Disaster Exposure and Migration: The Impact of Major and Minor Flood Events on Population Loss

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Sea level rise and an increased propensity for major precipitation events due to climate change are expected to drive a dramatic reduction in the availability of habitable land and induce population migrations away from vulnerable areas (Allen et al. 2018; R. A. McLeman 2011). However, there is little understanding of how changing risk exposure influences individual decisions to relocate or the thresholds at which these decisions are made (Black, Adger, and Arnell 2013; Bardsley and Hugo 2010). In this paper, we seek to understand how different aspects of environmental risk interact to impact relocation decisions. More specifically, we ask: how does physical vulnerability to flooding and exposure to major storm events influence population change over time in relationship to geographical conditions?

To explore this question our study examines population change from 1990 to 2010 in North Carolina, using census tract-level decennial census data. Our three key explanatory variables are: (1) exposure to major storm and flooding events, (2) flood vulnerability, and (3) the geographic setting in regards to coastal or inland locations. Exposure to disasters is quantified by the Major Disaster Declarations due to floods or storms as recorded by the Federal Emergency Management Agency (FEMA) (Federal Emergency Management Agency 2018). Flood vulnerability was constructed in a multi-step process that estimates vulnerability at the census tract-level. This was developed by mapping Microsoft's U.S. Building Footprints dataset (Microsoft Corporation 2018) to 2010 census tracts and overlaying it with the National Flood Insurance Program (NFIP) flood hazard maps (North Carolina State Government 2019). This contextualized the data by its geopolitical boundaries and vulnerability to flooding. For our study, we prioritized areas located within the 100-year flood plain, which are defined as high risk. Finally, to study the geographic setting, we performed a spatial analysis to determine whether or not census tracts were primarily coastal rather than landlocked or riverine based.

To control for other factors that would influence this analysis, we added a variety of socio-economic variables. These were selected based on an extensive review of the literature and have been consistently used in studies designed to control for the influence of existing conditions when establishing the impact of vulnerability and disasters (Cutter, Boruff, and Shirley 2003). To construct the socio-economic variables, we used data from the U.S. Census Bureau for 1980, 1990, 2000, and 2010. All data was normalized using 2010 census boundaries through Social Explorer and Brown University's Longitudinal Tract Data Base (U.S. Census Bureau 2019; Spatial Structres in the Social Sciences 2018).

			Hazazrds and Vulnerability: Impact on Pop. % Change 1990 - 2000			
Table 1	*c*	*t*	**Model 1A**	**Model 1B**	**Model 1C**	**Model 1D**
Base Variables						
Disasters (1990 - 1999)	•		-0.148 **	-0.167 **	-0.114	-0.147 *
% High Risk		•	-1.463 **	-2.983 *	-4.724 ***	-1.463 **
Coastal		•	-0.275	-0.252	-1.266 ***	-0.241
Interaction Terms						
Disasters & % High Risk	•	•	-	0.411	-	-
% High Risk & Coastal		•	-	-	6.504 ***	-
Coastal & Disasters	•	•	-	-	-	-0.011
Socio-Economic Variables						
Pop. % Change (1980 - 1990)	•		0.048 ***	0.047 ***	0.048 ***	0.048 ***
Housing Value (1990)		•	0.000 ***	0.000 ***	0.000 ***	0.000 ***
Diversity Index (1990)		•	1.239 ***	1.263 ***	1.263 ***	1.237 ***
Median Income (1990)		•	0.000 ***	0.000 ***	0.000 ***	0.000 ***
% Unemployment (1990)		•	-9.911 ***	-9.770 ***	-8.309 ***	-9.923 ***
% Urban (1990)		•	-0.707 ***	-0.700 ***	-0.736 ***	-0.707 ***
% w/ College Degree (1990)		•	1.037	0.998	1.157	1.037
% Vacant (1990)		•	5.115 ***	5.148 ***	4.686 ***	5.113 ***
% Owner Occupied (1990)		•	4.863 ***	4.867 ***	4.850 ***	4.860 ***
% 18 or Younger (1990)		•	3.945 **	3.880 **	4.189 **	3.942 **
% 60 or Older (1990)		•	-3.554 ***	-3.607 ***	-3.304 ***	-3.555 ***
Constant			-1.496 **	-1.461 **	-1.606 **	-1.495 **
Data Information						
Wald Chi2			1249.23	1248.47	1290.91	1249.65
Observations (Census Tract)		•	2,178	2,178	2,178	2,178
Groups (County)	•		100	100	100	100

****p < 0.01, **p < 0.05, *p < 0.10 • c = county, t = tract*

Table 2	*c*	*t*	**Model 2A**	**Model 2B**	**Model 2C**	**Model 2D**
			Hazazrds and Vulnerability: Impact on Pop. % Change 2000 - 2010			
Explanatory Variables						
Disasters (2000 - 2009)	•		-0.020	-0.055	-0.009	-0.042
% High Risk		•	-6.295 ***	-7.778 *	-0.579	-6.363 ***
Coastal		•	-0.828	-0.792	0.684	-1.342
Interaction Terms						
Disasters & % High Risk	•	•	-	1.474	-	-
% High Risk & Coastal		•	-	-	-11.768 ***	-
Coastal & Disasters	•	•	-	-	-	0.689
Socio-Economic Variables						
Pop. % Change (1990 - 2000)	•		0.036 ***	0.036 ***	0.039 ***	0.036 ***
Housing Value (2000)		•	0.000 **	0.000 **	0.000 **	0.000 **
Diversity Index (2000)		•	0.210	0.208	0.087	0.195
Median Income (2000)		•	0.000 ***	0.000 ***	0.000 ***	0.000 ***
% Unemployment (2000)		•	-7.113 **	-7.175 **	-8.083 **	-7.019 *
% Urban (2000)		•	0.703	0.720	0.826	0.718
% w/ College Degree (2000)		•	0.206	0.095	-0.185	0.110
% Vacant (2000)		•	7.193 ***	7.220 ***	7.669 ***	7.142 ***
% Owner Occupied (2000)		•	4.906 ***	4.915 ***	5.068 ***	4.927 ***
% 18 or Younger (2000)		•	-3.489	-3.646	-4.203	-3.596
% 60 or Older (2000)		•	-9.605 ***	-9.686 ***	-10.139 ***	-9.652 ***
Constant			-0.892	-0.834	-0.977	-0.864
Data Information						
Wald Chi2			169.41	169.55	184.28	169.65
Observations (Census Tract)		•	2,178	2,178	2,178	2,178
Groups (County)	•		100	100	100	100

****p < 0.01, **p < 0.05, *p < 0.10 • c = county, t = tract*

Our models looked at the relationship between the explanatory variables of interest across two decades. The results are shown in Table 1 and Table 2 (above). Table 1 looks at population change from 1990 to 2000. Table 2 looks at the population change from 2000 to 2010. Both are broken into models A, B, C, and D, which consider the influence of the main explanatory variables controlled for socio-economic factors in distinct ways. Model A treats these variables independently, while Models B – D use interaction terms that are designed to explore the relationships between the explanatory variables of interest. Together, these results show that high-risk areas face population loss, the conceptualization around coastal areas is changing, and the influence of disasters vary based on their severity.

In Table 1 (1990 – 2000), we see that both the number of disaster declarations and the percent of the buildings within high risk flood zones are significant at the 95th confidence level in Model 1A. These effects vary somewhat when interactions terms are considered in Models 1B – 1D, but remain consistently impactful with a negative influence on population change, indicating population loss. In Model 1B, disasters and high risk geography are interacted, but fail to be significant, while the residual effects of these variables on their own continue to be significant with negative coefficients. This shows that, although the impacts of disasters can lead to population loss and that census tracts with high levels of vulnerability are losing population compared to similar tracts with less vulnerability, the relationship between the two is not the driving factor. In other words, the evidence **does not** suggest that disasters act as "focusing events" for individuals and households in which residents become more cognizant of pre-existing vulnerabilities and more willing to relocate. Rather, their influence is more effective when considered independently. This flies in the face of both our initial results, which did not yet include controls for all socio-economic factors, and some existing literature, which has suggested that disasters could highlight vulnerabilities and lead to population shifts (Birkland 1997).

Second, Table 1 gives insight into the variation that we see in the importance of coastal conditions. When considered on its own (Model 1A), or when interacted with hurricanes (Model 1D), coastal conditions remain insignificant. However, when interacted with highly vulnerable areas (Model 1C), the population impact is actually positive, whereas the residual impact of coastal areas **not** interacted with high risk areas is negative. This indicates that people seemed to prefer high risk areas if they were coastal. We believe that this is a reflection of housing market influences, where coastal areas are considered highly desirable irrespective of risk. Simply put, people like beach front property.

This is not a condition that holds true in the following decade (2000 – 2010). In analyzing Table 2, Model 2C, we can see that this influence flipped, and that population declined for the interaction of high risk and coastal areas. We believe that it is possible that this reflects the rising profile of climate change, which may drive down the desirability of coastal communities that are at risk. However, we must also acknowledge that the decade from 2000 to 2010 was complicated, with a major boom and bust in housing market that led to a major recession. These external forces further complicate the narrative and require further investigation that cannot be covered in the scope of this paper.

Another area where the tables differ across the decades is in the significance of hurricane events. In 1990 to 1999 there were seven named storms that resulted in disaster declarations for at least some counties in North Carolina. This includes Hurricanes Fran in 1996 and Floyd in 1999, two of the worst storms in the state's history. While the geographic span of the disaster declarations varied, the hardest hit counties had five disaster declarations in their jurisdiction during this period. In contrast, the following decade was much quieter. There were only four named storms that led to disaster declarations, and the hardest hit counties had two disaster declarations over this period. Therefore, the most logical reason for the decline in significance for disaster declarations is that the disasters became less common and severe. This also explains why the Wald Chi statistic drops from Table 1 to Table 2.

The change in model fit mirrors the changing intensity and density of storm events, which lends credibility to the concept of threshold events leading to precipitous settlement abandonment. This theory holds that as conditions change, communities will invest in *in situ* adaptation strategies, which, in the case of storms and floods, may include elevating their homes, building protective levees, etc. However, if those fail or prove to be ineffective, then storms may trigger settlement abandonment. The differences from Table 1 to Table 2 suggests that multiple events can push communities to these threshold conditions where they abandon their homes and communities in preference of more resilient settlements (R. McLeman 2017). This is reflected in anecdotal information provided by town managers in the aftermath of the paired events of Hurricane Matthew in 2016, which was rapidly followed by Hurricane Florence in 2018. We have heard from a number of towns impacted by both of these events that they are now considering more dramatic managed retreat options, including the dissolution of town charters and the discontinuation of municipal services, in the face of rising costs. On the individual level, town managers are seeing a number of residents who selected demo-rebuild or elevation options through FEMA's Hazard Mitigation Grant Program, which was initiated post-Hurricane Matthew (but which was not implemented before Hurricane Florence) that are now switching their project type to buyout so that they might move elsewhere.

In conclusion, this paper used a multi-level regression and spatial-temporal analysis to examine the interaction between the exposure to major hazard events, pre-existing conditions of high vulnerability, and geographic conditions. From this research, we have three main findings. First, the existence of conditions of high-vulnerability within the 100-year flood plain is significantly correlated with population loss. This indicates that, in aggregate, individuals within these zones are aware of their risk and are interested in mitigating it via relocation. Second, the awareness of this risk is not dependent on the **realization** of this risk, as expressed by exposure to major disaster events. However, the repetition of major disaster events may push communities towards tipping points where their pre-existing settlements are no longer considered viable. As climate change conditions becomes increasingly dire, and as people have a greater awareness of the associated risk through an increase focus at local and national levels, we expect to see this increasingly leading to non-linear population loss and the dissolution of existing municipalities. As noted in the previous paragraph, through other research projects involving conversations with planners and city officials in municipalities across the state, this possibility is starting to be realized. Third, the relationship between hazards and coastal conditions is complicated. Coastal areas have faced increased development and rising housing values. However, the change in the polarity of the effect coefficient for this variable indicates that we may be reaching an increased awareness of the dangers and risks inherent to coastal living.

The implication of this is that population change is coming. If we fail to plan for these patterns, a number of social and environmental problems will arise and increase existing disparities, at high cost to all parties involved. Previous relocation programs have frequently involved great investment and marginal gains. Studies have shown that many buyout programs enacted in the United States "have found displacement to be associated with a range of social costs including losses in homeownership, social networks, access to healthcare, employment, income, and physical and mental health" (Binder and Greer 2016, 97). Time and again, rushed programs have shown a failure to support the participants by severing their community connections and failing to ensure resettlement in areas with greater resiliency. Major population shifts have been a part of our past, are a problem of our present, and will become a crisis in the future without proper planning. This provides some early empirical evidence as to how these shifts will play out and what areas are at the greatest risk of population loss. Additionally, this provides a foundation for future studies to help further define the areas that most need planning and support.

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