Increasing global temperatures have led to rising global sea level, largely attributed to thermal expansion of oceans and accelerated melting of polar ice-caps (Church et al. 2013). The global mean sea level rise (SLR) could range from 28 to 98 cm over the course of this century depending on the trajectory of global greenhouse gas emissions and other factors (IPCC 2013).

The impacts of SLR include the submergence, erosion, and flooding of coastal lands, and the salinization of freshwater resources (Nicholls and Cazenave 2010). Within the USA, Louisiana, Florida, and North Carolina have the greatest amount of land area within 1.5 m of sea level (Titus and Richman 2001; Bhattachan et al. 2018b) and are, therefore, highly vulnerable to these impacts. In North Carolina, the Albemarle-Pamlico Peninsula (APP) holds most of this low-lying terrain (Titus and Richman 2001). Recent projections have indicated that by the end of the century, North Carolina is very likely to experience between 54 and 154 cm of SLR under the IPCC high emission scenario (Kopp et al. 2015).

Certain anthropogenic activities exacerbate the submergence, erosion, and flooding of coastal lands by seawater. Groundwater withdrawal for industrial and agricultural use, for example, is a main contributor to the 3 mm per year subsidence rate in coastal North Carolina (Karegar et al. 2016). Additionally, artificial drainage networks, such as those common on the APP, increase the vulnerability of freshwater-dependent wetlands to saltwater intrusion (Bhattachan et al. 2018a). Drought can also promote saltwater intrusion into freshwater-dependent wetlands on the APP (Ardón et al. 2013) and elsewhere (Williams et al. 1999; Doyle et al. 2007), and models predict that the southeastern USA will experience severe and persistent drought in the future (Carter et al. 2014). Given that the APP is expected to experience increased rates of storm surge flooding (Kopp et al. 2015), the region is vulnerable to accelerated rates of saltwater intrusion in the coming decades during both wet and dry weather extremes.

Efforts to integrate climate change responses and adaptation concerns into policy and outreach with general public audiences to build support for climate change adaptation planning face many challenges (Haywood et al. 2014), and researchers are working to better understand pathways to climate action (Kearney and Bell 2019). For example, research on climate action has considered social networks (e.g., Dow et al. 2013), information pathways (e.g., Lackstrom et al. 2014), and the psychological predictors of risk perceptions (e.g., Kettle and Dow 2016). Risk perception is particularly important because it can motivate and mobilize action for climate change adaptation planning (Slovic 2000; Kettle and Dow 2016); here, we define risk perception as judgments made by people experiencing threats posed by a particular hazard (Slovic 1987; Leiserowitz 2006). Some of the psychological indicators of climate change risk perceptions explored to date include: personal experience, trust in science, trust in government, levels of uncertainty (in both climate and non-climate projections), and an individual's worldview (Liere and Dunlap 1980; Slovic 2000; Hamilton et al. 2010; Kahan 2012; Hamilton and Safford 2015; Kettle and Dow 2016; Cutler et al. 2018).

Relationships between physical landscape characteristics and risk perceptions have also been studied in some systems, as have the effects of previous hazard exposures and personal experience on risk perceptions. Exposure, defined by the nature and degree of risk, refers to geographic or physical location and the likelihood of experiencing a threat (Adger 2006; Turner et al. 2010) which could influence risk perceptions (Lujala et al. 2015). For example, US residential risk perceptions of climate change impacts are related to proximity and elevation metrics relative to coastlines (Brody et al. 2008). In the Netherlands, the risk perceptions of farmers in the Netherlands about drought-induced salinization of agricultural fields 'reflect actual drought risk exposure and drought sensitivity'(van Duinen et al. 2015, p. 752). A positive relationship between exposure from previous flooding events and risk perception is also documented by numerous studies (e.g., O'Connor et al. 1999; Kellens et al. 2011; Spence et al. 2011; Mills et al. 2016; Shao et al. 2018). However, there is limited knowledge about whether amplification of climate change hazards could actually motivate behavioral response (see Wolf and Moser 2011).

Rural coastal regions are often overlooked in climate change adaptation discussions (Bhattachan et al. 2018b; Jurjonas and Seekamp 2018). These discussions typically focus on urban areas and beach tourism destinations (VanKoningsveld et al. 2008; Hallegatte and Corfee-Morlot 2011). However, exposure to SLR in rural coastal regions and associated negative impacts to ecosystem services will disproportionately affect rural communities given their compounding social vulnerabilities (Arkema et al. 2013). Further, rural counties with higher levels of poverty may be most vulnerable despite perceiving little threat (Kearney and Bell 2019). Given that there is a strong connection between rural regions and their economic dependence on natural resources (e.g., Leach et al. 1999; Bodin and Crona 2008), rural coastal regions are likely characterized by strong connections between local communities and environmental resources. Moreover, an understanding of risk perception is necessary to develop policies that mitigate climate change risks (Bulla et al. 2017). Given that vulnerabilities to these risks are often correlated with socioeconomic factors (Fothergill and Peek 2004; Kleinosky et al. 2007; Barbier 2015; Hardy et al. 2017; Hardy and Hauer 2018), rural coastal regions may have unique outreach and informational needs (Kearney and Bell 2019; Bhattachan et al. 2018b; Spanger-Siegfried et al. 2017). In North Carolina, such risk perceptions studies have specifically focused on several audiences, including city and county officials (e.g., Bulla et al. 2017), local leaders (e.g., Haywood et al. 2014), critical climate sensitive sectors (e.g., Dow et al. 2013), and adolescents (e.g., Stevenson et al. 2014). However, there is limited understanding of how risk perceptions of residents living in coastal North Carolina relate to saltwater intrusion vulnerability.

To this end, in this study we seek to assess rural residents' perceptions of saltwater intrusion impacts to their property and community by comparing their perceptions with physical landscape characteristics as proxies of risk exposure. We used a survey to evaluate residential perceptions of risk to saltwater intrusion using survey research. To assess exposure, we acquired a broad, spatial snapshot of salinity in major surface water bodies across the study region using discrete water quality measurements. We also used freely available geospatial datasets to determine other physical characteristics of the landscape related to exposure.

2 Methods

2.1 Study area

Approximately 100,000 people live on the 6600 km^2 APP. The peninsula (Fig. 1) is surrounded by shallow estuaries on three sides, including the Albemarle Sound to the north, the Croatan Sound to the east, and the Pamlico Sound to the south. The surrounding waters constitute a micro-tidal, low-salinity estuarine complex separated from the Atlantic Ocean by a chain of barrier islands (Moorhead and Brinson 1995).

In the early twentieth century, farmers and timber companies began clearing, ditching, and draining the APP for commercial agriculture and forestry operations (McMullan et al. 2016). There was, on average, 12.5 km of canals and ditches per square kilometer of land area on the APP after ditching (Heath 1975). The artificial drainages allow saltwater to flow inland during periods of drought (Ardón et al. 2013) and can increase the overall vulnerability of inland landscapes to saltwater intrusion (Manda et al. 2014; Bhattachan et al. 2018a). In this study, we are limiting the discussion of saltwater intrusion to surface water. We define saltwater intrusion as the landward movement of saline water from sea level rise with negative impacts to vegetation communities and biogeochemical cycling (Herbert et al. 2015). A recent study showed that saltwater intrusion may be amplified by human alteration of the landscape including ditching and draining of wetlands (Bhattachan et al. 2018a).

Despite these negative ecological impacts associated with saltwater intrusion, land management activities such as ditching and draining of wetlands for agriculture have persisted for decades in coastal regions (Richardson 1983). On the APP, management activities are accompanied by additional shoreline infrastructure, including sea-walls and dikes

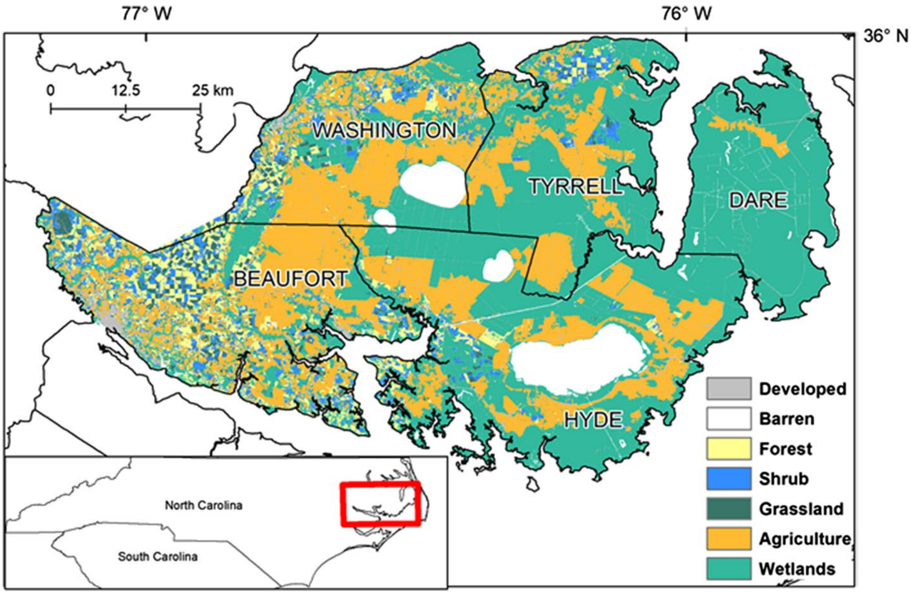

Fig. 1 The Albemarle-Pamlico Peninsula in eastern North Carolina. The land-cover classes are from 2011 and obtained from the National Land Cover Database (NLCD)

to protect residents against storm surge flooding (Poulter et al. 2009). Such efforts have been successful in some cases, including during Hurricane Matthew in October 2016 when a dike protected the community of Swan Quarter, NC (southeast APP) from storm surge flooding (Hampton 2017). However, this infrastructure is expensive and takes a long time to complete. Specifically, the Swan Quarter dike was completed over the course of decades and cost roughly $13 USD million (Hampton 2017).

Because resources are limited, financial considerations are important for discussions about protective infrastructure in rural coastal regions. In comparison with the nearby Outer Banks, the APP generates less revenue and has a weaker tax base, which limits the financing of climate adaptation planning (Jurjonas and Seekamp 2018). The APP also has a lower median household income, higher poverty rates, and highly vulnerable sub-populations (e.g., African-American communities) compared to national averages (US Census Bureau 2010; Jurjonas et al. in review). The lack of attention and resources to this rural coastal region and vulnerability to sea level rise impacts (e.g., Dahl et al. 2017) necessitates a study by comparing residential risk perceptions with physical landscape characteristics of saltwater intrusion.

2.2 Residential survey

We conducted survey research between January and May 2017 as part of a larger study to assess the community resilience to SLR impacts on the APP. Here, we use three statements from the larger survey specifically related to the threat of saltwater intrusion. The questions were measured on a 5-point Likert-type scale anchored between strongly agree, neutral, and strongly disagree, with an unsure option. The statements are listed below (short titles in parentheses):

1. My property is negatively impacted by saltwater intrusion (my property),
2. Saltwater intrusion is a problem in my community (my community now),
3. Saltwater intrusion will be a problem 20 years from now in my community (my community future).

The survey included a general definition of saltwater intrusion and definitions for the spatial extent of community and property. The unsure option was intended to identify residents who may not have sufficient awareness of saltwater intrusion in their property or community. The neutral option is different from the unsure option and was intended to identify residents who are not prepared to make an assessment, likely because they have some awareness of saltwater intrusion but hold mixed (i.e., ambivalent) opinions. We piloted the survey instrument with 50 respondents in two coastal counties located across the Albemarle Sound from the APP. A randomly selected set of 1000 residential addresses, stratified by population across the five counties in the APP, were subject to several waves of a modified drop-off and pickup survey following the procedures outlined by Steele et al. (2001) and Trentelman et al. (2016). Addresses were purchased from a survey sampling company (Survey Sampling International, Inc.).

We mailed a letter to all addresses 2 weeks prior to survey distribution to explain the scope of the project and to inform the 1000 residents of plans to visit them in the near future. We chose a sample size of 1000 addresses because of the limitations with labor and expenses. There was an option in the mailer to fill out the survey online rather than complete a paper version of the survey. Teams of research assistants went to each address to request voluntary participation in the study and, if agreed, provide a paper version of the survey in person. Participants could either arrange for a pickup of the survey or use a provided business reply envelope to return the survey. If there was no one home after two attempts, a survey package was left at the door. We sent a postcard reminder after all surveys were delivered before sending a final replacement of the survey to all addresses that had not yet completed a survey. This modified method of dropping off and picking up was preferred for a higher response rate (Trentelman et al. 2016). Of the 1000 addresses, 114 (11.4%) were undeliverable by the US Postal Service, resulting in a sample population of 886 residential addresses.

2.3 Physical landscape characteristics

We measured specific conductance (μS/cm) and temperature (°C) in June 2016 during a synoptic survey of natural and artificial water bodies on the APP. There was no precipitation on the APP during the synoptic survey or the 24 h beforehand. We identified locations that North Carolina highway network dataset intersected with a dataset of water bodies (both natural drainages such as streams and artificial drainages such as ditches and canals). We then divided the APP into seven geographic zones and assigned each of seven teams a zone containing 20–30 sets of coordinates for locations to measure specific conductance and water temperature. After arriving at a location, the team collected a measurement if the preselected point (bridge intersecting with a canal, ditch, or natural water body) had water to a depth of 0.5 m, was at least 1 m wide, and was a continuous water body for at least 10 m in either direction. We measured specific conductance and temperature with one of several handheld YSI Pro30 probes (YSI Incorporated, Yellow Springs, OH) that had all been calibrated to the same specific conductance standard immediately prior to the survey. During the survey, we measured a total of 198 water bodies. To compare the salinity measured during the synoptic survey, we included data collected at 5 permanent locations across the APP using a conductivity logger (Onset Instruments, Bourne, MA) which measures specific conductance (μS/cm) and temperature in 15-min intervals. We converted specific conductance collected during the synoptic survey and from 5 locations to salinity in parts per thousand of NaCl (Lewis and Perkins 1981).

We estimated the salinity of surface water near each physical address in the residential survey by interpolating the salinity data from the synoptic survey. For this operation, we used the inverse distance weighting interpolation function in ArcGIS (ESRI, Inc., Redlands CA). We assume that surface water salinity at a residential address is likely to be similar to nearby synoptic survey points on any given day. Other landscape variables are elevation, drainage density, and an index to assess saltwater intrusion vulnerability. For ground elevation, we used a digital elevation model (DEM; derived from data from North Carolina Floodplain Mapping Program), with a grid resolution of 6.1 m (vertical accuracy ± 0.13 m). We used the National Hydrography Dataset (NHD) to identify artificial drainages, and drainage density was calculated by using a buffer radius of 1 km (area: 3.14 km^2) at each respondent's address. We calculated the distance to nearest coastline from each address in ArcMap using the coastline dataset developed by the North Carolina Center for Geographic Information and Analysis. We also used results from the saltwater intrusion vulnerability index (SIVI) for the APP, which is a representative of the freshwater pressure against the inland moving saltwater front (Bhattachan et al. 2018a). Thus, we were able to estimate water salinity, ground elevation, drainage density, distance to coastline, and SIVI for each survey location.

2.4 Data analyses

We received a total of 278 completed surveys (31.3% response rate). We aggregated the 'strongly disagree' and 'disagree' to 'disagree' and likewise, 'agree' and 'strongly agree' to 'agree.' The bookend options on the 5-point Likert-type scale (strongly disagree and strongly agree) were aggregated with disagree and agree so that we could compare the physical characteristics of the landscape to either high- or low-risk perceptions. Such aggregation of Likert data has been performed elsewhere (e.g., Flanagan and Anderson 2008; Pidgeon et al. 2008; Alexander et al. 2012; Phillips et al. 2015). We interpret that the 'agree' responses represent the highest risk perception compared to the 'disagree,' 'neutral' and 'unsure' responses. Because there were a few instances of missing data (2 in 'my property' question, 1 each in 'my community now' and 'my community future' questions), we used a mean substitution method to impute those responses. We performed a one-way analysis of variance for responses, and Tukey–Kramer test determined the significant difference in mean values for each parameter between 'disagree,' 'neutral,' 'agree,' and 'unsure' at $p < 0.05$.

We imported the geographic locations of 278 surveyed addresses into ArcGIS, and we applied an inverse distance-weighted interpolation of responses for each question for the entire APP. Because the goal of this study was to assess how physical characteristics of a landscape influence risk perceptions, we assume that the risk exposure for residents close to one another is more alike than those far apart. We selected two transects to compare the survey response between the northern (Albemarle Sound) and southern (Pamlico Sound) coastline on the APP.

3 Results

3.1 Demographic information of residents

Of the total number of survey responses used in the analysis ($n=278$), there were 166 males, 108 females, and 4 ‘no responses,’ or ‘prefer not to say.’ The median age of the respondents was 63 years, and the median individual income was between \$70 k and \$79 k per year. The median individual income of the surveyed residents is far greater than the median household income of approximately \$32 k per year for all APP residents (US Census Bureau 2010). On average, respondents had lived within 50 miles of their current residence for 37 years. In comparison, the respondents were slightly older than the median age of 44 years of APP residents (US Census Bureau 2010). By ethnicity, the responses included 204 white (73%), 32 black or African-American (12%), one Asian, one American Indian or Alaskan Native, and 40 ‘no responses,’ or ‘prefer not to say.’ The racial makeup of the APP is about 62% white and 30% black (US Census Bureau 2010); the substantial number of no response on our survey makes it difficult to evaluate how representative our sample is (in terms of race) compared to the overall population of the region. Our sample is more educated than the general population within the region in the high school graduate or higher category (73%; US Census Bureau 2010) as 10 respondents had some high school, 58 completed high school, 64 reported some college, 33 associate graduates, 54 college graduates, 32 with a master’s degree or higher and 27 ‘no response,’ or ‘prefer not to say.’ One hundred thirty-one respondents reported that they were conservative, 29 reported no political leaning, 29 reported that they were liberal, and 89 ‘no response,’ or ‘prefer not to say.’

3.2 Risk perceptions

About half of the respondents did not perceive saltwater intrusion as a present risk to their property (46% ‘disagree’); however, the percentage of respondents that chose ‘agree’ increased for questions on the threat to the community now and in the future (29% of ‘agree’). While the percentage of respondents that chose ‘disagree’ decreased and ‘agree’ increased, respectively, from question #1 to #3, the percentage of respondents who are ‘neutral’ did not show any trend for all questions (between 23 and 27%, Table 1). The percentage of respondents who are ‘unsure’ also increased from question #1 to #3 (from 16 to 29%). The inverse distance-weighted responses for each question appear in Fig. 1a–c. The

Table 1 The percentage of disagree, neutral, agree, and unsure for each question

Question	Disagree (%)	Neutral (%)	Agree (%)	Unsure (%)
My property	46	23	15	16
My community now	29	27	22	22
My community future	19	23	29	29

warmer colors represent 'agree,' whereas the cooler colors represent 'disagree.' 'Neutral' is represented by white on the color scale. As the percent of respondents who agree with saltwater intrusion as a problem to the community now and in the future increased (Table 1), the heat map also starts to appear warmer (Fig. 2a–c). The two transects (Fig. 1a) are used to extract responses for all three questions, and the probability density function (pdf) of the interpolated responses is shown in Fig. 2d, e. As the entire APP seems to have shifted to agree that saltwater intrusion now and in the future could threaten the community, the pdfs for the two parts of the APP show the contrast between residents' perceptions to saltwater intrusion threats in two different parts of the region. The frequency of residents who agree is higher for questions on threat to 'my community now' and 'my community, future' from saltwater intrusion for the land near the Albemarle Sound than the land near the Pamlico Sound (Fig. 2e, f).

3.3 Salinity on the APP

78% of the synoptic survey locations were in artificial drainages. The average salinity measured during the survey was 1.36 parts per thousand with a standard deviation of 2.75. The average salinity is higher than an earlier estimate of salinity (~0.1 ppt) measured in an inland canal on the APP (Bhattachan et al. 2018b). Laboratory experiments indicate that wetland tree species such as bald cypress found abundantly in this region show signs of salinity stress at 1 ppt (Powell et al. 2016). From the salinity data collected during the synoptic survey and from the 5 permanent locations (Fig. S1, Table S3), we observe higher surface water salinity in the southern part of the APP, which is consistent with historically observed salinities of the Pamlico and Albemarle Sounds (Giese et al. 1985).

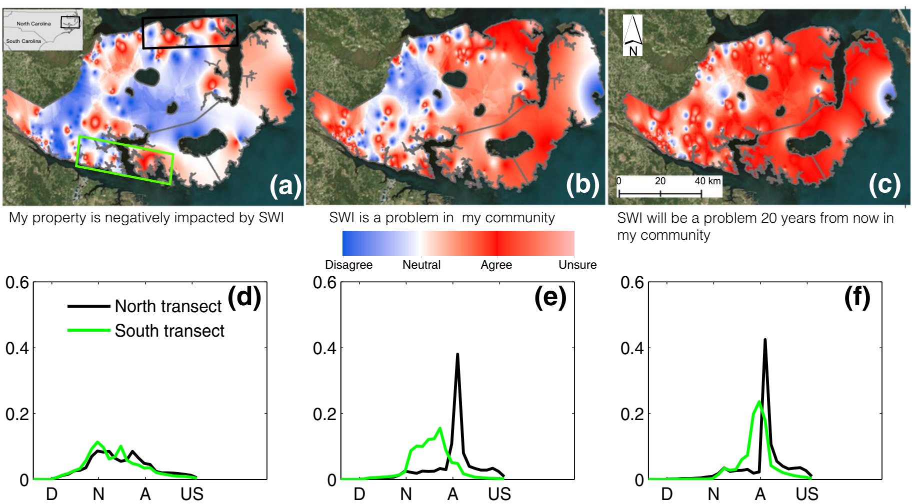

Fig. 2 The interpolated raster from the responses for 'my property,' 'my community now' and 'my community future' questions on saltwater intrusion (SWI) risks (D: disagree, N: neutral, A: agree). The warmer colors represent the response 'agree,' whereas the lighter colors are the 'disagree.' Two transects shown in Fig. 1a were used to extract the responses from each question, and the probability density function of the responses is shown in **d**–**f**

3.4 Relationship between risk perceptions and physical variables

The interquartile range of estimated nearby surface water salinity for the ‘agree’ response is greater than for the ‘disagree’ responses (Fig. 3), which suggests that residents living on properties exposed to higher salinity generally have high-risk perceptions and agree that saltwater intrusion is a threat to their properties. We only focus on the ‘disagree’ and ‘agree’ responses (Tukey–Kramer test showed that ‘neutral’ is not statistically different from either the ‘disagree’ or the ‘agree’ responses at $p < 0.05$) that have significant differences (ANOVA with Tukey–Kramer test of significance at $p < 0.05$), including (a) surface water salinity for the question on saltwater intrusion as a threat to property, (b) elevation and salinity for the questions on the threat of saltwater intrusion to my community now and in the future (Fig. 3, Table S2). In Table S2, we show the maximum, 75th percentile, median, 25th percentile, and minimum values of geospatially generated parameters such as distance to coastline (km), drainage density (m per km^2), elevation (m), salinity (ppt), SIVI (m^{-1}) for each question grouped by survey responses. However, other indicators such as distance to coastline, artificial drainage density, SIVI did not yield significant difference between the ‘disagree’ and ‘agree’ responses (Fig. 3, Table S2).

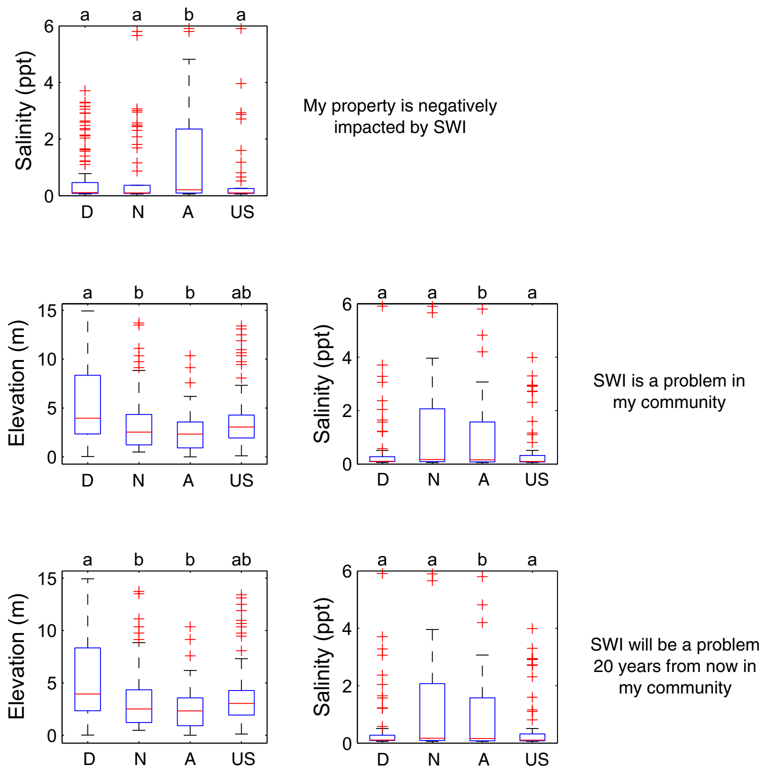

Fig. 3 Boxplots for survey response (D: disagree, N: neutral, A: agree, US: unsure) plotted against inverse distance-weighted salinity of nearby surface waters (parts per thousand) and elevation (m). The significant differences ($p < 0.05$) between the response for each category are shown and indicated by different letters. Saltwater intrusion is denoted by SWI in questions

Residents living at relatively high elevations on the APP disagree or are unsure that saltwater intrusion is a problem in their community, now or in the future (Fig. 3, Table S2). The ‘agree’ responses (high-risk perception) generally came from locations that are currently exposed to higher levels of salinity and are more vulnerable to saltwater intrusion. These responses tend to be associated with residents who live in areas where salinity is higher and the elevation is lower (Fig. 3). Residents who agree that saltwater intrusion is a threat to community in the future (high-risk perception) tend to live on low-lying areas vulnerable to saltwater intrusion.

3.5 Unsure responses

We found that most people who were uncertain about saltwater intrusion tend to have properties or live in communities on the APP with no discernible exposure to the risks of saltwater intrusion. Most of the residents who were uncertain about the risks of saltwater intrusion (99 of 278) lived on land with few natural or artificial water drainages (drainage densities between 0 and 500 m/km^2) and lived at higher elevations (greater than 2 m). Surface drainages located near these residents showed little or no salinity (less than 0.5 ppt) during our synoptic survey (Table S2). Surface water salinity was significantly lower in the vicinity of the unsure respondents than in the vicinity of the sure (disagree, neutral and agree) responses ($p < 0.05$). However, we did not find any significant differences in drainage density (threshold of 500 m/km^2) and elevation (threshold of 2 m) between unsure and sure respondents at $p < 0.05$ level.

4 Discussion

Risk perception is a type of cognitive indictor that links climate change hazards with the motivation to respond and adapt to such environmental changes (Grothmann and Patt 2005). Our survey documents that local risk perceptions on the APP correlate with exposure to saltwater intrusion, as residents who perceive saltwater intrusion as a risk tend to live on the lowest lying lands. With the residential survey and variables generated from physical datasets for those locations, we document the risk perception of the residents on the APP and examine the relationship to physical variables of saltwater intrusion. It is also important to clarify that the risk perception that we document from our survey is grounded on the present-day physical characteristics of the location. However, the relationship between risk perception and saltwater intrusion is assessed between two time frames, saltwater intrusion impacts to property and community in the present and saltwater intrusion impacts to community in 20 years. Therefore, the interpretations and analysis of results are tied to two timeframes and we explain how the physical characteristics of the current landscape could also change in the future and if the risk perceptions align with the future trajectory of environmental changes in this region. The saltwater intrusion risks are driven by sea level rise, regional drought, and land management.

4.1 SLR impacts over time

Drought-driven saltwater intrusion is observed in the freshwater wetlands connected to the slightly ‘fresh’ Albemarle Sound via artificial drainages on the northern APP (Ardón et al. 2013) and could potentially increase the rate of saltwater intrusion in the region. This increase in saltwater intrusion could be temporarily beneficial to some residents, especially fishers, on the APP as it provides habitat to valuable species that thrive in brackish waters. However, the economic impacts of SLR and saltwater intrusion will be negative as agriculture and forestry are major industries in the region (McMullan et al. 2016; Bhattachan et al. 2018a). The risk of saltwater intrusion will continue to increase as sea level rises with greater incidence of storm surge flooding imminent in coastal North Carolina (e.g., Kopp et al. 2015). While properties with higher elevation land and lower drainage density could have led to uncertainty of risk perceptions, North Carolina actually experienced accelerated SLR during the twentieth century (Kemp et al. 2009). Moreover, the physical impacts of SLR will have direct and indirect socioeconomic impacts (property loss, beach erosion, displacement, agricultural abandonment) to the coastal communities (Nicholls et al. 2007), such as those on the APP where expected impacts are overwhelmingly negative.

Given the large number of respondents with uncertain risk perception, future research is warranted to identify at what point risk perception would become high enough to motivate and support a more mainstreamed and publicly supported climate change adaptation planning strategy. Residents are less concerned about current SLR risks when they perceive sea level rise impacts as ‘invisible or distant’ instead of a visible reality (Covi and Kain 2016). Here we found that, beyond trust in science or political ideology, the reality may be that residents only perceive risk when the danger is at their doorstep. We argue that physical exposure to climate change threats (represented by physical variables) may serve as baseline measures and a guiding tool to design future research to study climate change risk perceptions and actual behavioral responses (implementation of adaptation measures on properties) within coastal communities such as the APP. Future research should also consider physical risk exposure in combination with other studied psychological predictors, such as those included in Grothmann and Patt’s (2005) process model of private proactive adaptation to climate change (MPPACC), to develop a more holistic understanding of actual and perceived saltwater intrusion risks and adaptive responses.

4.2 Improving societal resilience

On the APP, residential risk perceptions align with the physical variables; specifically, we show how lack of exposure to residential properties and communities on higher elevations with lower salinity is related to either a lack of perceived risk or uncertainty in residents’ risk perceptions. The effect of periodic droughts on increasing the upland reach of saltwater intrusion (e.g., Ardón et al. 2013) and intensification of land-use activities (e.g., Hackney and Yelverton 1990; Manda et al. 2014) may expose the currently protected residents to the risk of saltwater intrusion and, therefore, influence their risk perceptions in the future. Previous research has shown that perceived risk is an important criterion in motivating action toward climate change adaptation (e.g., O’Connor et al. 1999; Zahran et al. 2008; Wolf and Moser 2011), and there is some evidence that even though risk perception could be high, there are other related factors such as the lack of consensus among policymakers in formulating long-term adaptation plans (e.g., Yusuf et al. 2014). Despite the current state of contention between the policymakers, Wolf and Moser (2011) suggested that ordinary citizens generally are ready to act on climate change adaptation if policymakers would cooperate to build consensus.

Given the forecasted SLR and pending impacts in North Carolina (Kopp et al. 2015; Hauer et al. 2016), outreach activities that target areas not yet exposed to risks of saltwater intrusion but projected to experience impacts in the future may be the most effective target to improve climate resilience by allowing the timely adoption of management practices. The adaptation plans to improve climate resilience should consider both modest and extreme sea level rise projections and should be more anticipatory in nature (Nicholls 2011). When considering broader implications of our study, it is important to note that Americans as a whole perceive global climate change as a moderate risk and not an imminent threat (Leiserowitz 2005). Additionally, given that rural counties in the southeast US (like the APP) with high levels of poverty are even less likely to perceive climate change as a threat compared to national averages, pose an even greater outreach challenge (Kearney and Bell 2019). Some have suggested that public education and outreach play an important role in overcoming climate change skepticism (e.g., Stevenson et al. 2014) and facilitating and strengthening support of climate change adaptation (Moser et al. 2012; Dow et al. 2013). Because local-level initiatives are sometimes acknowledged as quick fixes (e.g., Lorenzoni and Pidgeon 2006), the support of state and federal agencies is crucial to ensure the long-term success of the adaptation plans (Allen et al. 2018). It is also necessary to provide information early to residents before saltwater intrusion risks become obvious (Covi and Kain 2016; Bostick et al. 2017) to encourage implementation of adaptation plans. However, as APP residents agree that the risk of saltwater intrusion to their community in the future will increase, which is also consistent with sea level rise projections for this region, the motivation for action is likely building up in the grassroots level.

4.3 Proximity to coastline

Despite the hypothesis that proximity and/or exposure to hazards influences risk perception, the current evidence is limited (Spence et al. 2011) and mixed (confirming studies: Brody et al. 2008; Whitmarsh 2008; disconfirming studies: Zahran et al. 2006; Dessai and Sims 2010). In the context of inundation risk from SLR, Zahran et al.'s (2006) study found that residents living within 1 mile of the coastline and in areas of low elevation were less likely to support climate change adaptation initiatives led by the government. Brody et al. (2008) suggested that these residents within 1 mile of the coast tend to have high-risk perception of sea level rise impacts. The dependence of residential risk perception on proximity to other potential hazards is demonstrated in other studies; for example, Gawande and Jenkins-Smith (2001) found that distance from the route used to ship radioactive nuclear waste in South Carolina drove perceptions of risk among residents and distance from the nearest creek influenced risk perception of residents to flooding (Brody et al. 2004). It is plausible that the extensive network of drainages in the APP could have influenced the lack of significant relationship between distance to coastline and risk perception. Thus, it is quite likely that even though distance to coastline does not significantly affect the risk perception, increased exposure to saltwater intrusion in the future could influence risk perceptions.

4.4 Other considerations

The 18-mile dike (Fig. S1b) constructed in Swan Quarter in Hyde County (near Pamlico Sound) has protected the residents against the risk of flooding since 2009 (NRCS 2009; Hampton 2017; Jonsson 2018). The motivation for its construction was not only to mitigate hurricane and flood impacts but also reduce saltwater intrusion impacts (NRCS 2009). It is likely that this barrier could have contributed to the general lack of perceived saltwater intrusion risks documented in the southern part of our study region even though salinity in the Pamlico Sound is higher than the Albemarle Sound. Low-saltwater intrusion risk perceptions in Hyde County may then actually be a result of reduced exposure from the dike project, as the northern part of the APP does not have major infrastructure to protect against flooding and saltwater intrusion, which could potentially explain why risk perception there is higher (Fig. 2). Regardless, the risk of saltwater intrusion during flooding in the southern part of the APP, at least in the near future, seems latent due to current infrastructure. Although unexplored in our study as discrete components of the landscape, future research could explore if protective infrastructure, such as the dike in Swan Quarter, contributes to a sense of security that leads to no perceived risk of saltwater intrusion among residents.

A recent study that has placed residents of Hyde County, which includes Swan Quarter, and Tyrell County as the most-at-risk population from sea level rise within the USA (Hauer et al. 2016) is concerning given our findings of limited risk among residents. Moreover, the installation and maintenance of dikes and tide gates (see Fig. S1c) along the entire coastline on the APP not only creates a logistical and financial challenge for city and county managers (Poulter et al. 2008) but also diverts the surging water, ultimately allowing water to travel farther inland elsewhere and amplifying the impact of flooding and erosion in less protected inland sections of the region (Neal et al. 2017). As such, longitudinal studies that consider the presence and absence of such infrastructure are needed to document the relationships between changing salinization exposure and perceptions of risks.

5 Conclusions

Understanding risk perceptions of rural coastal communities in relation to actual climate change risks is important given SLR projections; yet, rural communities receive less attention in both resilience research and adaptation planning efforts. Research efforts that demonstrate the growing exposure and vulnerability of rural coastal residents like those living on the APP could help create greater accountability within the state legislature. To address this research gap, we conducted a residential survey in a rural coastal region in eastern North Carolina to document the risk perception of the residents of saltwater intrusion as a threat to their property and community, now and in 20 years. We then investigated the relationship between risk perceptions and physical characteristics of the coastal landscape that influence exposure to saltwater intrusion risks. We found that physical variables such as drainage density, salinity, elevation, and saltwater intrusion vulnerability index serve as useful indicators to gauge risk perception. Although residential risk perceptions align with the physical variables, protective infrastructure may reduce perceived risk.

The implications of this study are not limited to coastal North Carolina, as human activity along the US coast has led to environmental consequences like increased erosion and flooding (Scavia et al. 2002), and climate change can impact the economic integrity of coastal rural communities with natural resource dependent livelihoods (Poulter et al. 2009). Likewise, the cost of protecting the coastal population against SLR will be substantial in the future (Nicholls 2011; Arkema et al. 2013). Community engagement to communicate the impacts of SLR and saltwater intrusion to the local public may amplify the risk perception and strengthen long-term adaptation solutions in rural coastal areas such as the APP (Jurjonas and Seekamp 2018). Our findings can help researchers, managers, and communities in fostering outreach efforts for SLR and saltwater intrusion by linking climate adaptation planning needs to local perceptions, thereby enhancing societal adaptation to SLR and saltwater intrusion.

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Affiliations

Abinash Bhattachan[1,2] · Matthew D. Jurjonas[3] · Priscilla R. Morris[4] · Paul J. Taillie[1] · Lindsey S. Smart[1,2] · Ryan E. Emanuel[1,2] · Erin L. Seekamp[3]

1 Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, USA

2 Center for Geospatial Analytics, North Carolina State University, Raleigh, USA

3 Department of Parks, Recreation, and Tourism Management, North Carolina State University, Raleigh, USA

4 Department of Forest Biomaterials, North Carolina State University, Raleigh, USA