COASTAL VERSUS INLAND HURRICANE EVACUATION BEHAVIOR ANALYSIS

by

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HURRICANE EVACUATION

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ABSTRACT

This research investigates the evacuation behavior of coastal and inland populations, with inland areas defined as counties that do not touch the coast. Differences in evacuation decisions and the reasons for those differences are investigated in this work. The study is based on data from a web-based survey deployed after Hurricanes Florence and Michael in 2018 and Hurricanes Barry and Dorian in 2019. The results show that there is a difference in rates of evacuations between the two populations, but no conclusive difference in evacuation timing across storms. The results also suggest that inland populations are less aware of and responsive to orders as well as less concerned about the physical impact of a hurricane, implying that a different method of information dissemination may be necessary in inland counties in order to effectively convey the need to evacuate for a hurricane.

Chapter 1

INTRODUCTION

Hurricanes are typically considered coastal phenomena, but they cause many hazards inland as well, including strong winds, rain, and flooding. As more is being learned about inland effects of hurricanes, it is important to keep inland populations safe. Preliminary qualitative work suggests that evacuation behavior of inland populations may differ from that of coastal populations. If that is the case, better understanding of how inland populations respond to hurricanes and evacuation orders could allow more effective methods of warning and evacuation in the future, potentially saving lives.

The purpose of this research is to compare evacuation behavior among coastal and inland people and determine if there is a fundamental difference between the two. For the purposes of this research, inland is defined as being in a county that does not touch the coast. This study utilizes survey data collected after four hurricanes in the 2018 and 2019 hurricane seasons: Florence, Michael, Barry, and Dorian. Two research questions are addressed in this report: (RQ1) Does evacuation behavior differ between coastal and inland populations, and if so, in what way? (RQ2) What factors can explain the difference in coastal and inland behavior?

This thesis proceeds as follows: Chapter 2 is a literature review, Chapter 3 provides a description of the data collection methods and data, Chapter 4 summarizes survey results and discusses the responses to each of the research questions, and

Chapter 5 contains the conclusions drawn from these results and implications for future research.

Chapter 2

LITERATURE REVIEW

A significant amount of research exists regarding hurricane evacuation behavior, but none that explicitly compares coastal and inland behaviors in this way. In this work, inland is defined as being from a county that does not touch the coast; in other studies inland is used differently and may describe populations within coastal counties. In four research summaries of hypothetical and real scenarios, no studies make conclusions about inland evacuation behavior (Baker, 1991; Dash and Gladwin, 2007; Sorensen, 2000; Thompson et al., 2017). Sorensen (2000) mentions proximity to threat and Thompson et al. (2017) cites two studies, which appear to use the same data set, with "greater sampling weights in coastal counties," implying that it includes inland counties, but none of its conclusions relate to location. In addition, Thompson et al. (2017, p. 827) cites Huang et al. (2012) mentioning coastal location as a factor in predicting "perceived storm characteristics," but that research does not include any data from inland counties. These four summaries cover a wide range and large number of studies, none of which have gone in-depth into inland evacuation behavior. A study by Matyas et al. (2011) finds that coastal tourists are more likely to evacuate than inland tourists, using two Florida counties, Pinellas (on the coast) and Orange (inland), based on a stated preference survey. The study suggests that a lower risk perception may be the reason for the lower inland evacuation intent, though this was not supported by the statistical analysis. This introduces questions for research on coastal and inland evacuation behavior, which have not been addressed by other works.

Many studies only refer to coastal risks, and do not include any data from inland counties (e.g., Arlikatti et al., 2006; Baker, 1979; Karaye et al., 2019). Some studies have data from inland counties, but do not include location as a variable or compare results between coastal and inland counties (Cahyanto et al., 2014; DeYoung et al., 2016; Kyne and Donner, 2018; Meyer et al., 2018; Stein et al., 2010). In addition, some studies have included distance to coast or other bodies of water as a variable, mostly concluding that being closer to the coast increases probability of evacuation (Huang et al., 2017; Lindell et al., 2005; Lindell and Prater, 2007; Mei, 2002; Yang et al., 2016; Yin et al., 2016). Though not all studies are explicit in defining what distance that is from the coast, Mei (2002) separates within 1 mile of the coast and farther than 1 mile, and Yin et al. (2016) normalizes based on the farthest distance, which appears to be less than 30 kilometers from the coast. Cutter et al. (2011, p. 34) mentions that "evacuation intent diminishes farther from the coast," but does not include any inland counties. Contrarily, Huang et al. (2012) found that perceived storm characteristics increase with distance from the coast, again only with data from coastal counties. Similarly, Xu et al. (2016) determined that location is significant with a lower probability of evacuation closer to the coast. These studies do not all draw the same conclusions, nor do they cover a wide array of hurricane events or geographic areas, but they suggest that coastal, and therefore inland, location has a role in evacuation behavior.

Another variable relating to coastal and inland location is risk area. Risk areas are typically ordered from highest to lowest risk, moving inland and away from low-lying areas. Huang et al. (2017) uses risk as a proxy for closeness to the coast, partially supporting the hypothesis that risk area relates to probability of evacuation. Lindell

and Prater (2007) also use risk area as a variable, concluding that inland populations are less likely to evacuate, will evacuate later, and will take less time to prepare for evacuation. Kyne and Donner (2018) consider two coastal and two inland counties along the Rio Grande, but risk area accounts for flooding, and the coastal and inland counties are not compared. In another study, ASCE 7-98 wind risk zones are used as a variable. Location was found to be "the most important factor determining risk perception," and those risk zones generally follow the contour of the state of Florida, at intervals moving inland (Peacock et al., 2004, p. 131).

While evacuation orders are issued differently in every state, they are generally given by county or evacuation zone within a county. Even with additional subdivisions, knowing differences between coastal and inland behavior and response will allow emergency managers and other public officials to distribute more effective orders. Past studies that mention inland areas often do not refer specifically to inland counties, and that "inland" classification is not well-defined. For example, Lindell and Prater (2007) draw a conclusion about inland behavior, but it is unclear if any inland counties are included in the study. Any differences in behavior based on their location were therefore overlooked, and all respondents are being treated the same no matter their location. This study aims to address that research gap by explicitly including inland counties and comparing their evacuation behavior to that of coastal populations, as well as using data from four different hurricanes in different regions of the U.S. to find consistently applicable differences.

Chapter 3

DATA

This study uses data from four surveys, which is summarized in the following chapter. First, the four hurricanes are described in the Summary of Events, and the method and timing of distributing the survey as well as the response timing is described in Survey Deployment. The Survey Content section describes the questions included in the survey and changes made to the surveys between hurricanes. The Post-Processing section explains how the data was handled and categorized to be used for the study. Finally, the demographic summary of respondents and a comparison to the population demographics is in the Data Summary.

Summary of Events

The survey used for these case studies was deployed after four hurricanes in 2018 and 2019: Florence, Michael, Barry, and Dorian. These events cover a variety of geographic areas and represent various storm intensities, timings, and characteristics (Table 1). This variety of circumstances strengthens the analysis and applicability of the study, allowing some examination of the generalizability of conclusions.

The four storms impacted different portions of the United States, as well. Both Hurricanes Michael (2018) and Barry (2019) formed in the Gulf of Mexico, whereas Hurricanes Florence (2018) and Dorian (2019) impacted the Atlantic coast. Figure 1 shows the hurricane tracks along with locations of survey respondents for each event,

by zip code area. Those coded as “multiple” for hurricane means that there were responses related to more than one hurricane from the same zip code.

Table 1 Summary of Hurricanes used in study

Hurricane	***Florence***[1]	***Michael***[2]	***Barry***[3]	***Dorian***[4]
Date of Formation	31-Aug-18	7-Oct-18	11-Jul-19	24-Aug-19
Date of Landfall	14-Sep-18	10-Oct-18	13-Jul-19	6-Sep-19
Date of Dissipation	18-Sep-18	15-Oct-18	15-Jul-19	10-Sep-19
Landfall Location	Southeastern NC	FL Panhandle	South-central LA	Cape Hatteras, NC
Max. Category	Cat. 4	Cat. 5	Cat. 1	Cat. 5
Category at Landfall	Cat. 1	Cat. 5	Cat. 1	Cat. 1
Monetary Damages (in the US)	$24 billion	$25 billion	$600 million	Unknown[5]
Fatalities (in the US)	22 + 30 indirect	16 + 43 indirect	0	Unknown[5]
Power Outages (in the US)	1.1 million	1.5 million[6]	300,000	190,000 in NC

[1] Stewart, S. R., & Berg, R. (2019). *Hurricane Florence*. National Hurricane Center. Retrieved from https://www.nhc.noaa.gov/data/tcr/AL062018_Florence.pdf

[2] II, J. L. B., Berg, R., & Hagen, A. (2019). *Hurricane Michael*. National Hurricane Center. Retrieved from https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf

[3] Cangialosi, J. P., Hagen, A. B., & Berg, R. (2019). *Hurricane Barry*. National Hurricane Center. Retrieved from https://www.nhc.noaa.gov/data/tcr/AL022019_Barry.pdf

[4] National Weather Service. Hurricane Dorian - September 6, 2019. Retrieved from https://www.weather.gov/mhx/Dorian2019

[5] National Hurricane Center Tropical Cyclone Report not published for Hurricane Dorian as of February 6, 2020.

[6] Breslin, S. (2018). Hurricane Michael's Staggering Power Loss Documented by NASA. Retrieved from https://weather.com/news/news/2018-10-17-hurricane-michael-power-outages-nasa

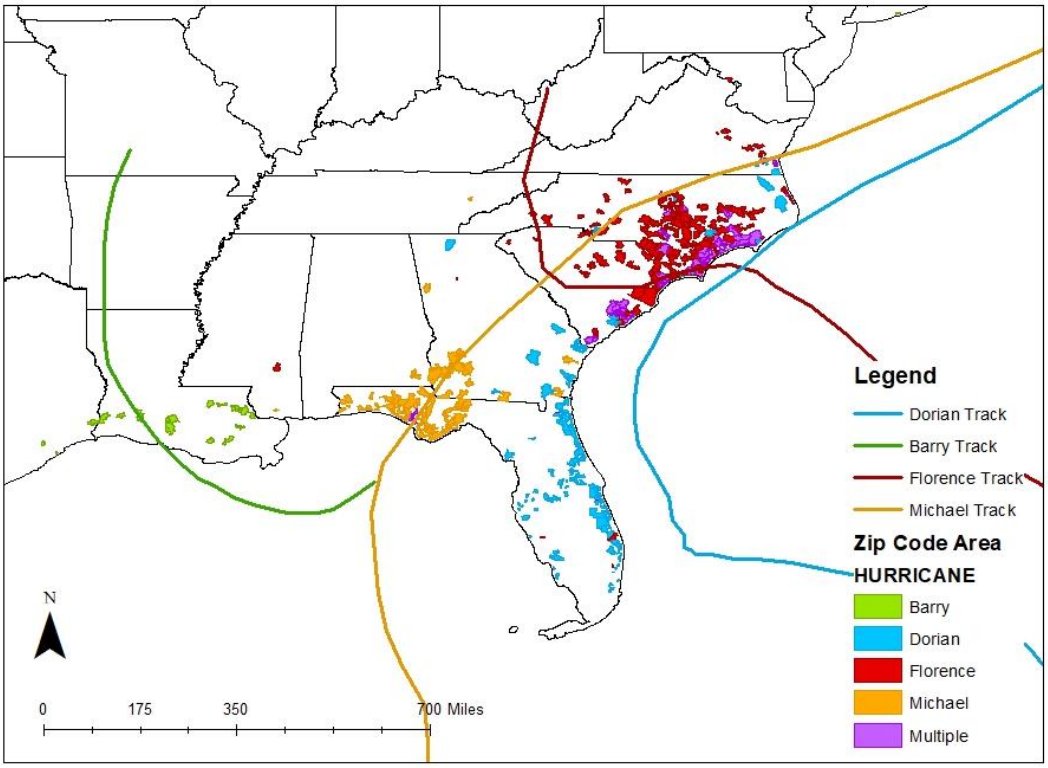

Figure 1 Respondent Locations and Hurricane Tracks

Survey Deployment

The data for this study was collected through a web-based survey coded in Qualtrics. The survey was distributed on Facebook and Reddit. Relevant groups and pages were chosen that focused on the specific hurricane, general hurricane-watch pages, or specific to the affected area. Some examples from Hurricane Florence are the Facebook page “Hurricane Florence 2018 Eastern NC” and Reddit pages “Hurricane Florence” and “Myrtle Beach.” Members of the research team joined the groups, requested access to post when necessary, and posted a link to the survey with an explanation of the study on each page. The link could be used by anyone, so it was sharable once deployed. One to two weeks after the initial posting, a comment was

added to most posts to push them to the top of the page and inform potential respondents of the date the survey would close. A few circumstances occurred where the post was removed from the page or asked to be removed, with which we complied, or commenting was closed by the administrator so it could not be boosted.

Each survey was deployed within one week of landfall (Table 2) to collect data while respondents could still recall details about the event and the timing of their evacuation or knowledge of orders. Although each survey was open for approximately one month, most responses for all of the surveys except Michael were received in the first week (Figure 2). Responses in Hurricane Michael were most affected by boosting the posts with comments, as they had another spike in responses after about two weeks. The ability to obtain quick responses is a benefit of the web-based survey deployment method, as people have a more accurate memory of an event soon afterwards.

Table 2 Summary of Survey Deployment Timing

Hurricane	***Landfall***	***First Post***	***Date Closed***	***Days After Landfall***	***Days Open***	***Responses***
Florence	14-Sep-18	19-Sep-18	15-Oct-18	5	26	1421
Michael	10-Oct-18	17-Oct-18	27-Nov-18	7	41	443
Barry	13-Jul-19	17-Jul-19	27-Aug-19	4	41	38
Dorian	6-Sep-19	7-Sep-19	7-Oct-19	1	30	512

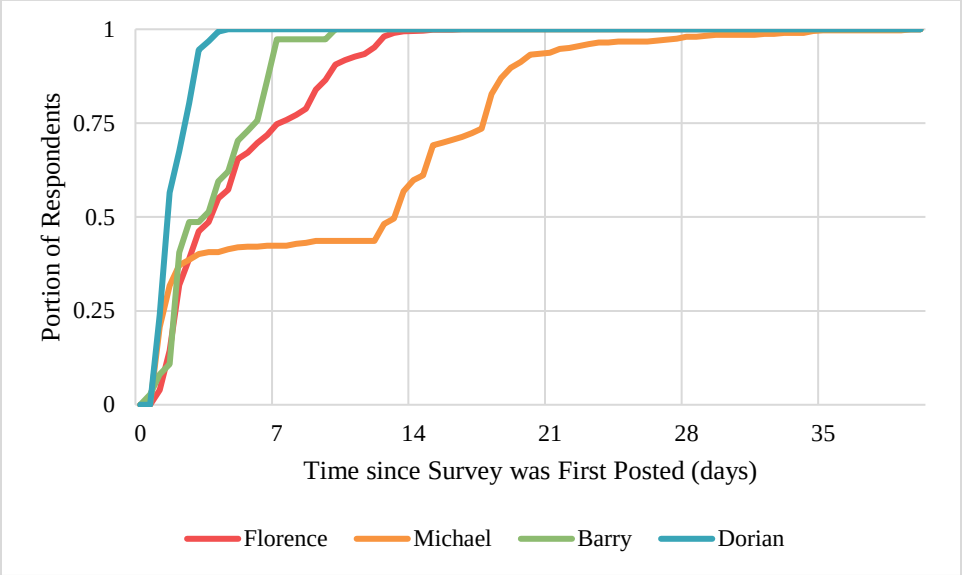

Figure 2 Timing of Survey Responses

Table 3 outlines the numbers of groups posted to and number of members of those groups. In total, there were 1421, 443, 38, and 512 useable responses for Hurricanes Florence, Michael, Barry, and Dorian, respectively, for a total of 2414 respondents.

The survey used was relatively short, with an average response time of 11.9 minutes and a median of 5.3 minutes. The survey was completed in under 16 minutes by 95% of respondents.

Table 3 Summary of Survey Deployment Response

				Num. members in a group					
Hurricane	**Days Open**	**Facebook Groups**	**Reddit Groups**	**Min**	**Median**	**Mean**	**Max**	**Total Members**	**Number of Responses**
Florence	26	28	10	199	1893	30,721	589,930	1,136,695	1421
Michael	41	43	7	46	2832	13,665	419,801	669,561	443
Barry	41	14	4	46	2577	10,178	40,300	174,140	38
Dorian	30	14	5	229	5352	39,105	482,784	725,322	512

This method of survey deployment was used by Farmer and DeYoung (2019) to collect information on pets during disasters. While they used pages geared toward pet owners in mandatory evacuation zones, the method and type of sample used is comparable to this study.

This relatively new deployment method has both advantages and drawbacks. The aforementioned benefit of rapid data collection suggests that recollections about decisions and timing will be more accurate than those collected via mail survey later. In addition, it is less expensive than traditional methods. Unfortunately, the sample provided by this method of survey deployment is not random. In addition, this method cannot include low income or homeless populations without access to the internet. Another drawback is that the deployment on hurricane-based Facebook pages suggests that the sample may be more informed about the event than the general population and may not reflect the age distribution of the population. A demographic comparison of respondents to the population is in the Data Summary section.

Survey Content

The survey was designed to determine the evacuation behavior of respondents and analyze the reasons for different evacuation behaviors. The full survey is included in Appendix A. The questions fall into four main categories: location information, evacuation travel, evacuation decision-making, and demographic information. The location information included state, city, and zip code to determine where respondents were located before the hurricane. Evacuation travel included whether the respondent did or did not evacuate, destination location and type, as well as path and timing of that evacuation. Evacuation decision-making questions included selection of determining factors in evacuating or preventing or delaying evacuation, with the opportunity for the respondents to write in their own responses. In addition, respondents were asked if and when they received an official evacuation order, if they had enough time to evacuate, and how many of their family and friends evacuated. Finally, demographic questions include race, employment status, income, language, vehicle access, and having children or animals, based on past studies (Thompson et al. 2017). These variables were used for both a demographic analysis to determine the makeup of the sample as well as to examine possible correlations between these variables and evacuation behavior.

The survey was the same across hurricanes with a few minor differences. Before the Hurricane Michael survey, an additional question about past evacuation experience was added to the original survey. In addition, before Hurricane Dorian, the question about the respondent's job changed. Previously, the survey asked a respondent to input a job title, but the Dorian survey asked the respondent to select any job categories from a list of fifteen to which at least one member of their household belongs. Some examples of categories are healthcare, food services, and

managers. This change was to avoid ambiguity and more confidently categorize job types, as well as to avoid discrepancies between income and job, such as a respondent being unemployed but having a high household income due to a spouse's employment. In addition, the highest income range was changed to $200,000+ for the survey after Hurricane Dorian in order to align with the U.S. Census.

Post-Processing

The post-processing of the data included coding responses with numbers and correcting any errors in the data, as well as classification of each respondent as coastal or inland and determining the actual evacuation order that they received. Most corrections to the data involved switching city and state locations which were entered in opposite spaces or correcting misspellings, commonly for cities, which were checked for correctness using the zip code. A total of 108 responses were discarded where either the respondent did not agree to the study or did not answer any questions. As much data as possible was retained, although it could not all be used for each analysis due to unanswered questions.

For the purposes of this study, coastal respondents are those located in counties that touch the coast. The county location of each respondent was determined based on their city and/or zip code. The locations of respondents, categorized into coastal and inland, are shown in Figure 3. For Florida, coastal respondents were separated by Gulf and Atlantic coasts. They were then designated "other coast" if the hurricane impacted the opposite coast (Dorian impacted the Atlantic coast and Michael the Gulf coast). These 19 responses were analyzed to see if respondents from the non-impacted coast had a more similar evacuation behavior to coastal or inland respondents.

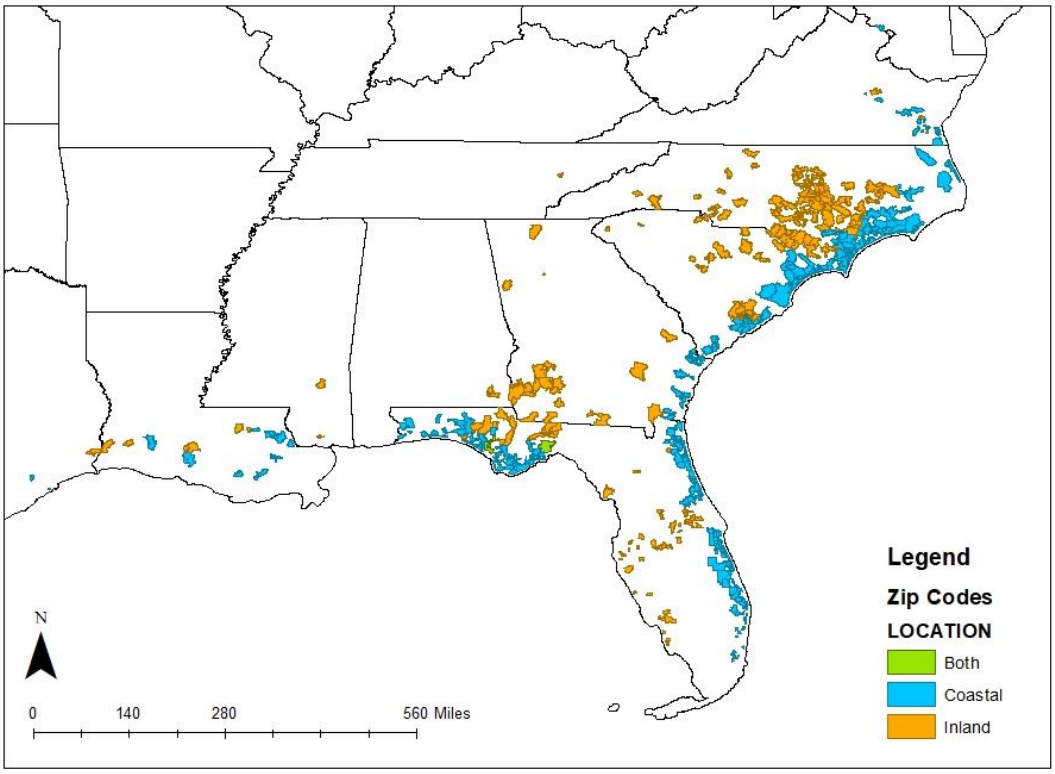

Figure 3 Locations of Coastal and Inland Respondents by Zip Code Areas

An analysis was performed on the 19 “other coast” respondents to determine if they could be grouped with either coastal or inland respondents. None of them received evacuation orders, evacuated, or lived in a mobile home. In general, a higher percentage of inland respondents live in a mobile home, making “other coast” more similar to coastal. Despite this, it would be misleading to decrease the proportion of coastal respondents who evacuated without an order. Although they live on a coast, if it is not the coast that was affected then they neither have an order to evacuate nor were impacted by storm surge. Due to their behavior similarities with inland respondents, “other coast” respondents were grouped with inland, and those areas with respondents for both Michael and Dorian are labeled “both” in Figure 3.

Information about the official evacuation orders that were issued had to be processed and applied to the survey responses. Official orders were obtained by request directly from the relevant state emergency management office, with the exception of orders in Louisiana for Hurricane Barry, which were compiled from news sources (Advocate Staff, 2019; Nowak, 2019). The orders were then applied to respondents using a combination of their county, zip, and city. Some orders were for a small and specific area which only covers part of a city or zip, such as east of I95, only in flood-prone areas, or certain roads. In the cases where a respondent could not confidently be placed within or outside of an evacuation zone, the official order is "unknown."

Data Summary

The demographic summary of respondents was consistent across hurricanes, despite them covering a wide geographic area. A table with the demographic summary by hurricane is available in Appendix B. As survey demographics were consistent with the same trends, the combination of all four hurricanes is provided in this section. For comparison, the demographics of the population were computed using county-level U.S. Census data, with each county weighted based on the number of respondents from that county. Overall, the racial makeup of the survey respondents was more white than the population (92.4% vs. 75.1%), consistently underrepresenting Black/African American populations (Figure 4). Only 6% of respondents live in a mobile home, much lower than the 13.2% of the population who live in mobile homes (Table 4), although that data is provided from the U.S. Census for the entire state, not separated into county. A larger percentage of respondents (97.5%) had access to a vehicle to evacuate compared to the percentage of the population who owns at least

one car (94.0%), though this is a different question, and could reflect people evacuating together or taking public transportation. Finally, respondents tended to have higher incomes than the population in the area (Figure 5). In particular, only 18.2% of respondents had an annual income under $35,000, compared to 35.5% of the population (Figure 5). Although the unemployment among respondents was higher than the population (Table 4), the possibility of a respondent answering for themselves and not their household before the survey was changed diminishes the validity of that statistic. The sample unemployment rate from Hurricane Dorian (Appendix B), after the survey question was changed (4.6%) is lower than that of the population (7.3%).

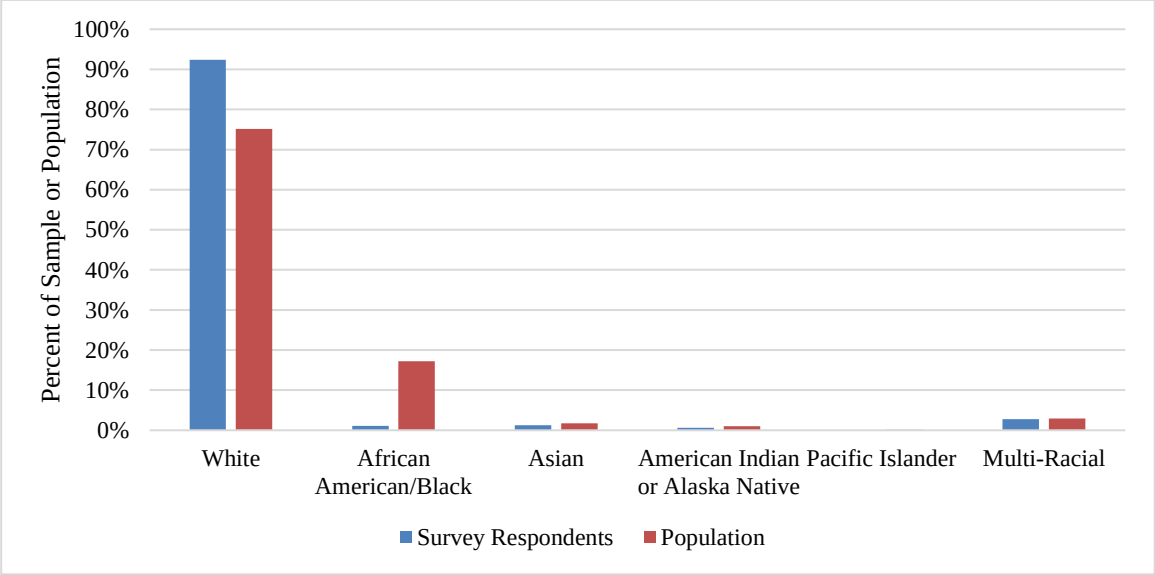

Figure 4 Race of Sample versus Population

Table 4 Population versus Sample Demographics, Combined

	Survey Respondents	***Population***
Mobile Home (By State)	6.0%	13.2%
Vehicle		
No Vehicle	1.1%	6.0%
Had Vehicle Access	97.5%	94.0%
Children		
% of Households w/children	39.5%	40.3%
Unemployed	16.8%	8.0%

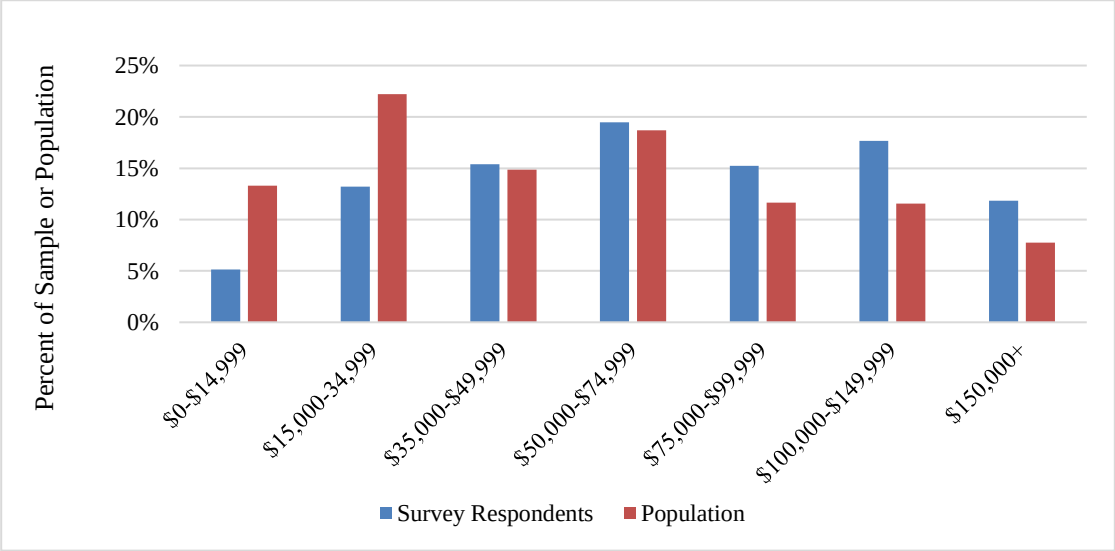

Figure 5 Income Distribution of Sample versus Population

Overall, despite not being generated as a random sample, the respondents are reasonable representative of the population in terms of demographics with a few exceptions being that the sample is more white and higher income. The discrepancies between sample and population demographics reflects the sampling bias caused by the deployment method and may be at least partially explained by the digital divide. In

order to take the survey, respondents needed access to a computer, as well as social media and to be connected to the pages to which the survey was shared. Overall, white and Asian populations have higher access to internet (United States Census Bureau, 2011), which could help explain why African American/Black populations are underrepresented by this survey. Regardless, the literature suggests that race and income are not determining factors in evacuation, so this is not expected to affect the results (Huang et al., 2017).

In addition to comparing sample and population demographics, coastal and inland respondents were compared to determine if other factors could be the cause of differences in evacuation behavior. Chi squared tests were performed on each variable to determine if the differences were statistically significant. Presented in Table 5, coastal and inland respondents have differences including number of family and friends who evacuated and if they live in a flood-prone area, which are expected. Differences in vehicle access, living in a mobile home, and owning pets all have small p-values, however the differences between the percentages of different responses are less than 5%. The same can be said of the racial makeup of respondents, which has a p-value of 0.0247. Also, the average annual income of coastal respondents ($91,000) was higher than that of inland ($80,000).

Table 5 Summary of Survey Responses

		Num. (%) Respondents			
Categorical Variable	Levels	Coastal	Inland	**Combined**	P-value
Number of Family and Friends who Evacuated	0- Almost none	327 (18)	190 (44)	**517 (23)**	<<0.0001
	1- Some	628 (35)	151 (35)	**779 (35)**	
	2- Many	506 (28)	50 (12)	**556 (25)**	
	3- Almost all	286 (16)	23 (5)	**309 (14)**	
	888- Do not know	40 (2)	17 (4)	**57 (3)**	

Location as Hurricane Approached	0- Home you own	1116 (63)	250 (58)	**1366 (62)**	0.1002
	1- Home you rent primary residence	462 (26)	136 (32)	**598 (27)**	
	2- Home rented for vacation	16 (1)	2 (0)	**18 (1)**	
	3- Other	182 (10)	41 (10)	**223 (10)**	
Mobile Home	0- No	1689 (95)	392 (91)	**2081 (94)**	0.0018
	1- Yes	97 (5)	41 (9)	**138 (6)**	
Flood Prone Area	0- No	917 (51)	323 (75)	**1240 (56)**	<<0.0001
	1- Yes	802 (45)	96 (22)	**898 (40)**	
	888- Do not know	67 (4)	14 (3)	**81 (4)**	
Vehicle Access	0- No	12 (1)	13 (3)	**25 (1)**	<0.0001
	1- Yes	1773 (99)	419 (97)	**2192 (99)**	
Children	0- No	1055 (59)	265 (61)	**1320 (60)**	0.4324
	1- Yes	729 (41)	168 (39)	**897 (40)**	
Pets	0- No	424 (24)	126 (29)	**550 (25)**	0.0215
	1- Yes	1359 (76)	307 (71)	**1666 (75)**	
Employed	0- No	341 (19)	81 (19)	**422 (19)**	0.8293
	1- Yes	1410 (81)	345 (81)	**1755 (81)**	
Race	0- Caucasian/White	1665 (95)	393 (92)	**2058 (94)**	0.0247
	1- African American/Black	18 (1)	6 (1)	**24 (1)**	
	2- Asian	18 (1)	8 (2)	**26 (1)**	
	3- American Indian	7 (0)	7 (2)	**14 (1)**	
	4- Pacific Islander	0 (0)	0 (0)	**0 (0)**	
	5- Multi-racial	50 (3)	11 (3)	**61 (3)**	
Income	0- $0- 14,999	71 (4)	42 (10)	**113 (5)**	0.000275
	1- $15,000- 34,999	231 (14)	55 (13)	**286 (13)**	
	2- $35,000- 49,999	264 (15)	70 (17)	**334 (16)**	
	3- $50,000- 74,999	341 (20)	83 (20)	**424 (20)**	
	4- $75,000- 99,999	273 (16)	55 (13)	**328 (15)**	
	5- $100,000- 149,999	308 (18)	75 (18)	**383 (18)**	
	6- $150,000+	216 (12)	40 (9)	**256 (12)**	
Received Evacuation Order	0- No	590 (32)	338 (77)	**928 (41)**	<<0.0001
	1- Yes	1184 (65)	78 (18)	**1262 (56)**	
	888- Do not know	60 (3)	24 (5)	**84 (4)**	
Official Order[1]	0- No	214 (12)	360 (83)	**574 (26)**	<<0.0001
	1- Mandatory	1045 (58)	47 (11)	**1092 (49)**	
	2- Voluntary	532 (30)	27 (6)	**559 (25)**	

[1] Official Order not taken from survey; determined using location of respondents.

Chapter 4

RESULTS AND DISCUSSION

Using the survey response data, analyses compare evacuation behavior between coastal and inland respondents. Both research questions are addressed: (RQ1) Does evacuation behavior differ between coastal and inland populations, and if so, in what way? and (RQ2) What factors can explain the difference in coastal and inland behavior? As results were consistent across hurricanes, most of the analysis refers to the combined dataset to provide a larger sample. Comparisons and chi-squared tests were performed to identify statistically significant differences in behavior and determining factors in decision-making.

Coastal and Inland Evacuation Behavior

In response to RQ1, does evacuation behavior differ between coastal and inland populations, and if so, in what way, this study found that evacuation behavior does vary between inland and coastal populations. The evacuation rate of inland respondents was only 24% compared to the 55% of coastal respondents who evacuated (Table 6). Although rates varied for each hurricane, coastal respondents consistently evacuated more than their inland counterparts (Table 6). Chi-squared tests confirmed that these results were statistically significant at $\alpha=0.05$ for all except Hurricane Barry, which had a low sample size.

Table 6 Evacuation Rates of Respondents (Num. of evacuees)

Hurricane	***Florence***	***Michael***	***Barry***	***Dorian***	***Combined***
Coastal	66%	60%	16%	27%	55%
	(801)	(173)	(5)	(114)	(1093)
Inland	26%	30%	0%	7%	24%
	(59)	(46)	(0)	(6)	(111)

An additional analysis was performed to determine if the timing of evacuation also differed between coastal and inland populations, with the hypothesis that inland residents would evacuate later than coastal ones. Considering only evacuees, evacuation timing was determined relative to landfall, to the nearest day. As shown in Figure 6, the hurricane is more predictive of evacuation timing than location. The Hurricane Barry data did not include any inland evacuees, so it is not included. The survey from Hurricane Dorian did not have enough respondents to yield statistically significant results. Dorian devastated the Bahamas 5 days before making landfall in the U.S. (National Weather Service), possibly explaining the early evacuations for that storm. Hurricane Michael formed near the coast and moved quickly, making landfall 3 days after formation compared to 14 and 13 days for Florence and Dorian, respectively (Table 1). This may explain why Hurricane Michael evacuees left closer to landfall than those from other storms. A Kolmogorov-Smirnov test on the Florence data determined that the coastal and inland evacuation timing curves were significantly different at $\alpha=0.05$. Two days before landfall, 93% of coastal evacuees had evacuated, compared to 72% of inland evacuees. 8% of inland evacuees left after landfall, though that only accounts for 4 respondents. Although Florence represents a more typical storm, no generalization can be made.

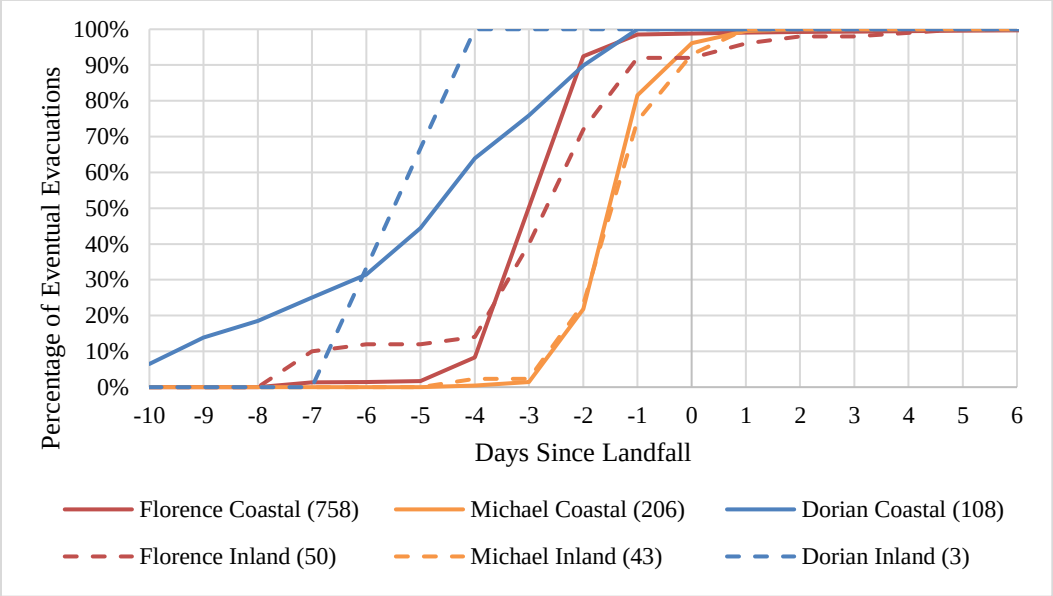

Figure 6 Evacuation Timing Relative to Landfall

Reasons for Differences in Coastal and Inland Behavior

Since initial analyses determined that coastal and inland populations have significantly different rates of evacuation, RQ2 was posed to ask why. Various explanations were explored including (1) the demographic differences between the populations, (2) the existence and effectiveness of evacuation orders, and (3) other reasons chosen by respondents to either evacuate or stay/delay evacuation.

As discussed in the Data Summary, there are slight differences in the demographics of the coastal and inland respondents. These differences are marginal, suggesting that demographic differences are not the only or main cause for differences in evacuation behavior. There are differences in coastal and inland responses regarding evacuation of friends and family, believing to live in a flood-prone area, and receiving official evacuation orders (Table 5). Since these results have small p-values,

they are significant at high confidence, and demonstrate a fundamental difference in experience between coastal and inland populations.

Official evacuation orders are the primary method of encouraging evacuation among those expected to be affected by a hurricane. Since inland respondents were less likely to evacuate, the question was posed if that could be due to lack of evacuation orders, not knowing about them, and/or not complying with them. The following conditional probability tree (Table 7) summarizes this information. It indicates, for example, that given a coastal respondent, there was a 58% chance they received a mandatory order ($P(mand \mid coastal)=0.58$), and that given a coastal respondent with a mandatory order, there was an 85% chance they knew about the order ($P(know \mid coastal \cap mand)=0.85$). It suggests that coastal respondents are more likely than inland respondents to have a mandatory order, more likely to know about an order, mandatory or voluntary, and more likely to evacuate given they have an order that they know about. The exception is inland respondents given a voluntary order, which was not statistically significant due to the low number of respondents in that category. This shows that evacuation orders are more effective in coastal counties, where people are more aware of and responsive to them. Even within respondents without an order that knew there was no order, coastal residents were more likely to evacuate, showing that there are other factors involved besides the existence and response to an evacuation order.

Table 7 Probability Tree of Evacuation Order Response for Coastal and [Inland]

ORDER	***KNOWLEDGE***	***EVACUATE***
Mandatory*	Thought no order*	
0.581	0.133	0.504*
[0.108]	[0.362]	[0.118]
	Knew of order*	
	0.853	0.622*
	[0.638]	[0.267]
	Unsure*	
	0.014	0.467
	[0.000]	[N/A]
Voluntary*	Thought no order	
0.297	0.509	0.413
[0.062]	[0.630]	[0.294]
	Knew of order	
	0.414	0.623
	[0.296]	[0.875]
	Unsure	
	0.077	0.659
	[0.074]	[0.500]
None*	Knew no order*	
0.119	0.734	0.229
[0.829]	[0.836]	[0.166]
	Thought was order*	
	0.252	0.352
	[0.103]	[0.324]
	Unsure*	
	0.014	0.333
	[0.061]	[0.455]

* Statistically significant difference between coastal and inland at $\alpha=0.05$.

In addition to evacuation orders, other factors affect people's decision to evacuate or stay in place. Respondents were asked to choose up to five major determining factors that led to their decision to ultimately evacuate, as well as up to five major factors in causing delays or preventing them from evacuating. The possible

responses are listed in questions 10 and 11 of the survey instrument (Appendix A). Results from these questions are shown in Figures 7 and 8, respectively.

The most common reason cited for evacuating for both coastal and inland evacuees was concern about power loss (59% and 67%, respectively). A close second for coastal respondents was having a mandatory order (52%), followed by house risk (37%), whereas experience staying in prior hurricanes (35%) and urging of family and friends (35%) were other reasons frequently cited for inland residents leaving. This implies that inland populations see less risk for themselves and their house than their coastal counterparts. The storm's impact in other areas as well as seeing the storm's effects firsthand were not chosen by many respondents in either location, implying that the storm itself has less of an impact than anticipated effects, prior experience, and information from other sources.

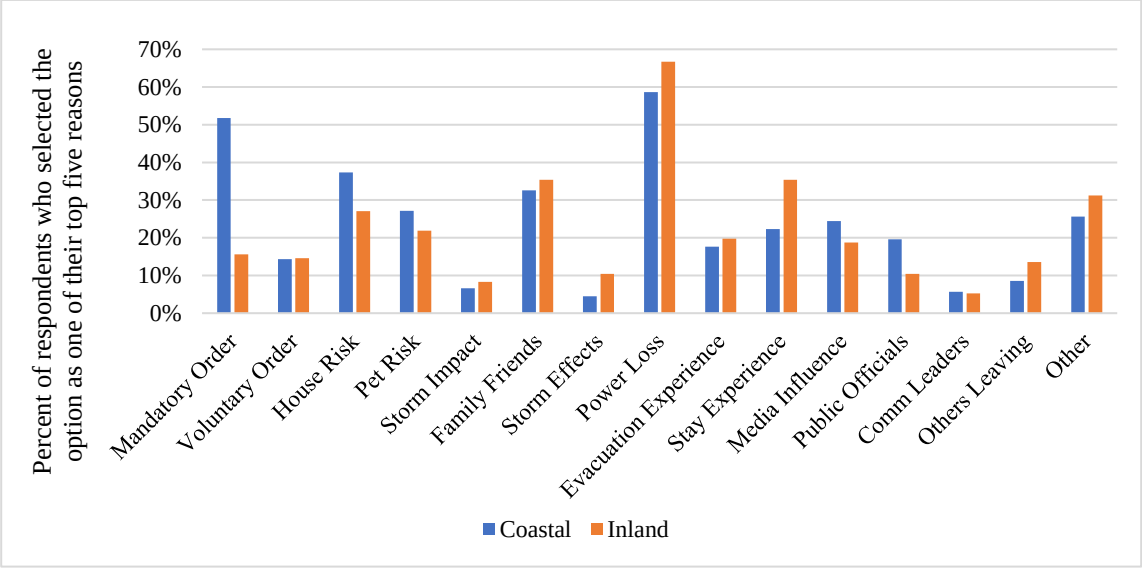

Figure 7 Reasons for Evacuating among Coastal and Inland Respondents

Many reasons were cited for not evacuating or for delaying eventual evacuation by both coastal and inland respondents (Figure 8). Work obligations, expense, and protecting property were reasons to delay evacuation regardless of location. Coastal and inland respondents had some similar reasons to stay, including caring for animals and not being impacted. Believing they did not have an order was a common reason for inland respondents to stay (56%). Despite having a higher average income, coastal residents more commonly cited expense as a reason to stay. This may be because inland respondents did not see a reason to evacuate in the first place, so they did not consider the potential expense. The same goes for the lower responses for traffic and no destination, as those would not affect someone who is not considering evacuation.

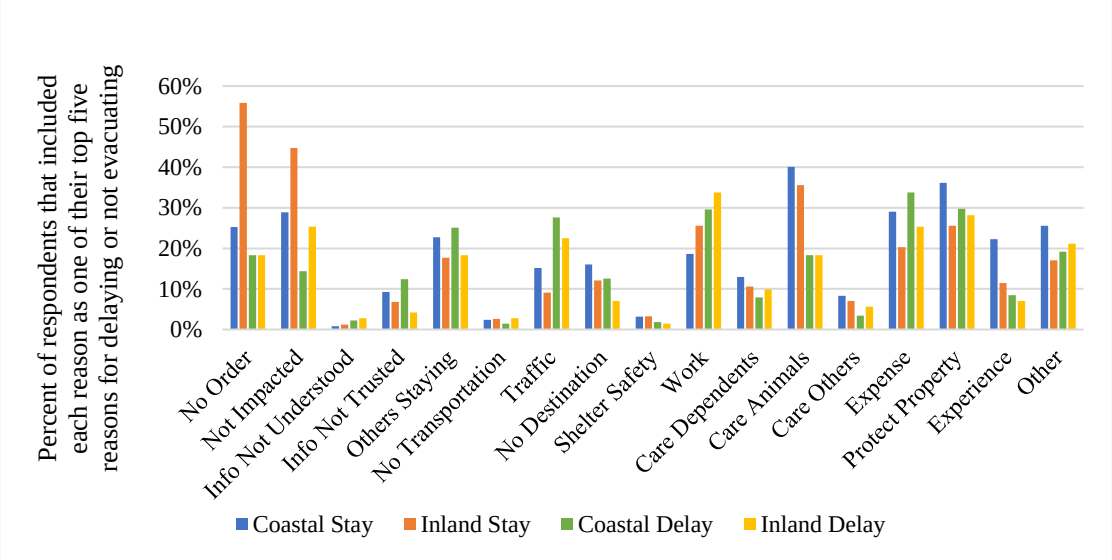

Figure 8 Reasons for Staying or Delaying Evacuation among Coastal and Inland Respondents

Overall, many factors contribute to evacuation decisions among both coastal and inland respondents. Besides demographic differences and differences in orders, location classification is a contributing factor in evacuation decision. Every stage in disseminating evacuation orders results in higher evacuation among coastal residents, from more frequent orders, higher likelihood that they will be aware of the order, and a higher response rate given they have an order and know about it. In addition, these results suggest that inland residents are more affected by past experience staying and the urging of their family and friends, whereas coastal residents cited media influence and urging of public officials more than their inland counterparts. Finally, inland respondents were more likely to stay due to not having an order or not being impacted, but coastal respondents were more likely to stay to care for animals, to protect property, or due to the expense of evacuation. Both evacuated due to anticipated power loss, but coastal respondents also evacuated due to evacuation orders and house risk.

Chapter 5

CONCLUSIONS

Evacuation behaviors between coastal and inland populations have fundamental differences including overall evacuation rate, response to evacuation orders, and reasons behind the decision to stay or evacuate. No conclusion could be drawn from the data regarding a difference in evacuation timing, as the hurricane was a more important factor than location, and the relationship between location and timing changed with each storm. Overall, coastal populations evacuate more, and are more likely to be in a location that receives evacuation orders, be aware of evacuation orders, and comply with a given order. Inland respondents were less likely to cite reasons to stay or delay evacuation that implied they had considered evacuating than coastal respondents, such as expense, traffic, and not having a destination. Instead, they often cited believing to not have an order or not be impacted by the storm. This may be a result of hurricanes being considered coastal phenomena that do not affect inland populations.

These results imply that the same messaging that is used in coastal counties to disseminate warnings and orders may not work in inland counties. In order to increase the effectiveness of evacuation orders in inland counties, the reasons for evacuation must be understood, and awareness of hurricane impacts affecting inland areas must be increased. If hurricanes continue to be considered coastal phenomena, orders will continue to be ineffective and ignored by inland populations.

Future research should continue to include inland populations and compare them with coastal populations to further understand differences in their behaviors. In addition, research should be done to find effective methods of communicating hurricane threats and evacuation orders to inland populations. Further investigation in the relationship between evacuation timing and coastal or inland location should also be performed, as the results from this study were inconclusive on that question.

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Appendix A

SURVEY INSTRUMENT

Hurricane Dorian

Start of Block: Default Question Block

Q41 **STATEMENT OF INFORMED CONSENT** Decision-Making and Evacuation for Hurricane Dorian You are invited to participate in a survey about how people make decisions about evacuation from a hurricane. This is part of a study conducted by the University of Delaware and funded by the National Science Foundation. You must be 18 years old or older to participate. There are no anticipated risks associated with this study. The survey will last approximately **5-10 minutes**, but may last longer if you wish to write more. There is no compensation for your participation. The information collected will be used for research and educational purposes. Your participation in this study is voluntary. If you wish to withdraw from the study, you may do so at any time during the survey. You cannot withdraw once you have completed the survey. We will ask you to recollect your experiences during disaster events and evacuations. We will not ask your name or associate your identity with the information you provide. We will not use your name in reports or publications. Data will be kept at the Disaster Research Center indefinitely on a secure server and may be shared in the future with permission of the director of the Disaster Research Center. If you have any questions or concerns, you may contact the study's Principal Investigator, Dr. Rachel Davidson, at the Disaster Research Center, University of Delaware at rdavidso@udel.edu (302-831-6618). Alternatively, if you have any questions about your rights as a participant in this study, you may contact the University of Delaware's Chairperson of the Institutional Review Board (302-831-2137). By continuing with this form, you acknowledge to the researcher that that you understand your rights as a research subject, have read this form, and voluntarily consent to participate in this study. *(Name of hurricane different for each survey)*

- ○ Yes, I agree to proceed and participate.
- ○ No, I do not wish to take this survey.

Skip To: End of Survey If STATEMENT OF INFORMED CONSENT Decision-Making and Evacuation for Hurricane Dorian You are inv... = No, I do not wish to take this survey.

Page Break

End of Block: Default Question Block

Start of Block: Block 1

Q43 Where were you located as Hurricane Dorian approached the U.S.? Please provide the state, city, and 5-digit zip code if possible. *(Name of hurricane different for each survey)*

- State _____
- City _____
- Zip code _____

Q1 Did you evacuate for Hurricane Dorian, any related storm activity (including inland flooding), or any impact after the storm had started (like secondary flooding or trees falling)? *(Name of hurricane different for each survey)*

- Yes
- No
- I was rescued

Skip To: Q10 If Did you evacuate for Hurricane Dorian, any related storm activity (including inland flooding), or... = No
Skip To: Q10 If Did you evacuate for Hurricane Dorian, any related storm activity (including inland flooding), or... = I was rescued

Q3 On what date did you evacuate? For reference, the hurricane made landfall in the Bahamas on Sunday, September 1 at 12:40pm, and in North Carolina on Friday, September 6 at 8:35am *(Changed for each survey)*

- ○ Tuesday, August 27
- ○ Wednesday, August 28
- ○ Thursday, August 29
- ○ Friday, August 30
- ○ Saturday, August 31
- ○ Sunday, September 1
- ○ Monday, September 2
- ○ Tuesday, September 3
- ○ Wednesday, September 4
- ○ Thursday, September 5
- ○ Friday, September 6
- ○ Saturday, September 7

Q4 On that day, approximately what time did you evacuate?

- midnight
- 1:00 am
- 2:00 am
- 3:00 am
- 4:00 am
- 5:00 am
- 6:00 am
- 7:00 am
- 8:00 am
- 9:00 am
- 10:00 am
- 11:00 am
- 12 noon
- 1:00 pm
- 2:00 pm
- 3:00 pm
- 4:00 pm
- 5:00 pm
- 6:00 pm
- 7:00 pm
- 8:00 pm
- 9:00 pm
- 10:00 pm
- 11:00 pm

Q6 Where was your final destination? Please provide the state, city, and 5-digit zip code if possible.

- ○ State _____
- ○ City _____
- ○ Zip Code _____

Q6 What was your final destination?

- ○ Family or friend's home
- ○ American Red Cross public shelter
- ○ Other public shelter
- ○ Others (Please specify)

_____

Q55 What was the primary route you took to get to your final destination? Please list the main interstates, highways, and/or other roads you used to evacuate. The map is available for reference. *(Map of affected area included with the question and changed for each survey)*

_____

Q7b Did you change your path at any point to take an alternative route from the one you started out on?

- ○ Yes
- ○ No
- ○ Not sure

Q8 On what date did you arrive at your final destination? (For reference, the hurricane made landfall in the Bahamas on Sunday, September 1 at 12:40pm, and in North Carolina on Friday, September 6 at 8:35am) *(Changed for each survey)*

- ○ Tuesday, August 27
- ○ Wednesday, August 28
- ○ Thursday, August 29
- ○ Friday, August 30
- ○ Saturday, August 31
- ○ Sunday, September 1
- ○ Monday, September 2
- ○ Tuesday, September 3
- ○ Wednesday, September 4
- ○ Thursday, September 5
- ○ Friday, September 6
- ○ Saturday, September 7
- ○ Sunday, September 8

Q48 On that day, approximately what time did you arrive at your final destination?

- midnight
- 1:00 am
- 2:00 am
- 3:00 am
- 4:00 am
- 5:00 am
- 6:00 am
- 7:00 am
- 8:00 am
- 9:00 am
- 10:00 am
- 11:00 am
- 12 noon
- 1:00 pm
- 2:00 pm
- 3:00 pm
- 4:00 pm
- 5:00 pm
- 6:00 pm
- 7:00 pm
- 8:00 pm
- 9:00 pm
- 10:00 pm
- 11:00 pm

*

Q9 What were the major determining factors that led to your decision to ultimately evacuate? (Choose no more than five)

- [ ] Mandatory evacuation order issued
- [ ] Voluntary evacuation order issued
- [ ] Determination others in household were at risk
- [ ] Determination pets were at risk
- [ ] Storm's impact in other areas
- [ ] Urging of friend or family member
- [ ] Seeing the storm effects first hand (e.g., flooding, rough seas, strong winds)
- [ ] Expected loss of power or other utilities
- [ ] Prior experience with evacuating for a hurricane
- [ ] Prior experience with staying for a hurricane
- [ ] Urging from news media/meteorologists
- [ ] Urging from public officials
- [ ] Urging from community leaders
- [ ] Saw others leaving
- [ ] Others (Please specify)

_____

*

Q10 Which, if any, of the following were major factors in causing delays or preventing you from evacuating? (Choose no more than five)

- [ ] No official evacuation order
- [ ] Did not think your location would be impacted
- [ ] Did not understand information about the storm's severity
- [ ] Did not trust information about the storm's severity
- [ ] Saw others staying in place
- [ ] Access to transportation
- [ ] Concern about traffic
- [ ] Lack of evacuation destination
- [ ] Concerns about shelter safety
- [ ] Work obligation
- [ ] Caring for dependents (children, elderly, medically fragile, other)
- [ ] Caring for pets or other animals
- [ ] Caring for others in the impacted area who did not/could not evacuate
- [ ] Expected expense of the evacuation
- [ ] Protecting property
- [ ] Prior experience with evacuation
- [ ] Other (Please Specify

_____

Q11 To your knowledge, did your location receive an official evacuation order before the storm hit?

- ○ Yes
- ○ No
- ○ Do not know

Skip To: Q13 If To your knowledge, did your location receive an official evacuation order before the storm hit? != Yes

Q49 On what date did you become aware of the official evacuation order for your location? (For reference, the hurricane made landfall in the Bahamas on Sunday, September 1 at 12:40pm, and in North Carolina on Friday, September 6 at 8:35am) *(Changed for each survey)*

- ○ Tuesday, August 27
- ○ Wednesday, August 28
- ○ Thursday, August 29
- ○ Friday, August 30
- ○ Saturday, August 31
- ○ Sunday, September 1
- ○ Monday, September 2
- ○ Tuesday, September 3
- ○ Wednesday, September 4
- ○ Thursday, September 5
- ○ Friday, September 6
- ○ Saturday, September 7
- ○ Sunday, September 8

Q50 On that day, approximately what time did you become aware of the official evacuation order for your location?

- ○ midnight
- ○ 1:00 am
- ○ 2:00 am
- ○ 3:00 am
- ○ 4:00 am
- ○ 5:00 am
- ○ 6:00 am
- ○ 7:00 am
- ○ 8:00 am
- ○ 9:00 am
- ○ 10:00 am
- ○ 11:00 am
- ○ 12 noon
- ○ 1:00 pm
- ○ 2:00 pm
- ○ 3:00 pm
- ○ 4:00 pm
- ○ 5:00 pm
- ○ 6:00 pm
- ○ 7:00 pm
- ○ 8:00 pm
- ○ 9:00 pm
- ○ 10:00 pm
- ○ 11:00 pm

Q13 How many of your family, friends, neighbors, and acquaintances evacuated?

- ○ Almost none
- ○ Some
- ○ Many
- ○ Almost all
- ○ I do not know

Q15 Which best describes your location as Hurricane Dorian approached? *(Name of hurricane different for each survey)*

- ○ In a home you own
- ○ In a home you rented as your primary residence
- ○ In a home you rented for a vacation or other short period of use (e.g., week or two)
- ○ Other (Please explain)

_____

Q16 Were you in a mobile home?

- ○ Yes
- ○ No

Q14 Were you in a low-lying area, or in an area near a beach, river, or other body of water that might be prone to flooding?

- ○ Yes
- ○ No
- ○ Do not know

Q17 Did you have a vehicle or access to a vehicle to evacuate?

- ○ Yes
- ○ No

Q19 Did you have any children with you?

- ○ Yes
- ○ No

Q20 Did you have pets, livestock, or other animals with you?

- ○ Yes
- ○ No

Q18 Is there an adult in your household that fits in the following job category? (Check all that apply) *(Question changed from earlier surveys which asked if respondent was employed, with options yes or no, and, if they selected yes, then a question asking their job, which was open-ended)*

- ☐ Unemployed
- ☐ Healthcare
- ☐ Tourism
- ☐ Food Services
- ☐ Education (K-12)
- ☐ Higher Education
- ☐ First Responders/Disaster Services
- ☐ Managers
- ☐ Professionals/ Technicians/ Administrative Support Workers
- ☐ Operatives/ Craft Workers
- ☐ Sales Workers
- ☐ Labors/ Helpers
- ☐ Service Workers
- ☐ Military
- ☐ Self-Employed
- ☐ Other/Unsure

Q21 Which category best describes your race?

- ○ Caucasian/White
- ○ African American/Black
- ○ Asian
- ○ American Indian
- ○ Pacific Islander
- ○ Multi-racial

Q22 What is the primary language you speak at home?

- ○ English
- ○ Spanish
- ○ Arabic
- ○ Chinese
- ○ Farsi
- ○ German
- ○ Hebrew
- ○ Hindi
- ○ Japanese
- ○ Korean
- ○ Vietnamese
- ○ Other (Please specify)

_____

Q23 Please mark the income range that best describes your annual household income from all sources. This is before taxes and other deductions. *(Top income bracket changed from previous surveys to align with the U.S. Census)*

- ○ $0-$14,999
- ○ $15,000-$34,999
- ○ $35,000-$49,999
- ○ $50,000-$74,999
- ○ $75,000-$99,999
- ○ $100,000-$149,999
- ○ $150,000-$199,999
- ○ $200,000+

Q24 Did you have enough time to evacuate? Why or why not?

_____
_____
_____
_____
_____

Q25 How did you find out about this survey?

- ○ Facebook
- ○ Twitter
- ○ Reddit
- ○ Other (please specify)

_____

Q51 Is there anything else you would like to share?

_____

End of Block: Block 1

Appendix B

DEMOGRAPHIC SUMMARY BY HURRICANE

Hurricane	*Combined*		*Florence*		*Michael*		*Barry*		*Dorian*	
	Sample	Population	Sample	Population	Sample	Population	Sample	Population	Sample	Population
Mobile Home (By State)	6.0%	13.2%	5.8%	14.3%	7.4%	9.3%	10.0%	11.9%	5.0%	13.5%
Vehicle										
No Vehicle	1.1%	6.0%	0.9%	5.9%	2.0%	6.1%	2.5%	8.6%	0.8%	6.1%
Had Vehicle Access	97.5%	94.0%	99.1%	94.1%	90.3%	93.9%	97.5%	91.4%	99.2%	93.9%
Children										
% of Households w/own children	39.5%	40.3%	44.2%	42.1%	33.9%	37.6%	32.5%	43.1%	32.1%	37.4%
Unemployed	16.8%	8.0%	19.1%	8.3%	24.6%	7.6%	7.5%	7.3%	4.6%	7.3%
Race										
White	92.4%	75.1%	93.8%	75.3%	83.7%	72.2%	92.5%	68.0%	96.0%	77.6%
African American/Black	1.1%	17.2%	1.2%	16.1%	1.1%	21.8%	2.5%	25.9%	0.6%	15.7%
Asian	1.2%	1.7%	1.5%	1.6%	1.1%	1.8%	2.5%	2.1%	0.4%	2.0%
American Indian or Alaska Native	0.6%	1.0%	0.9%	1.4%	0.5%	0.5%	0.0%	0.6%	0.0%	0.4%
Pacific Islander	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%
Multi-Racial	2.8%	2.9%	2.6%	3.2%	3.2%	2.6%	2.5%	2.0%	2.9%	2.5%

Income										
$0-$14,999	5.1%	13.3%	5.2%	13.2%	6.5%	14.9%	7.7%	14.3%	3.5%	12.1%
$15,000-34,999	13.2%	22.2%	13.6%	22.2%	14.2%	23.0%	5.1%	20.8%	11.8%	21.5%
$35,000-$49,999	15.4%	14.9%	16.9%	15.1%	14.0%	14.9%	20.5%	12.6%	12.0%	14.4%
$50,000-$74,999	19.5%	18.7%	21.6%	19.0%	15.1%	17.7%	20.5%	16.5%	17.2%	18.7%
$75,000-$99,999	15.2%	11.7%	16.6%	11.6%	11.7%	11.7%	5.1%	11.5%	15.3%	11.9%
$100,000-$149,999	17.7%	11.6%	16.8%	11.4%	14.7%	11.2%	23.1%	13.4%	22.3%	12.2%
$150,000+	11.9%	7.8%	9.4%	7.5%	12.2%	6.7%	17.9%	10.8%	9.2%	4.5%
(Dorian only) $200,000+									8.7%	4.7%