The Public Health Consequences of Compounding Disasters and Colonialism in Puerto Rico: A Mixed-Methods Investigation

by

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Dedication

La presente disertación es una obra de amor dedicada a todos aquellos puertorriqueños y puertorriqueñas que perdieron su vida o vieron su calidad de vida severamente afectada durante el periodo de desastres examinado durante el estudio presente. Mi compromiso es siempre trabajar de alguna forma u otra por atender asuntos de equidad y bienestar en Puerto Rico.

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Abstract

In recent decades, the ongoing climate crisis has disproportionately impacted historically marginalized populations globally through environmental hazards and disasters. Understanding the health impacts of multiple disaster exposure has become increasingly critical as disasters associated with climate change and environmental hazards are increasing in frequency, intensity, and duration, and can precede or co-occur with other disasters such as pandemics, oil spills, biological attacks, and other natural and/or human-made disasters. The U.S. territory of Puerto Rico provides a unique opportunity to examine this relationship since it has been plagued by multiple disaster events in the past decade–including a category five hurricane, earthquakes, and the COVID-19 pandemic—and its political relationship with the United States can be considered colonial. Importantly, colonialism could be characterized as a social determinant of health, but it has been scarcely examined as such in epidemiologic literature. This dissertation considers social, occupational, and environmental factors and explores the relationship between multiple disaster exposure, physical, mental, and reproductive health outcomes, and the role of colonialism in modifying this relationship.

Aim 1 explored associations between multiple disaster exposure and self-reported physical health, mental health, and health behaviors, and identified effect modifiers, among Puerto Rican participants from the Behavioral Risk Factor Surveillance System from 2017 to 2021. Overall, we found higher levels of poor physical and mental health, substance use, and self-reported perceptions of health in disaster periods compared to pre-disaster levels. Further,

sociodemographic characteristics including sex, income, education, and employment status, modified the relationship between exposure and outcome. However, the direction and magnitude of these associations varied by disaster period.

Aim 2 explored multiple disaster exposure and pregnancy-related maternal and newborn health outcomes using United States official vital records from 2017 to 2021, focusing on Puerto Rico and using Texas and Florida as comparisons to consider the role of colonialism. Overall, adverse maternal health outcomes (i.e., gestational hypertension, gestational diabetes, and excessive weight gain) were higher among Puerto Rican women in disaster periods compared to pre-disaster levels, and colonialism modified this relationship. Newborn health outcomes (i.e., preterm birth and low birthweight) were not similarly elevated in disaster periods, but this association may be underestimated due to live birth bias.

Aim 3 contextualized the results from the first two aims through in-depth interviews with 30 participants in Puerto Rico. We found considerable geographic-level differences in terms of health trajectories and disaster experience, a significant toll on mental and behavioral health, widespread lack of healthcare access, worsening financial conditions over time, complications with prenatal care and worsening reproductive health, a sense of hopelessness about prosperity and quality of life, and participants feeling discouraged from having children. These results helped us identify future research to fill gaps and interpret epidemiology findings.

Altogether, the results of this dissertation suggest widespread adverse health impacts from multiple disaster exposure in Puerto Rico and socio-structural inequities due to colonialism, persisting socioeconomic inequity, and governmental mismanagement of pre- and post- disaster conditions. Findings highlight the need for improved disaster preparedness and response, investment in more resilient climate and disaster-ready infrastructure, early disaster interventions

to increase access to mental healthcare, and other policies and interventions to address financial inequities, improve quality of life, and reduce the impacts of disasters and colonialism.

Chapter 1
Introduction

1.1 Dissertation Overview

Recent decades have seen academic, political, and grassroots movements warn about the implications of climate change. While historically we have focused on increases in global surface temperature, global climate change is a driver of sea level rise, changes in weather patterns (e.g., flooding and droughts), wildfires, and disruptions in planetary ecosystems. This has significant implications for water, energy, transportation, wildlife, agriculture, ecosystems, and human health. Global warming has and will continue to impact health by reducing the availability of drinking water, disrupting the availability of crops and food systems, modifying patterns of infectious disease transmission and vector-borne disease, influencing patterns of migration, increasing the frequency, intensity, and duration of extreme heat and environmental disasters (e.g., hurricanes, floods, and tornadoes), and through several other mechanisms.[1-3] Disasters have documented impacts on human health and can lead to psychological distress, depression, infectious disease incidence, changes in body composition, and other physical and mental health endpoints.[4-6] However, more research is needed to fully understand the implications of these complex and evolving phenomena.

The present dissertation explored three analytic examples of the physical, mental, and reproductive implications of living through disasters. In the first aim, I used self-reported data from the Behavioral Risk Factor Surveillance System to understand the physical and mental implications of multiple disaster exposure and potential individual-level protective factors. In the

second aim, I used vital records from the National Center for Health Statistics to understand the reproductive health implications of multiple disaster exposure and structural-level protective factors. Finally, in the third aim, I interviewed participants who lived through various disasters to understand their physical, mental, and reproductive health trajectories and provide context and additional insights for interpreting results from the first two aims. Findings from these collective studies can inform the development of structural, individual, and community-level interventions to address disaster preparedness, mitigation, and recovery, and ultimately improve health outcomes associated with these events, particularly among historically oppressed populations.

1.2 Colonialism and the Social, Historical, and Political Context in Puerto Rico

Puerto Rico is a Caribbean archipelago with a rich history, vibrant culture, and diverse ecosystem. It is the easternmost territory of the Great Antilles chain and lies approximately 50 miles east of the Dominican Republic, 40 miles west of the Virgin Islands, and 1,000 miles southeast from its closest U.S. state, Florida. It is situated in the Northeastern Caribbean Sea, with its northern shore facing the Atlantic Ocean. According to estimates from the U.S. Census Bureau, Puerto Rico has approximately 3,205,691 inhabitants and has seen a population decline since 2004.[7] Puerto Rico's capital is San Juan, and it has a total of 78 municipalities, including Vieques and Culebra, two smaller islands off the east coast.

Puerto Rico has been a territory of the United States since 1898, after it was taken from Spain by force following the Spanish-American War, as part of the federal governments' interest in conquering island nations for economic exploitation, military strategic aims, and geopolitical power .[8,9] In 1917, the United States instituted the Jones Act, a policy that granted Puerto Ricans U.S. Citizenship, but also monopolized imports and exports to the islands. This has been characterized by some researchers as an embargo on international trade with Puerto Rico that

hikes the cost of goods and services for people on the islands and seriously hampers emergency response.[8,10] Puerto Rico later became a United States "Commonwealth" in 1952—after a referendum imposed by the U.S. Congress—and this granted the islands authority over their decisions; however, this authority does not supersede U.S. congressional laws.

The political and historic relationship between Puerto Rico and the United States is complex and has been described by historians and political scientists as oppressive and colonial.[8,10-14] Colonialism is described as a practice of domination involving the subjugation of one people to another and is enforced through territorial, juridical, cultural, linguistic, political, mental, epistemic, and economic oppression.[15] There are many current and historical examples of colonialist policies and practices imposed on Puerto Rico by the United States. The U.S. territory has historically had differential access to financial and political resources compared to other U.S. states and jurisdictions. For example, under the Territorial Clause, Puerto Rico is considered a state for many purposes, but not for others such as paying U.S. income tax on corporate profits realized in Puerto Rico and electing representatives to congress.[11] A 1984 revision of the federal Bankruptcy Code also excluded Puerto Rico, limiting Puerto Rico's ability to address the recent economic crisis that started in 2010.[8,11] Instead, President Obama and Congress doubled down on enabling corporate interests by signing into law the Puerto Rican Oversight, Management, Economic Stability Act (PROMESA). This law handed control over Puerto Rico's finances to an unelected fiscal control board—appointed by the President—with oversight over the entire budget of the islands. This board swiftly privatized the islands' electric grid, increased taxes, and instituted austerity measures that resulted in the closure, rapid deterioration, and/or private sale of countless schools and hospitals.[8,16-18] These, and other, colonial policies and systems have been cited as the main drivers of Puerto Rico's financial

recession, resulting economic hardships, deindustrialization, growing government debt, unemployment rates, corruption in the governmental and financial sectors, and other social, political, and financial factors that left the island vulnerable in the time before and after recent disasters.[12]

1.3 Multiple disaster exposure in Puerto Rico

Over the course of the past decade, Puerto Rico has experienced historic and unprecedented disasters including Hurricane Maria, a magnitude 6.4 earthquake and subsequent increased seismic activity, and the COVID-19 pandemic. These events have resulted in widespread structural impact, disruption of occupational and financial prosperity, loss of human life, and countless adverse experiences among Puerto Ricans. The string of compounding disasters began with Hurricane Maria, a category 5 hurricane that made landfall in Puerto Rico on September 20 of 2017. The aftermath of the storm saw damaged roads, loss of homes, and interruption in water supply, electricity, telecommunications, and access to medical care. Puerto Ricans saw disruptions in power for extended periods, with some communities spending as long as a year with no electricity, making it the longest blackout in U.S. history.[19] The unprecedented structural damage from the storm, compounded with pre-existing social and economic conditions, resulted in adverse morbidity and mortality, with an estimated death count of over 3000 thousand.[20-23] The federal response to Hurricane Maria was delayed, with Puerto Rico receiving a slower delivery of federally appropriated funds, less federal resources (i.e., staffing, food, water, tarps, and helicopters), and fewer Federal Emergency Management Agency (FEMA) dollars in the initial 6 months post-disaster, compared to similar disaster events in the continental United States.[12,24,25] Traditionally, recovery from disasters of this magnitude can take several years; however, recovery efforts were hindered by subsequent disasters that plagued the islands.

During the last month of 2019 and the early part of 2020, Puerto Rico saw an alarming amount of seismic activity. These events started with two 4.7 and 5.0 magnitude earthquakes in December 2019, followed up with multiple replicas, and ultimately leading up to two stronger magnitude earthquakes, including a 5.8 earthquake on January 6th, and a 6.4 earthquake on January 7th of 2020. While the epicenter of these earthquakes was in the South/Southwestern region of Puerto Rico, close to Guánica and Ponce, they were generally felt throughout the Puerto Rican mainland. In the months following the main magnitude 6.4 earthquake, Puerto Rico saw thousands of aftershocks, 171 of which had magnitudes greater than 3.5.[26] The structural damages from these events resulted in thousands of families with significant damages to their homes (including over 2,500 houses that were considered uninhabitable), service interruptions, and significant mental health implications.[27] Finally, on March 8th of 2020, Puerto Rico reported its first suspected case of coronavirus and several more possible cases over the following week. The Governor signed an Executive Order on March 15th of 2020, directing a "shelter in place policy" and the closure of non-essential businesses, excluding pharmacies, supermarkets, gas stations, and banks. Although these measures were initially conceived as temporary, the global threat of the pandemic continued over the course of subsequent years. While the impacts of the coronavirus pandemic were global, Puerto Rico was uniquely affected since these disruptions further delayed recovery efforts from prior disasters.

1.4 Specific Aims

Aim 1: To analyze and describe the relationship between multiple disaster exposure, self-reported health, and potential effect modifiers, among residents of Puerto Rico by examining time trends.

Sub aim 1. To understand the relationship between disaster exposure and the number of days of poor physical and mental health in the past 30 days.

Hypothesis 1a. Compared to the pre-disaster period, we expect that post-disaster periods will be associated with more days of poor physical and mental health.

Hypothesis 1b. We also expect that there will be a stronger association with days of poor mental health—compared to physical health—given that the disruptions caused by disasters are more likely to affect physical health in the long-term.

Sub aim 2. To understand the relationship between disaster exposure and health modifying behaviors, namely alcohol consumption, tobacco smoking, and exercise.

Hypothesis 2a. We expect that post-disaster periods will be associated with increased levels of smoking and alcohol consumption compared to pre-disaster.

Hypothesis 2b. We expect that individuals will be less likely to exercise in post-disaster periods compared to pre-disaster due to disruptions in daily life patterns.

Sub aim 3. To understand the relationship between disaster exposure and self-perception of general health status.

Hypothesis 3a. We expect that post-disaster periods will be associated with higher reporting of negative general health compared to pre-disaster periods.

Sub aim 4. To explore if the relationship between disaster exposure and our outcomes of interest is modified by demographic characteristics to determine what societal factors may be protective and/or harmful for health in a disaster context.

Hypothesis 4a. We expect that sex, income, education, and employment status are effect modifiers in the relationship between disaster exposure and health.

Aim 2: To analyze and describe the relationship between multiple disaster exposure and maternal and child health by examining time trends in Puerto Rico, Texas, and Florida and examining the role of colonialism as an effect modifier in this relationship.

Sub aim 1. To understand the relationship between disaster exposure and maternal and child health in Puerto Rico.

Hypothesis 1a. We expect that post-disaster periods will be associated with increased rates of preterm birth, low birthweight, and extreme low birthweight.

Hypothesis 1b. We expect that post-disaster periods will be associated with increased rates of gestational diabetes and hypertension and maternal morbidity.

Sub aim 2. To understand the role of geographic location and severity of disaster experience based on residence on the relationship between maternal and child health and disaster exposure in Puerto Rico.

Hypothesis 2a. We expect that the relationship between post-disaster periods and maternal and child health will vary significantly across geographic sectors in Puerto Rico.

Sub aim 3. To explore if the relationship between disaster exposure and maternal and child health outcomes is modified by colonialism.

Hypothesis 3a. We expect that the rates of adverse maternal and child health outcomes will be higher among Puerto Ricans compared to those in Texas and Florida among those exposed to multiple disasters.

Aim 3: To explore and contextualize the results of aims 1 and 2 by describing the experiences of Puerto Rico residents that have been exposed to multiple disasters, their physical and mental

health trajectories, barriers and protective factors to disaster adjustment, and the contrast between different disaster hazard experiences.

Sub aim 1. To explore the health experiences of participants that have been exposed to multiple disasters and how their well-being compares pre- to post-disasters.

Sub aim 2. To understand potential barriers and facilitators to health and well-being amidst multiple disaster exposure.

Sub aim 3. To explore the disaster experiences of Puerto Ricans who have experienced multiple disaster and how they compare different disaster events to see if particular disaster events have affected them more, if they believe they are building resilience over time, and/or if adverse health is building over time.

Sub aim 4. To explore the perspectives of participants with reproductive health and how multiple disaster events may have impacted maternal and child health. Particularly, we are interested in understanding how these disasters may have affected their decision-making about having children, if they faced any disaster-related complications during pregnancy, and other factors concerning reproductive health.

Sub aim 5. To explore Puerto Rican perspectives about the role of colonialism and how it potentially impacts their health amidst multiple disaster exposure.

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Chapter 2
The Association of Physical, Mental, and Behavioral Health with Multiple Disaster Exposure in Puerto Rico

2.1 Introduction

Over the past century, experts, advocates, and political figures have warned about the potential implications of global climate change and how it can affect and disrupt human life. More recently, the public health community has begun to recognize the impending threat of the climate crisis and its potential impacts on human health, with researchers arguing that climate change should be considered a public health emergency.[1-3] Global warming and climate change are known to impact health by increasing the frequency, intensity, and duration of extreme heat, affecting the availability of drinking water, reducing the productivity of crops, and disrupting food systems, increasing the frequency and intensity of disasters associated with natural hazards (e.g., hurricanes, floods, and tornadoes), modifying patterns of infectious disease transmission and vector-borne disease, influencing patterns of migration, and several other mechanisms.[2-4] Literature considering the impacts of climate change on human health and well-being has emerged from the fields of disaster preparedness, emergency response, urban planning, and epidemiology, reflecting the multidisciplinary approaches needed to understand and appropriately address this complex issue.[5-7] To inform adaptation and preparation, more research is required in order to elucidate the complexity of the problem, the diverse mechanisms and exposures associated with climate and climate-induced social phenomena, and the impact of these on diverse health outcomes.

2.1.1 Multiple disaster exposure and its potential to impact health outcomes

When considering the potential impacts of climate change on human health, one of the major causes of concern is the relationship between disaster exposure and health. Disasters can be conceptualized as sudden and often large-scale events that have destructive and disruptive consequences to individuals and communities that are impacted.[8-10] They often result in loss of resources, widespread morbidity and mortality, and have the potential for long-term impacts in communities and individuals.[11,12] It has been well documented that major disaster events—such as hurricanes and earthquakes—are associated with increased psychological distress, post-traumatic stress disorder (PTSD), depression, infectious disease incidence, changes in body composition (commonly measured as body mass index [BMI]), mortality, and other physical and mental health endpoints.[12-15] While the scope of the disaster research literature is extensive, it frequently focuses on a select cluster of singular disaster events that have received global and national recognition (e.g., Hurricane Katrina, 9/11, and COVID-19). This focus fails to consider a larger number of catastrophic events and, importantly, rarely examines the population health impacts of cumulative disaster events on singular populations. The impetus to examine the health impacts of multiple disaster events has become increasingly evident as disasters associated with climate change and natural hazards are increasing in frequency, intensity, and duration, and can co-occur with or precede other disasters such as pandemics, oil spills, biologic attacks, and other natural and/or human-made hazards.

2.1.2 Disasters and physical, mental, & behavioral health

Large-scale disaster events have documented ramifications for human health through physiologic, psychologic, and behavioral endpoints. In terms of physical health, disasters can lead to major health impacts such as increases in respiratory illnesses, infectious diseases,

cardiovascular complications, and exacerbation of pre-existing health conditions.[16] For example, a cross-sectional study following Hurricane Katrina found that participants exposed to the storm suffered from upper and lower respiratory symptoms due to roof damage, outside mold, dust, and flood damage caused by the storm.[17] Other disasters, such as floods, earthquakes, tornadoes, and tropical cyclones have resulted in the destruction and deterioration of essential public health infrastructure such as food, health services, power, sanitation, and shelter, jeopardizing access to treatment, medication, and leading to increased morbidity and mortality.[18-20] Exposure to disasters has been further associated with a variety of mental and behavioral health consequences, particularly due to the disruptive, life threatening, and potentially violent nature of these events. While a majority of individuals cope well with disasters, many studies have documented that these events can result in various types of psychopathology, including minor psychological impairments, and more severe mental health disorders including PTSD, major depressive disorder, substance use disorders, and other conditions.[21-25] Moreover, while the literature examining the mental health impacts of successive disaster exposure is limited, some exploratory studies have found that more adverse experiences in successive disasters may be associated with more detrimental mental health impacts.[26-28] Additionally, some studies have found evidence of some level of substance use problems post-disasters, but substantial increases occur, particularly among those with a history of substance use or those who developed other mental health conditions following the disaster.[29,30] However, to the best of our knowledge, research on substance use disorders has yet to examine the potential implications of multiple disaster exposure on substance misuse.

Better epidemiological understanding and documentation of etiologic pathways, measured health impacts, and other potential health implications of multiple disaster exposure

can be critical to determine appropriate emergency preparedness measures required, distribution of disaster preparedness supplies and resources, and considerations of populations that need particular attention amidst these events. This study aims to address some of these questions on multiple disaster exposure by considering the physical, behavioral, and mental health impacts of Hurricane Maria and the COVID-19 pandemic in Puerto Rico. More specifically, we aim to analyze and describe the relationship between disaster exposure and self-reported health outcomes, and potential modifiers of these associations, among residents of Puerto Rico from 2017 to 2022.

2.2 Methods

2.2.1 Data source

The primary data source for this analysis will be the U.S. Centers for Disease Control and Prevention's (CDC) Behavioral Risk Factor Surveillance System (BRFSS) yearly surveys.[31] The BRFSS is a nation-wide system that collects data about participant health-related risk behaviors, chronic health conditions, use of healthcare and preventive services, and self-reported health.[31] It is used throughout the United States by health departments, public health agencies, and other organizations at the state, local, and federal levels to identify emerging behavioral health concerns, track health objectives, develop targeted health promotion interventions, inform policies, and examine the current and historical state of behavioral health issues.[31] It collects data in all U.S. States, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, Guam, American Samoa, and Palau. It collects data from more than 400,000 interviews nationwide per year, making it the largest continuously conducted health survey system in the world.[31] BRFSS data is collected by state health departments with technical and methodological assistance from the CDC.[31] These departments use in-house interviewers or contract with telephone call centers

or universities to administer the BRFSS surveys continuously through the year.[31] The survey is conducted using Random Digit Dialing (RDD) techniques on both landlines and cellphones. Sampling methodologies from the BRFSS are designed to obtain sample information of the population of interest (i.e., the adult population residing in each individual state).[31]

Publicly available BRFSS yearly data files from 2015 to 2021 were obtained from the CDC's website and downloaded in the fall of 2022 for analysis.[31] Yearly data are collected from January of the dataset year until March of the following year; therefore, for the purposes of this study, BRFSS survey data from January 1st, 2015, until March 15, 2022, will be analyzed to examine time trends. The BRFSS does not follow individuals over time, but rather it collects data all through each year by sampling different individuals over time and achieving state-wide representation. In epidemiologic terms, our study can thus be characterized as a repeated cross-sectional design, rather than a longitudinal cohort study. Individual yearly data files were merged using SAS OnDemand for academics. Survey data used for this analysis will only include responses from participants in Puerto Rico—which was collected in Spanish—and observations from other U.S. states and jurisdictions will be excluded from our analysis. No sensitive information or private information that can be traced back to individual study participants is made available through the publicly available datasets used in this analysis, so the Institutional Review Board at the University of Michigan classified this study as exempt (HUM00230376).

2.2.2 Weighting

To help make sample data more representative of the population from which the data were collected, the BRFSS uses data weights that consider the probability of selection, adjustments for no response bias and non-coverage errors.[31] Design weights are calculated using the weight of each geographic stratum, the number of phones within a household, and the

number of adults aged 18 years and older in the respondents' household.[31] BRFSS uses raking to adjust for demographic differences (i.e., age, sex, ethnicity, geographic regions within states, marital status, education level, home ownership, and type of phone ownership) between those persons who are sampled and the population they represent.[31,32] Sampling weights are incorporated into all analyses conducted in this study—including regression models and descriptive statistics—to ensure that results represent the adult population in Puerto Rico.

2.2.3 Measures of interest

2.2.3.1 Exposure of interest

Our primary exposure of interest is disaster exposure. Ideally, in a post-disaster scenario one would have data on participants' experiences prior to, during, and following a disaster to properly assign disaster exposure categories. However, the BRFSS standard questionnaire does not include questions about disaster experiences in individual states and territories. Therefore, we utilized the recorded date of the interview to create pre-/post- disaster categories as a proxy for actual disaster experiences. The date of the interview will be used in reference to the date in which a disaster first occurred in Puerto Rico and exposure categories will be considered to assess the individual impact of different disaster periods, always compared to the referent period before any of the disasters occurred (pre-disaster).

Specifically, in Puerto Rico, the first major disaster to impact the island in the past decade was Hurricane Maria, which made landfall on September 20th of 2017. Following this, Puerto Rico had an extended recovery period that eventually coincided with multiple earthquakes that occurred between 2019 and 2020. Finally, Puerto Rico was affected by the COVID-19 pandemic which further hindered recovery efforts. To properly consider the impact of different events and variation at different stages of the recovery process, we divided the hurricane and the

pandemic into four key stages, two for each disaster. During the early post-hurricane period (0-6 months post-hurricane) was associated with increased suicide rates, psychological distress, and mental and resource scarcity.[33-35] Efforts were focused on cleaning debris, providing food and covering essential needs for affected individuals, and restoring electricity, water, and communications. The late post-hurricane period (6+ months post-hurricane but pre-pandemic) was focused on long-term recovery and coincided with earthquakes occurring in the southwestern region of the island. The pandemic was divided into early pandemic, starting at the time when an emergency declaration was made in Puerto Rico (March 12, 2020), and late pandemic, starting at the time when vaccine distribution started for the general population (April 15, 2021), due to the differences in terms of lockdowns and understanding of the virus at these time points. The period associated with the earthquakes was not divided into another category due to 1) these events coinciding with the pandemic period and 2) we did not have access to geographic-level data and these earthquakes were considered more regional disasters, affecting more severely the Southern and Western regions of Puerto Rico. In summary, for the purposes of our analysis, the exposure of interest will be categorized into the following periods: (1) pre-disaster [unexposed], (2) early post-hurricane, (3) late post-hurricane, (4) early pandemic, (5) late pandemic.

2.2.3.2 Outcome variables of interest

Due to potential concerns with temporality and considering the aforementioned limitations of the BRFSS dataset with respect to disaster research, we are focusing on outcome variables that correspond to self-reported health perceptions, rather than clinical diagnoses. In other words, given the inability to ascertain the specific date of self-reported clinical diagnoses, we could expect that participants interviewed post-disaster could have pre-disaster diagnoses and

this could introduce bias to our analysis. Therefore, we only consider variables that fall under the following categories: (1) days of poor physical/mental health in the past 30 days, (2) self-perception of general health status at the time of the interview, (3) current behaviors that can modify health status. More details follow:

Days of poor health. These variables represent self-reported days of poor physical health and poor mental health in the 30 days prior to the interview. These come from the following question: "Now thinking about your physical [mental] health, which include physical illness and injury [which includes stress, depression, and problems with emotions], for how many days during the past 30 days was your physical [mental] health not good?" These two questionnaire items are reported by the BRFSS datasets with values from 0 to 30, corresponding to the total number days of poor health in the 30 days prior to the interview.

Current general health status. The second outcome variable of interest is self-reported perception of general health status at the time of the phone interview. This comes from a question in the BRFSS that asks participants to rate their health in general from 1 to 5. The corresponding values are as follows: Excellent (1), Very Good (2), Good (3), Fair (4), and (5) Poor. For our analysis, this variable will be recoded and dichotomized to represent those who reported their general health to be "positive" (score 1-3) and those who reported their general health to be "negative" (score 4-5) to assess changes in self-perceived health post-disaster.

Health modifying behaviors. The third set of outcome variables of interest are health modifying behaviors at the time of the interview, specifically, cigarette smoking, alcohol consumption, and exercise. The smoking variable comes from a question that asked participants if they currently smoke every day, some days, or not at all. For our analysis, we restructured the variable as a binary yes/no variable for smoking, categorizing participants as current smokers if

they smoke every day or some days and as non-smokers if they responded, “not at all.” Secondly, we included two variables that examine alcohol consumption; the first is a dichotomous yes/no variable that was calculated if adults had reported having at least one alcoholic drink in the 30 days prior to the interview and the second is a dichotomous variable that was calculated if they had a heavy drinking episode (i.e., consistent with binge drinking). Finally, our exercise outcome variable is a dichotomous yes/no variable that asked participants if they had participated in physical activity or exercise outside of work in the past month.

2.2.4 Covariates

We selected the following covariates to be included in our models: age, sex, income, education, marital status, and employment status. These were selected based on their potential to confound the association between our exposure and outcomes of interest. In other words, covariates were selected if—based on prior literature—they met all of the following criteria: (1) were considered an independent cause of our outcome, (2) were associated with our outcome of interest, and (3) were not in the causal pathway between exposure and outcome (DAG, Figure 1). Specific categories for covariates can be found in Table 1.

2.2.5 Analytic approach

Descriptive statistics will be presented for all relevant outcome variables and covariates of interest. Categorical variables will be presented as frequencies with percentages while continuous variables will be reported as means with standard deviations or medians with interquartile ranges. Initially, the health outcome variables will be reported in each period of interest, with no adjustment. Then, multivariate regression models will be utilized to examine the relationship between disaster exposure and self-reported health outcomes. For continuous

outcome variables, we will examine the relationship between disaster exposure and days of poor health using multivariate linear regression models holding confounding variables constant. These models will reveal any increase/decrease in the number of days of self-reported poor health corresponding to each disaster period in Puerto Rico. For categorical outcome variables (i.e., self-reported health perception and health behaviors), we will examine the relationship between disaster exposure and health using log-binomial models controlling for relevant confounders. We will report prevalence ratios to identify potential changes in self-perceived health and health behaviors corresponding to each disaster period. Missing data patterns will be assessed, and the percent of missing data will be determined. If missing data is larger than 10 percent, multiple imputation techniques will be used to complete that data to estimate unbiased statistical parameters. Sampling weights are incorporated into all analyses conducted in this study — including regression models and descriptive statistics—to ensure that results represent the adult population in Puerto Rico. A p-value of 0.05 or less will be considered statistically significant for all analyses conducted, although result interpretation will not focus solely on significance and will also consider direction of association.[36] All analyses will be conducted using SAS OnDemand for Academics and all analyses will utilize the PROC Survey type procedures to account for the BRFSS sampling design and appropriately consider weights.

2.3 Results

Our data represents the experiences of 35,517 individuals living in Puerto Rico who were interviewed for the BRFSS from 2015 to early 2022. Covariate categories with highest representation included participants who were employed (42.0%), married or partnered (45.6%), had some level of college education (48.1%), and who were over 45 years old (49%). Most respondents also identified as female (53.2%), earned a yearly income lower than $25,000

(74.2%), and did not have children (71.0%). Most participants self-identified as non-smokers (90.0%), had positive perceptions of their current health status (67.0%), and reported exercising in the 30 days prior to the interview (52.4%). Participants also largely reported not drinking any alcoholic beverages in the 30 days prior to the interview (69.9%) and not engaging in binge drinking (87.1%). Additionally, in terms of days over the past 30 days with poor health, participants reported 4.8 days of poor physical health and 3.7 days of poor mental health in the 30 days prior to the interview. Due to missingness with regard to our income variable (18.4% missing), multiple imputation was performed for all multivariate regression models presented below and 100 imputations were produced using the PROC MI procedure in SAS.

2.3.1 Main effects: Days of poor health

Multivariate linear regression models were run for outcomes of interest. Models adjusted for age, income, sex, marital status, and employment status. Sampling weights were incorporated to the regression model using PROC Survey procedures. The pre-disaster period was used as the reference point for all analyses and multiple imputation was used to account for missingness. Overall, our estimates for days of poor health in the 30 days prior to the interview showed that different disaster periods affected our sample in multiple ways (Table 2). The early post-hurricane period was consistently harmful for both poor mental and physical health, with reported 2.47 days and 0.80 additional days of poor health ($p<0.001$), respectively. The late post-hurricane period was also particularly harmful for physical health, with 1.17 additional days of poor health ($p<0.001$) but did not show a significant difference for days of poor mental health. On the other hand—contrary to our hypothesis—the two pandemic periods showed mostly protective associations across days of poor mental and physical health, compared to the pre-disaster period. The early pandemic period was associated with fewer days of poor mental (-0.55

days, p<0.001) and physical health (-0.72, p<0.001), while the late pandemic period was associated with fewer days of poor mental health (-0.32 days, p<0.001) and more days of poor physical health (0.38, p<0.001). More information on these regression results can be found in Table 2.

2.3.2 Main effects: Current General Health Status & Health Modifying Behaviors

Multivariate log-binomial regression models were run, adjusting for age, income, sex, marital status, and employment status. The pre-disaster period was used as the reference point for all analyses and multiple imputation was used to account for missingness. Estimates from log-binomial model were exponentiated and presented as prevalence ratios with 95% confidence intervals (CIs) for ease of interpretation. Overall, estimates for current general health status and health modifying behavior were consistent with those for the continuous outcome variables. Estimates for general health status showed participants were more likely to report negative general health perceptions in both the early post-hurricane period (PR=1.32, 95% CI: 1.22, 1.43) and the late post-hurricane period (PR=1.18, 95% CI: 1.14, 1.23); on the other hand, in both the early pandemic period (PR=0.73, 95% CI: 0.69, 0.78) and the late pandemic period (PR=0.76, 95% CI: 0.70, 0.82) participants were less likely to report negative general health perceptions.

Our estimates for health modifying behaviors showed similar results. Across outcomes, the early post-hurricane period yielded the most significant harmful effects with participants being less likely to report exercising in the past month (PR=0.65, 95% CI: 0.61, 0.70), being more likely to identify as current smokers (PR=1.20, 95% CI: 1.07, 134), and more likely to report alcohol consumption (PR=1.06, 95% CI: 0.98, 1.15); however, it did not yield significant results for binge drinking. The late post-hurricane period did not yield statistically significant results across health-modifying behaviors, except in the case of binge drinking, with participants

being more likely to report a heavy drinking episode (PR=1.08, 95% CI: 1.02, 1.14) during this period. Similar to prior results, pandemic periods showed mostly protective associations across outcomes. During the early pandemic period, participants were more likely to exercise (PR=1.15, 95% CI: 1.10, 1.20), but alcohol consumption, binge drinking, and smoking did not yield significant results compared to the pre-disaster period. Further, the late pandemic period was associated with participants exercising more (PR=1.14, 95% CI: 1.09, 1.20), being less likely to smoke (PR=0.88, 95% CI: 0.81, 0.95), and less likely to engage in binge drinking (PR=0.91, 95% CI: 0.84, 0.97). Alcohol consumption did not yield statistically significant results in either of the pandemic periods, compared to the pre-disaster period.

2.3.3 Effect Modification: Days of poor health

Multivariate linear regression models were run for outcomes of interest and interaction terms were used to assess effect modification. All models were controlled for age, income, sex, marital status, and employment status. The pre-disaster period was used as the reference point for all analyses and multiple imputation was used to account for missingness. We tested for effect modification within categories of sex, income, education, and employment status. To test for effect modification, the category that was associated with the highest privilege was selected as the reference point. In other words, identifying as male, falling under the highest income and education categories, and being employed were selected as the reference points for sex, income, education, and employment status, respectively. Overall, our estimates showed that these variables modified the relationship between days of poor health and disaster exposure to some extent, but strength and direction of effect modification varied within levels of these categories and across disaster period (Table 3).

Consistent with our hypothesis, female sex was associated with significantly more days of poor mental health in the early (β=0.43) and late pandemic periods (β=0.53). Female sex was not associated with statically significant difference in days of poor mental health in the early and late post-hurricane periods. However, opposite to our hypothesis, female sex was consistently protective for days of poor physical health across disaster periods, with significantly fewer days in the early post-hurricane period (β=-0.95), and lower—although not statistically significant—differences in the late post-hurricane (β=-0.14), early pandemic (β=-0.30), and late pandemic (β=-0.22) periods.

Our results show that lower income levels were associated with more days of poor mental and physical health across disaster periods compared to being in the highest income category (i.e., earning $50k or more). In particular, participants earning $15k or less had significantly more days of poor mental health in the early post-hurricane (β=1.24) and early pandemic period (β=0.80) and significantly more days of poor physical health in the late post-hurricane (β=0.69), early pandemic (β=0.66), and late pandemic (β=1.33) periods. Moreover, participants in the $15k - $25k income group had similar differences, with significantly more days of poor mental health in the early post-hurricane period (β=1.18) and significantly more days of poor physical health in the early post-hurricane (β=1.20), late post-hurricane (β=0.53), and early pandemic (β=0.62) periods.

Similarly, lower education levels were mostly associated with more days of poor mental and physical health across disaster periods compared to being in the highest education category (i.e., college graduates). In particular, individuals with less than high school education had significantly more days of poor mental health in the early post-hurricane period (β=0.93), and significantly more days of poor physical health in the early post-hurricane (β=1.20), late post-

hurricane (β=1.15), early pandemic (β=1.79), and late pandemic (β=0.61) periods. The late post-hurricane, early pandemic, and late pandemic periods were not associated with significant differences in the lowest education group. On the other hand, those with a completed high school degree had significantly more days of poor mental health in the late post-hurricane period (β=0.36), and significantly more days of poor physical health in the late post-hurricane (β=0.97) and early pandemic (β=0.98) periods. However, contrary to our hypothesis, individuals with a completed high school education had significantly fewer days of poor mental health (β=-1.44) compared to those with college degrees in the early post-hurricane period. Additionally, we also found that, during the early post-hurricane period, those with some college education had the strongest stratified effect for additional days of poor mental health, with 1.83 additional days of poor mental health ($p<0.001$) compared to those with a college degree.

Our results show that employment status modified the relationship between days of poor mental and physical health and disaster exposure in unexpected ways. Contrary to our hypothesized directions of association, being unemployed was mostly not associated with more days of poor mental or physical health, except in the early pandemic period (β=0.78), and was statistically protective (β=-2.02) for poor physical health in the early post-hurricane period compared to participants who were employed. Moreover, participants who were unable to work had lower rates of poor mental health in the late post-hurricane (β=-1.45), early pandemic (β=-1.76), and late pandemic (β=-1.18) periods, but had higher rates in the early post-hurricane period (β=1.56). However, they had significantly higher rates of poor physical health in both the early post-hurricane (β=4.36) and late post-hurricane (β=1.59) periods. On the other hand, participants who identified as homemakers/housewives had significantly higher rates of days of poor mental health in the late pandemic (β=1.45) and significantly higher rates of days of poor

physical health in the late post-hurricane (β=0.94), early pandemic (β=1.12), and late pandemic (β=0.97) periods, consistent with our hypothesis.

2.3.4 Effect modification: Current General Health Status & Health Modifying Behaviors

Multivariate log-binomial regression models were fit for outcomes of interest and interaction terms were used to assess effect modification. All models were controlled for age, income, sex, marital status, and employment status. The pre-disaster period was used as the reference point for all analyses and multiple imputation was used to account for missingness. We tested for effect modification within categories of sex, income, education, and employment status. To test for effect modification, the category that was associated with the highest privilege was selected as the reference point. In other words, identifying as male, falling under the highest income and education categories, and being employed were selected as the reference points for sex, income, education, and employment status, respectively. Overall, our estimates showed that the variables we selected modified the relationship between our outcome variables and disaster exposure, but effect modification strength and direction varied within levels of these categories and across disaster periods. Prevalence ratios are presented in reference to the highest privilege categories in Tables 4 (for exercising, smoking, and negative general health) and 5 (for drinking and heavy drinking episodes), and stratified prevalence ratios are also included in Table 6 (for exercising, smoking, and negative general health) and 7 (for drinking and heavy drinking episodes).

Contrary to our hypothesis, female sex was not a consistently harmful effect modifier for exercising, smoking, and negative general health perceptions. For exercising, identifying as female did not yield significant results across disaster periods, except in the late post-hurricane period which was associated with slightly higher likelihood of exercising (PR=1.05, 95% CI:

1.00, 1.10). Similarly, identifying as female was only associated with higher levels of smoking in the late post-hurricane period (PR=1.07, 95% CI 1.01, 1.13). In terms of perceptions of current health status, identifying as female was associated with lower likelihood of reporting negative general health in the early post-hurricane period (PR=0.90, 95% CI: 0.83, 0.98) and higher likelihood in the early pandemic period (PR=1.06, 95% CI: 1.00, 1.14). In terms of drinking, female sex was not associated with significant differences, except in the case of heavy drinking episodes in the early post-hurricane period (PR=1.12, 95% CIL 1.00, 1.26).

Consistent with our hypothesis, lower levels of income were associated with exercising, smoking, negative general health perceptions, and drinking in particular disaster periods. We found that participants in the lowest income category (<$15k) had slightly lower exercising rates than those in the highest income ($50k+) category in the late post-hurricane (PR=0.95), early pandemic (PR=0.95), and late pandemic (PR=0.94) periods, although these differences were not statistically significant. Smoking was reported at higher levels among individuals in lower income categories, with participants in the lowest income groups having particularly harmful associations in the early pandemic period (PR=1.28, 95% CI: 1.12, 1.46). Participants in the second lowest income category ($15k - $25k) had particularly harmful associations with smoking in the early post-hurricane period (PR=1.48, 95% CI: 1.17, 1.87). On the other hand, during the early post-hurricane period, negative general health perceptions were higher among participants in the lowest income group (PR=1.14), second lowest income group (PR=1.17), and third lowest income group (PR=1.39), compared to individuals in the highest income group. In terms of alcohol consumption, participants in the lowest income group did not have statistically significant differences compared to the highest income group. However, the second lowest income group had higher drinking rates in the late post-hurricane (PR=1.10, 95% CI: 1.03, 1.17)

and lower rates in the early post-hurricane period (PR=0.87, 95% CI: 0.75, 1.00). In terms of heavy drinking episodes, participants in the lowest income group had higher rates in the early post-hurricane (PR=1.13) and early pandemic (PR=1.16) periods.

Consistent with our hypothesis, lower education levels were associated with higher levels of smoking, negative general health perceptions, and heavy drinking in particular disaster periods, compared to individuals with the highest education level (i.e., college graduates). However, these results were not consistent across outcomes and periods. In terms of exercising, we did not find statistically significant differences across educational level. However, we found that participants with less than a high school education were more likely to smoke in the early post-hurricane (PR=1.33, 95% CI: 1.08, 1.64), but less likely to smoke in the late pandemic period (PR=0.66, 95% CI: 0.57, 0.79). Moreover, participants in the lowest education category were also more likely to report negative general health perceptions in the early post-hurricane (PR=1.20, 95% CI: 1.01, 1.42) and early pandemic period (PR=1.10, 95% CI: 0.98, 1.23), but less likely to report negative general health in the late post-hurricane period (PR=0.84, 95% CI: 0.78, 0.90). In terms of alcohol consumption, the lowest education did not have statistically significant differences compared to the highest educational category; however, the direction of association was harmful during the late post-hurricane (PR=1.06, 95% CI: 0.97, 1.16) and early pandemic (PR=1.13, 95% CI: 0.97, 1.31). Moreover, the early pandemic was also associated with higher levels of heavy drinking among participants in the lowest education category (PR=1.27, 95% CI: 1.05, 1.53).

Employment status yielded mixed results across all outcomes and disaster periods when comparing different groups to those who are employed. In particular, participants who are unable to work had significantly lower rates of smoking in the early post-hurricane period (PR=0.42,

95% CI: 0.28, 0.64) but significantly higher rates of smoking in the early pandemic (PR=2.08, 95% CI: 1.59, 2.72) and late pandemic (PR=1.50, 95% CI: 1.16, 1.93). On the other hand, they were also more likely to report negative general health perceptions during the late post-hurricane period (PR=1.16, 95% CI: 1.01, 1.33), but less likely to report it during the early pandemic (PR=0.68, 95% CI: 0.54, 0.85), compared to participants who were employed. In terms of drinking, participants who were unable to work had lower rates of alcohol consumption in the early post-hurricane period (PR=0.58, 95% CI: 0.41, 0.83), but higher rates in the late post-hurricane (PR=1.25, 95% CI: 1.08, 1.46) and early pandemic periods (PR=1.17, 95% CI: 0.94, 1.46). Similarly, participants who were unable to work were significantly less likely to have a heavy drinking episode in the early post-hurricane period (PR=0.23, 95% CI: 0.10, 0.50) but much more likely to have a heavy drinking episode in the late post-hurricane (PR=1.72, 95% CI: 1.31, 2.24), early pandemic (PR=1.77, 95% CI: 1.26, 2.48), and late pandemic periods (PR=1.27, 95% CI: 0.87, 1.87). On the other hand, participants who were unemployed were more likely to exercise in the late post-hurricane period (PR=1.17, 95% CI: 1.05, 1.30). They were also more likely to smoke in the early post-hurricane period (PR=1.20, 95% CI: 0.89, 1.63) and late post-hurricane (PR=1.18, 95% CI: 1.00, 1.38). Moreover, while differences were not statistically significant, unemployed participants were slightly more likely to report negative general health perceptions in the early post-hurricane (PR=1.16, 95% CI: 0.90, 1.50) and early pandemic (PR=1.16, 95% CI: 0.98, 1.38). In terms of alcohol consumption, unemployed participants were more likely to consume alcohol during the early post-hurricane period (PR=1.48, 95% CI: 1.17, 1.88) and significantly more likely to have a heavy drinking episode during the same period (PR=2.07, 95% CI: 1.47, 2.93). However, they were less likely to drink (PR=0.89, 95% CI 0.78,

0.99) and have a heavy drinking episode (PR=0.74, 95% CI: 0.62, 0.88) in the late post-hurricane period.

2.4 Discussion

2.4.1 Summary of research findings

This study examined the association between multiple disaster exposures and the physical, mental, and behavioral health of a sample of 35,517 adults living in Puerto Rico between 2015 and 2022 who participated in the BRFSS. Firstly, in the six months immediately after hurricane Maria, our main effects analysis showed that all of our outcomes—except for drinking and heavy drinking—had consistently harmful directions of association among participants, compared to before these disasters. Secondly, after the COVID-19 pandemic began, health outcomes showed an apparent improvement compared to the pre-disaster period, with participants having fewer days of poor mental health in the early and late pandemic periods, less heavy drinking episodes in the late pandemic, fewer days of poor physical health in the early pandemic period, less smoking in the late pandemic, and more positive perceptions of their general health status than pre-disaster in both the early and late pandemic. We also found that sex, income, education, and employment status modified the association between our exposure and outcomes of interest, but that the extent and direction of modification varied across disaster and outcome.

2.4.2 Main discussion and contextualization of results

Consistent with other studies, we found that disaster exposure had potentially significant adverse implications for mental health. This was particularly evident in the early post-hurricane

period, which was associated with 2.47 additional days of poor mental health in the 30 days prior to the interview, compared to the pre-disaster period. This period was also associated with increased smoking (PR=1.20), more negative perceptions of current health status (PR=1.32), and a harmful direction of association for alcohol consumption (PR=1.06); these findings could suggest that stress, anxiety, and other mental health conditions were driving substance use as a coping mechanism. A recent systematic review supports this idea, finding that biologic, natural, and man-made disasters were all associated with psychological distress, ranging from alcohol distress, PTSD, anxiety, anger, perceived risk, depression, and numerous other mental health endpoints.[37] While our observed association between disaster exposure and mental and behavioral health did not persist across disaster periods, it is important to note that the direction of association was consistently harmful for alcohol consumption and that sex, income, and education significantly modified mental health and substance use behaviors associated with disasters. For example, out stratified analysis (Tables 6 and 7) showed that participants with less than a high school education were significantly more likely to smoke during the early post-hurricane (PR=1.60, 95% CI: 1.30, 1.97), more likely to drink during the late post-hurricane (PR=1.12, 95% CI: 1.03, 1.23) and early pandemic (PR=1.15, 95% CI: 0.99, 1.34), and more likely to have a heavy drinking episode during the early pandemic (PR=1.26, 95% CI: 1.04, 1.51). This could suggest that while a disaster does not necessarily have widespread mental impacts in the general population, it could still have significant impacts in more vulnerable subgroups. We should further consider that a hurricane and a pandemic are disasters of different hazard type, and this could contribute to participants' experiences. Specifically, the context of the pandemic with the threat of a respiratory virus, might influence the likelihood of adopting behaviors such as smoking and drinking, which could increase the risk of COVID-19

complications. It is possible that while participants were feeling anxiety, depression, and other mental health complications, they resorted to other coping mechanisms to avoid COVID-19 related complications. Prior literature examining post-disaster substance use has similarly found that individuals with greater social vulnerability are more likely to adopt potentially harmful substance use behaviors to cope with stress post-disaster, but scarce research has examined the role of educational attainment in post-disaster contexts.[38,39] Importantly, we must also consider that interviewer bias may be underestimating the true association between disaster exposure and mental and behavioral health, since no prior rapport was established and participants may not be comfortable disclosing their mental or behavioral health status due to the social stigma associated with these.[40-42]

To the best of our knowledge, our study is one of the first exploratory epidemiologic studies to consider the impact of multiple disasters in a single population and to consider the potential impacts of multiple disasters at multiple timepoints. We found variability for how individuals reported their physical, mental, and behavioral health in multiple disaster contexts, even within different stages of the same disaster. While other studies have mostly found that self-reported health after a disaster is negative,[14,43] we found that this could depend on the type of disaster and the stage of the disaster at the time of data collection. For example, people were more likely to report their general health status negatively in the early post-hurricane period (PR=1.32) but were less likely to report their health status negatively in the early pandemic (PR=0.73) and late pandemic (PR=0.76) periods. A hypothesized explanation for the pandemic appearing to be protective, is that this apparent association might be the result of participants reporting their health as better than it is during the pandemic, due to comparing their own health with persons who were hospitalized, sick, or dying of COVID-19. However, we were unable to

identify any research that corroborates our hypothesis. On the other hand, a disaster such as Hurricane Maria, which broadly disrupted access to food, clean water, medication, and other essential needs, might affect participants' health status more directly, providing more immediately apparent health impacts. Nonetheless, our findings suggest that participants' perception of their health might vary depending on the nature of the disaster.

We also found that income and employment status significantly modified the relationship between disaster exposure and health outcomes. Importantly, in the early post-hurricane period, participants in the $15k or less (PR=1.14) and in the $15k-$25k (PR=1.48), and in the early pandemic period, participants in the $15k or less (PR=1.28), were significantly more likely to report smoking, compared to those in the highest income group. We also saw that participants who identified as unemployed (PR=1.20), retired (PR=1.21), and homemakers were more likely to smoke in the early post-hurricane period than those who were employed, while those who were unable to work were more likely to have higher smoking rates in the early pandemic (PR=2.08) and late pandemic (PR=1.50). Similarly, those who were unemployed were more likely to report drinking (PR=1.48) and heavy drinking episodes (PR=2.07) during the early post-hurricane period. On the other hand, those who were unable to work also reported higher rates of drinking in the late post-hurricane, and higher rates of heavy drinking in the late post-hurricane (PR=1.72), early pandemic (PR=1.77), and late pandemic (PR=1.27), compared to employed individuals. These findings suggest that income and employment may be a significant driver of health disparities, particularly in the earlier periods of disaster exposure. This could be the result of socioeconomic status driving access to essential resources, which might be particularly scarce earlier in a disaster. Our findings are consistent with other studies that showed that pre-existing

socioeconomic conditions played a significant role in the ability to respond to a disaster and cope with its impact.[44-46]

Importantly, for days of poor mental health, female sex was a significant harmful effect modifier during only the early and late pandemic periods. With women having 0.43 and 0.53 more days of poor mental health in the early and late pandemic, respectively. If we further consider that identifying as a homemaker/housewife was also associated with more days of poor mental health in the same periods, one potential explanation is that women may be experiencing additional mental health distress in the pandemic period due to added stress from responsibilities at home. This is consistent with findings from other studies showing that women were more likely to experience burnout and mental distress during the pandemic due to additional responsibilities as caregivers.[47-49] However, it is also important to recognize that identifying as female was not associated with increased rates of heavy drinking, drinking, or smoking across disaster periods, except for an increased rate of heavy drinking in the early post-hurricane period. This could be the result of women having different coping mechanisms during disasters, compared to those who identified as male, but more research is needed.

While our study does not explicitly consider the role of colonialism in shaping public health outcomes during disaster exposure, we wanted to briefly consider how it might contribute to our results. Particularly, our findings suggest that the early post-hurricane was especially harmful across outcomes since it was associated with more days of poor mental and physical health, less exercising, more smoking, more drinking, and more negative perceptions of general health status, compared to pre-disaster. While this could be due to the severity of Hurricane Maria, a major driver of these differences could be the lack of preparedness and delay in federal recovery efforts that was seen during this disaster, which was not seen during the pandemic. This

delay is particularly striking when comparing Puerto Rico's experience with Hurricane Maria to other similar disasters such as Hurricane Harvey and Hurricane Irma in Texas and Florida, respectively, and these disparities in recovery response time have been well-documented by a myriad of research.[50-54]

2.4.3 Limitations

This study has several key limitations. Firstly, the design we used, leveraging the publicly available BRFSS data, can be characterized as a repeated cross-sectional study and therefore does not follow people longitudinally. In other words, it does not represent the health and exposure trajectories of the same individuals over time, but rather it is meant to be representative of the target population over time. Future studies seeking to explore the same relationships could benefit from using a retrospective or prospective cohort and/or a case-control design to better understand causal relationships. Given the limitations with the BRFSS and Cross-Sectional studies, our study fails to capture the cumulative effects of multiple disasters and instead follows the prevalence physical, mental, and behavioral health outcomes at different disaster periods. Future studies would benefit from following individuals over time and considering their individual physical and mental health trajectories across disaster periods, rather than just compared to the pre-disaster period. Moreover, the cross-sectional design used for our study limits our ability to untangle the differences between confounders and mediators. Particularly, we could expect that employment status, income, marital status, and potentially other variables could be both mediators as well as confounders. Particularly because the status of these could change as a result of these disasters; however, due to the limitations in our cross-sectional design, we only have information on current sociodemographic characteristics and therefore can only analyze these variables as confounders. Future studies should consider the role of these type

of covariates at baseline as confounders, and their potential change over time as a result of disaster exposure to consider their mediation effect.

Secondly, we expect that our analysis is subject to selection bias due to survival bias, unintended censorship/exclusion of individuals most affected by disasters, and other key factors. Specifically, it is possible that those who are most likely to be disproportionately affected by a disaster (e.g., someone who lost their home during a hurricane and/or is without power and communication for months) are also less likely to be captured by the date because they cannot easily be contacted for the phone interview. Additionally, we expect that survival bias could also be playing a role in this study given that those with more severe disaster experiences are also more likely to have died or have been incapacitated and would therefore not be captured by the data. Similarly, population estimates have suggested that a significant proportion of the population in Puerto Rico emigrated in the year after Maria—and potentially after other disasters—meaning that these people are likely not captured by the BRFSS survey data in Puerto Rico. In all these scenarios, we would expect that selection bias could underestimate the true effect of disaster exposure and bias our results towards the null since we are expecting that those who are identified for interviews are likely more financially secure and possess more protective factors for post-disaster adjustment.

Thirdly, information/measurement bias is likely influencing our results due to error in both our exposure category and our outcome categories. Specifically, we expect measurement error in our exposure variable as it was operationalized based on the time of the event relative to the interview, not the level of exposure to a particular disaster. In other words, how we measured disaster exposure assumes that everyone who was observed during a period has the same level of exposure to a disaster, which is unlikely to be true for each particular disaster. For example, post-

hurricane experiences can vary widely as there was considerable variation in terms of hurricane wind speeds, mortality, and power outages, across different sectors of Puerto Rico.[55-57] Similarly, the available data does not allow us to capture individual level experiences with a disaster such as loss of home following the hurricane, COVID-19 infection, loss of a family member, and/or physical distancing practices.

The second likely issue with measurement error is with our outcome variables given that they are self-reported health outcomes instead of clinical diagnoses. We therefore expect that they are subject to social desirability, stigma, respondent bias, and other measurement bias. For example, we expect that social desirability and respondent bias could result in participants' reporting their health as better than it actually is particularly because (1) no prior rapport was established between interviewer and participant before the interview and (2) individuals from Latinx communities are generally more distrustful when participating in research and disclosing their health status.[58,59] Moreover, prior experience from the primary author while conducting research in post-disaster settings has also shown that individuals are more likely to feel grateful and report their health and general situation as better than it actually is because they compare themselves relative to people who they perceive had worse experiences during a disaster. For example, people may compare themselves to someone who lost their home during a hurricane or earthquake or someone who was hospitalized with COVID-19, despite having been without power for months or feeling isolated because of social distancing measures. Given that these scenarios would result in individuals who were affected by a disaster to report their health as better than it actually is, we expect that these issues could be biasing our results towards the null or showing protective associations that are not real.

Lastly, we also would like to recognize that most of the effect modification analyses presented in this paper utilize multiple comparisons due to these variables having multiple levels. Specifically, age, income, education, marital status, and employment status have anywhere from 2 to 6 levels, while our exposure categories have 5 levels. Based on mathematical principles, these type of simultaneous statistical analyses may widen confidence intervals.[60-62] Therefore, it is possible that some of the observed associations could be due to chance. This could be addressed using a Bonferroni correction; however, this was not incorporated to our analysis since it can become overly conservative and lead to type II errors.[60,63] Future research could benefit from incorporating false discovery rates to deal with multiple comparisons of this nature since it deals better with an increasing number of hypothesis tests.[64]

2.4.4 Strengths

This study has several key strengths. Firstly, multiple disaster exposure can be considered as an understudied area of epidemiological research and therefore observational and exploratory approaches to examining relationships can be seen as appropriate, especially when leveraging pre-existing data. Specifically, while cross-sectional study designs traditionally do not allow us to establish causality, our approach helps mitigate some of the traditional pitfalls of this study design. In particular, one of the main disadvantages of cross-sectional studies is the inability to determine cause-effect because of issues with temporality. This is because usually, exposure and outcome are assessed at the same time; however, this is not necessarily a concern in our study because our outcome measures are based on time periods and are self-perceptions of current health status, rather than clinical diagnoses, which can be compared to disaster periods and therefore avoid problems with temporality. Secondly, we believe that our methods are appropriate to examine our associations of interest because (1) it is impossible and unethical to

randomize individuals to disaster exposure and (2) it would be very difficult to conduct a cohort study that captures both pre- and post-disaster experiences due to the unexpected nature of these events. Moreover, the examination of these associations allows for further hypothesis generation and findings can be used to inform the development of cohorts and case-control studies that leverage existing longitudinal data. Thirdly, another key strength is that the nature, magnitude, and severity of the disasters discussed in this study (i.e., hurricane and pandemic) allow for the assumption that everyone who was interviewed during this period was exposed—to some extent—to the disasters. In other words, because both Hurricane Maria and the COVID-19 pandemic affected Puerto Rico island-wide, we do not expect misclassification of exposure status. Fourthly, the use of BRFSS data allowed us to examine several health outcomes that represent physical, mental, and behavioral health, allowing for a comprehensive examination of how these disasters may be associated with diverse health outcomes. Lastly, the use of a publicly available nationally representative yearly survey with over 300 variables is a key strength of this study because it leverages secondary data to examine associations, generate hypotheses, and inform future studies and interventions.

2.4.5 Conclusion

Overall, our results reveal important insights about the association between multiple disaster exposure and their public health implications. Consistent with prior literature on post-disaster mental health, we found that there was a harmful impact in self-reported mental health, smoking, and alcohol consumption. We also found that this varied by disaster, with the first six months post-hurricane being particularly harmful while the pandemic period protective. We also found that key factors such as sex, income, education, and employment status modified the association between disaster exposure and self-reported health. Overall, our findings suggest that

disasters can have harmful impacts on health and that future recovery efforts could benefit from targeted interventions among groups that are more likely to be harmed by a particular phenomenon. Future research could benefit from retrospective designs that are more carefully able to consider nuances in individual exposure levels across multiple disaster events.

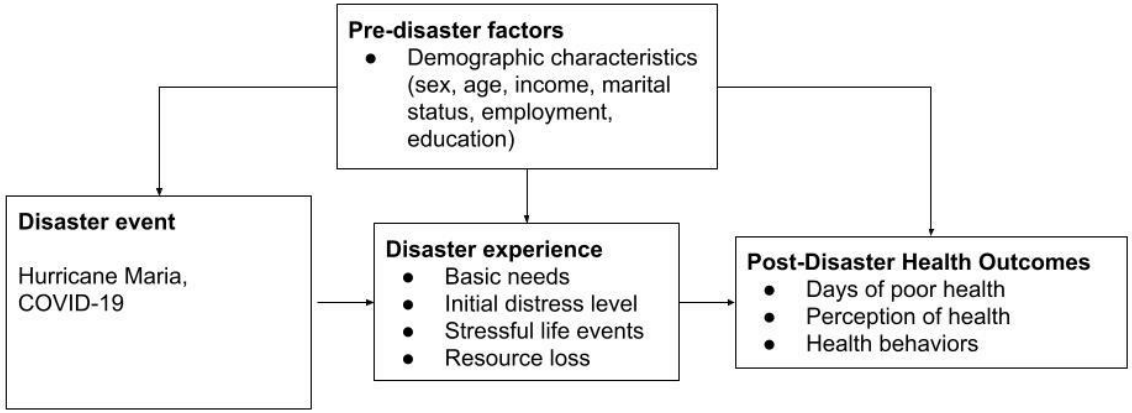

Figure 1: Chapter 2 Conceptual Model

Table 1: Weighted sociodemographic characteristics and distribution of key covariates by disaster; Behavioral Risk Factor Surveillance System Respondents from Puerto Rico, 2017-2022.

	Pre-Disasters	Early Post-Hurricane	Late Post-Hurricane	Early pandemic	Late pandemic	p-value*
	n = 14,837	n = 1,083	n = 10,533	n = 5,055	n = 4,009	
Age groups						<0.0001
18-24	13.1%	13.0%	12.5%	12.6%	12.7%	
25-34	16.4%	17.7%	16.1%	15.9%	15.8%	
35-44	16.2%	20.1%	16.1%	16.0%	16.1%	
45-54	16.7%	19.6%	16.6%	16.7%	16.6%	
55-64	15.8%	14.1%	15.8%	15.8%	15.8%	
65+	21.7%	15.5%	23.0%	23.0%	23.0%	
Income						<0.0001
<15k	49.9%	41.4%	43.2%	42.8%	38.1%	
15k-25k	28.8%	30.9%	30.2%	30.0%	26.4%	
25k-35k	9.0%	11.7%	10.5%	9.3%	12.3%	
35k-50k	6.2%	5.9%	7.1%	7.4%	10.5%	
>50k	6.1%	10.3%	9.0%	10.5%	12.8%	
Sex						<0.0001
Female	53.1%	54.6%	53.3%	53.1%	53.4%	
Education						<0.0001
Less than HS	25.9%	18.2%	23.4%	23.6%	23.5%	
HS Graduate	27.2%	25.9%	27.9%	27.5%	27.5%	
Some college	25.5%	27.2%	16.5%	16.5%	16.7%	
College grad	21.3%	28.8%	32.2%	32.4%	32.3%	
Children						<0.0001
Has children	28.9%	35.8%	29.9%	27.8%	27.6%	
Marital status						<0.0001
Single	23.9%	20.8%	17.6%	17.2%	16.9%	
Married or living with partner	48.8%	46.8%	42.7%	43.5%	43.8%	
Separated or divorced	18.3%	24.4%	28.5%	29.0%	27.8%	
Widowed	9.0%	8.0%	11.3%	10.3%	11.5%	
Employment status						<0.0001
Employed	36.5	47.0%	44.3%	44.5%	50.1%	
Unemployed	10.9%	8.2%	7.7%	11.2%	6.3%	
Homemaker/ Housewife	19.5%	18.8%	16.6%	14.1%	15.0%	
Student	7.2%	6.4%	5.5%	4.5%	4.4%	
Retired	18.6%	13.0%	18.8%	19.6%	16.9%	
Unable to work/Disabled	7.3%	6.5%	7.1%	6.1%	7.5%	

*p-values represent chi-square values for differences between subgroups by disaster periods.

Table 2: Results of multivariate regression models for main outcomes of interest; Behavioral Risk Factor Surveillance System respondents from Puerto Rico, 2017-2022.

Outcome	**Disaster period**	**Estimate**
Linear regression models		
Days of poor mental health in the 30 days prior to the interview		β (SE)
	Early post-hurricane	2.47 (0.24)**
	Late post-hurricane	-0.06 (0.08)
	Early pandemic	-0.55 (0.10)**
	Late pandemic	-0.32 (0.11)**
Days of poor physical health in the 30 days prior to the interview		β (SE)
	Early post-hurricane	0.80 (0.19)**
	Late post-hurricane	1.17 (0.08)**
	Early pandemic	-0.72 (0.16)**
	Late pandemic	0.38 (0.14)**
Log-binomial regression models		**Prevalence ratios**
Exercised in the 30 days prior to the interview		*PR (95% CI)*
	Early post-hurricane	0.65 (0.61, 0.70)**
	Late post-hurricane	1.02 (0.99, 1.04)
	Early pandemic	1.15 (1.10, 1.20)**
	Late pandemic	1.14 (1.09, 1.20)**
Smoked in the 30 days prior to the interview		*PR (95% CI)*
	Early post-hurricane	1.20 (1.07, 1.34)**
	Late post-hurricane	0.94 (0.88, 0.99)**
	Early pandemic	0.97 (0.90, 1.05)**
	Late pandemic	0.88 (0.81, 0.95)**
Consumed alcoholic drinks in the 30 days prior to the interview		*PR (95% CI)*
	Early post-hurricane	1.06 (0.98, 1.15)
	Late post-hurricane	1.01 (0.98, 1.13)
	Early pandemic	0.98 (0.93, 1.03)
	Late pandemic	1.02 (0.97, 1.07)
Binge drinking in the 30 days prior to the interview		*PR (95% CI)*
	Early post-hurricane	0.96 (0.85, 1.07)
	Late post-hurricane	1.08 (1.02, 1.14)**
	Early pandemic	1.00 (0.93, 1.08)
	Late pandemic	0.91 (0.84, 0.97)**
Current perception of their health as negative		*PR (95% CI)*
	Early post-hurricane	1.32 (1.22, 1.43)**
	Late post-hurricane	1.18 (1.14, 1.23)**
	Early pandemic	0.73 (0.69, 0.78)**
	Late pandemic	0.76 (0.70, 0.82)**

*All models were controlled for age, income, sex, education, marital status, and employment status. The pre-disaster period was used as the reference point for all analyzes.
** p-value < 0.05

Table 3: Effect modification in linear regression models by outcome and disaster periods; Behavioral Risk Factor Surveillance System respondents from Puerto Rico, 2017-2022.

	Outcomes							
	Mental health				**Physical Health**			
Effect modifier	Early Post Hurricane	Late Post Hurricane	Early Pandemic	Late Pandemic	Early Post Hurricane	Late Post Hurricane	Early Pandemic	Late Pandemic
Sex	Estimate (days of poor health)				Estimate (days of poor health)			
Male	ref	ref	ref	ref	ref	ref	ref	ref
Female	-0.39	0.00	0.43*	0.53*	-0.95*	-0.14	-0.30	-0.22
Income	Estimate (days of poor health)				Estimate (days of poor health)			
$50k or more	ref	ref	ref	ref	ref	ref	ref	ref
$35k - $50k	-2.28*	-0.13	0.59	-0.76*	-0.23	-0.63*	-0.09	0.25
$25k - $35k	-0.18	-0.36	0.82*	0.16	0.18	-0.36	0.06	-0.02
$15k -$25k	1.18	0.36	0.48	0.17	1.20*	0.53*	0.62	0.38
$15K or less	1.24	0.18	0.80*	0.06	0.36	0.69*	0.66*	1.33*
Education	Estimate (days of poor health)				Estimate (days of poor health)			
College grad	ref	ref	ref	ref	ref	ref	ref	ref
Some college	1.83*	0.17	-0.35	0.85*	0.28	0.71*	0.39	0.34
High School	-1.44*	0.36*	-0.07	0.39	-0.61	0.97*	0.98*	0.49
Less than HS	0.93*	0.00	-0.70*	0.12	1.20*	1.15*	1.79*	0.61
Employment	Estimate (days of poor health)				Estimate (days of poor health)			
Employed	ref	ref	ref	ref	ref	ref	ref	ref
Unemployed	-0.67	0.46	-0.41	-0.19	-2.02*	0.04	0.78*	0.16
Homemaker	0.10	0.32	0.27	1.45*	0.31	0.94*	1.12*	0.97*
Student	-0.50	0.17	0.05	1.92*	0.24	-0.33	0.16	1.72*
Retired	0.67	0.22	0.21	0.39	-0.72	0.54*	1.31*	1.33*
Unable to work	1.56	-1.45*	-1.76*	-1.18	4.36*	1.59*	-1.66*	0.72

*All models were controlled for age, income, sex, education, marital status, and employment status. The pre-disaster period was used as the reference point for all analyzes.
** p-value < 0.05

Table 4: Effect modification in log-binomial models by outcome and disaster periods; Behavioral Risk Factor Surveillance System respondents from Puerto Rico, 2017-2022.

	Exercising				Smoking				Negative General Health			
Effect modifier	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic
Sex	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
Male	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref
Female	1.04 (0.97, 1.12)	1.05 (1.00, 1.10)	0.97 (0.92, 1.01)	0.97 (0.94, 1.00)	0.95 (0.85, 1.07)	1.07 (1.01, 1.13)	1.00 (0.93, 1.08)	0.95 (0.87, 1.03)	0.90 (0.83, 0.98)	0.98 (0.94, 1.02)	1.06 (1.00, 1.14)	1.01 (0.95, 1.07)
Income	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
$50k or more	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref
$35k - $50k	0.94 (0.77, 1.16)	1.19 (1.08, 1.31)	0.93 (0.83, 1.05)	0.92 (0.82, 1.05)	0.44 (0.24, 0.80)	1.11 (0.89, 1.39)	1.41 (1.11, 1.80)	1.14 (0.86, 1.51)	0.85 (0.64, 1.13)	0.99 (0.87, 1.13)	0.97 (0.82, 1.15	1.14 (0.96, 1.34)
$25k - $35k	1.04 (0.88, 1.24)	0.89 (0.82, 0.96)	1.06 (0.96, 1.18)	1.02 (0.92, 1.14)	1.09 (0.80, 1.50)	1.05 (0.90, 1.23)	0.70 (0.57, 0.86)	1.08 (0.87, 1.34)	1.39 (1.10, 1.75)	0.98 (0.88, 1.09)	0.97 (0.83, 1.13)	0.86 (0.75, 0.99)
$15k -$25k	0.96 (0.84, 1.09)	0.98 (0.92, 1.04)	1.02 (0.94, 1.10)	0.99 (0.91, 1.08)	1.48 (1.17, 1.87)	0.86 (0.76, 0.96)	0.98 (0.85, 1.12)	0.99 (0.84, 1.16)	1.17 (0.99, 1.37)	1.00 (0.93, 1.07)	1.02 (0.92, 1.14)	0.88 (0.80, 0.98)
$15K or less	1.17 (1.04, 1.32)	0.95 (0.90, 1.01)	0.95 (0.88, 1.03)	0.94 (0.89, 0.99)	1.14 (0.91, 1.43)	0.98 (0.88, 1.08)	1.28 (1.12, 1.46)	0.82 (0.71, 0.95)	1.14 (0.99, 1.33)	0.95 (0.89, 1.02)	1.07 (0.97, 1.18)	0.94 (0.86, 1.03)
Education	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
College grad	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref
Some college	0.92 (0.82, 1.04)	1.04 (0.99, 1.11)	0.96 (0.89, 1.03)	1.04 (0.96, 1.13)	1.01 (0.85, 1.22)	0.96 (0.87, 1.05)	0.94 (0.83, 1.06)	1.14 (1.00, 1.31)	0.94 (0.82, 1.08)	1.07 (1.01, 1.15)	0.83 (0.76, 0.91)	1.10 (1.00, 1.20)
High school	0.95 (0.84, 1.08)	0.97 (0.91, 1.02)	1.07 (0.99, 1.15)	1.02 (0.94, 1.10)	0.92 (0.77, 1.10)	0.91 (0.83, 1.00	1.04 (0.91, 1.19)	1.32 (1.15, 1.51)	0.99 (0.86, 1.14)	1.06 (1.00, 1.13)	1.07 (0.97, 1.18)	0.93 (0.85, 1.01)
Less than HS	1.08 (0.93, 1.26)	1.07 (1.00, 1.15)	0.92 (0.83, 1.01)	0.94 (0.85, 1.03)	1.33 (1.08, 1.64)	1.08 (0.97, 1.20)	1.04 (0.90, 1.19)	0.66 (0.57, 0.79)	1.20 (1.01, 1.42)	0.84 (0.78, 0.90)	1.10 (0.98, 1.23)	0.99 (0.89, 1.09)
Employment	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
Employed	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref
Unemployed	0.87 (0.70, 1.08)	1.17 (1.05, 1.30)	1.02 (0.89, 1.17)	1.01 (0.87, 1.17)	1.20 (0.89, 1.63)	1.18 (1.00, 1.38)	0.95 (0.77, 1.17)	0.80 (0.63, 1.03)	1.16 (0.90, 1.50)	0.95 (0.84, 1.08)	1.16 (0.98, 1.38)	0.87 (0.72, 1.05)
Homemaker	1.22 (1.04, 1.43)	0.83 (0.77, 0.90)	0.99 (0.88, 1.12)	1.05 (0.93, 1.18)	1.30 (1.00, 1.70)	1.01 (0.87, 1.17)	0.84 (0.68, 1.04)	0.85 (0.68, 1.06)	1.24 (1.04, 1.49)	0.90 (0.82, 0.98)	0.98 (0.86, 1.13)	0.97 (0.85, 1.10)
Student	0.85 (0.65, 1.10)	1.04 (0.91, 1.19)	1.05 (0.87, 1.25)	0.88 (0.71, 1.10)	1.04 (0.59, 1.84)	0.88 (0.66, 1.18)	0.95 (0.65, 1.38)	0.83 (0.53, 1.31)	0.47 (0.29, 0.77)	1.25 (1.02, 1.54)	1.19 (0.88, 1.60)	1.14 (0.83, 1.55)
Retired	1.34 (1.14, 1.57)	0.89 (0.83, 0.96)	0.87 (0.78, 0.98)	1.04 (0.93, 1.15)	1.21 (0.90, 1.61)	1.09 (0.95, 1.25)	0.71 (0.59, 0.86)	1.13 (0.92, 1.39)	1.14 (0.95, 1.36)	0.83 (0.77, 0.90)	1.21 (1.07, 1.39)	1.00 (0.89, 1.13)
Unable to work	0.87 (0.67, 1.13)	1.16 (1.03, 1.30)	0.98 (0.82, 1.18)	1.03 (0.87, 1.21)	0.42 (0.28, 0.64)	0.90 (0.74, 1.08)	2.08 (1.59, 2.72)	1.50 (1.16, 1.93)	1.06 (0.79, 1.41)	1.16 (1.01, 1.33)	0.68 (0.54, 0.85)	1.13 (0.94, 1.37)

*All models were controlled for age, income, sex, education, marital status, and employment status. The pre-disaster period was used as the reference point for all analyses.

Table 5: Effect modification by alcohol drinking behaviors and disaster periods; Behavioral Risk Factor Surveillance System respondents from Puerto Rico, 2017-2022.

	Drinking				Heavy Drinking			
Effect modifier	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic
Sex	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
Male	ref	ref	ref	ref	ref	ref	ref	ref
Female	1.02 (0.95, 1.11)	0.97 (0.93, 1.00)	1.00 (0.95, 1.05)	1.03 (0.98, 1.08)	1.12 (1.00, 1.26)	0.96 (0.91, 1.01)	0.92 (0.85, 0.98)	1.06 (0.99, 1.14)
Income	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
$50k or more	ref	ref	ref	ref	ref	ref	ref	ref
$35k - $50k	1.10 (0.89, 1.35)	0.99 (0.90, 1.09)	1.07 (0.95, 1.20)	0.92 (0.75, 1.14)	1.35 (1.02, 1.79)	1.01 (0.88, 1.15)	0.84 (0.71, 0.98)	0.96 (0.82, 1.14)
$25k - $35k	0.96 (0.80, 1.15)	0.97 (0.88, 1.05)	0.94 (0.84, 1.05)	1.13 (1.01, 1.27)	0.78 (0.57, 1.07)	0.95 (0.83, 1.09)	1.00 (0.85, 1.19)	1.22 (1.03, 1.43)
$15k -$25k	0.87 (0.75, 1.00)	1.10 (1.03, 1.17)	0.97 (0.89, 1.05)	1.00 (0.91, 1.10)	0.91 (0.74, 1.12)	1.08 (0.99, 1.19)	0.99 (0.88, 1.11)	0.94 (0.82, 1.08)
$15K or less	1.00 (0.88, 1.15)	1.03 (0.96, 1.09)	1.05 (0.96, 1.16)	0.93 (0.85, 1.02)	1.13 (0.93, 1.38)	0.93 (0.84, 1.02)	1.16 (1.02, 1.32)	0.91 (0.80, 1.04)
Education	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
College grad	ref	ref	ref	ref	ref	ref	ref	ref
Some college	1.10 (0.96, 1.27)	1.04 (0.97, 1.11)	1.00 (0.92, 1.09)	1.06 (0.97, 1.17)	1.07 (0.87, 1.30)	0.91 (0.83, 1.00)	0.87 (0.77, 0.97)	1.23 (1.08 ,1.39)
High school	1.11 (0.97, 1.28)	0.93 (0.87, 0.99)	0.89 (0.81, 0.97)	0.91 (0.82, 1.00)	0.98 (0.80, 1.20)	1.07 (0.97, 1.17)	1.04 (0.93, 1.17)	0.88 (0.78, 1.01)
Less than HS	0.85 (0.70, 1.00)	1.06 (0.97, 1.16)	1.13 (0.97, 1.31)	0.95 (0.83, 1.07)	1.01 (0.75, 1.35)	0.94 (0.83, 1.07)	1.27 (1.05, 1.53)	0.84 (0.70, 1.02)
Employment	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
Employed	ref	ref	ref	ref	ref	ref	ref	ref
Unemployed	1.48 (1.17, 1.88)	0.89 (0.78, 0.99)	0.93 (0.78, 1.11)	0.89 (0.75, 1.06)	2.07 (1.47, 2.93)	0.74 (0.62, 0.88)	0.90 (0.67, 1.19)	0.95 (0.75, 1.21)
Homemaker	1.11 (0.90, 1.36)	0.88 (0.79, 0.98)	1.05 (0.91, 1.21)	0.92 (0.78, 1.07)	1.22 (0.83, 1.79)	0.84 (0.71, 1.00)	1.06 (0.84, 1.34)	0.91 (0.72, 1.16)
Student	1.01 (0.75, 1.35)	1.00 (0.87, 1.15)	0.96 (0.80, 1.16)	1.10 (0.89, 1.37)	1.23 (0.80, 1.91)	0.98 (0.80, 1.20)	0.78 (0.59, 1.01	1.03 (0.77, 1.39)
Retired	0.88 (0.72, 1.06)	1.07 (0.98, 1.17)	0.99 (0.85, 1.16)	1.07 (0.94, 1.21)	0.99 (0.69, 1.41)	1.07 (0.92, 1.24)	0.95 (0.79, 1.15)	0.90 (0.73, 1.12)
Unable to work	0.58 (0.41, 0.83)	1.25 (1.08, 1.46)	1.17 (0.94, 1.46)	1.09 (0.87, 1.38)	0.23 (0.10, 0.50)	1.72 (1.31, 2.24)	1.77 (1.26, 2.48)	1.27 (0.87, 1.87)

*All models were controlled for age, income, sex, education, marital status, and employment status. The pre-disaster period was used as the reference point for all analyses.

Table 6: Stratified effects of log-binomial models by outcome and disaster periods; Behavioral Risk Factor Surveillance System respondents from Puerto Rico, 2017-2022.

	Exercising				Smoking				Negative General Health			
Effect modifier	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic
Sex	Prevalence Ratio (95% confidence interval)**				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)**			
Male	0.65 (0.60, 0.70)	1.02 (0.99, 1.06)	1.15 (1.10, 1.21)	1.14 (1.08, 1.20)	1.19 (1.06, 1.32)	0.95 (0.90, 1.01)	0.97 (0.90, 1.04)	0.86 (0.80, 0.94)	1.34 (1.24, 1.46)	1.18 (1.14, 1.23)	0.72 (0.68, 0.77)	0.76 (0.71, 0.80)
Female	0.68 (0.63, 0.73)	1.07 (1.02, 1.10)	1.12 (1.06, 1.16)	1.11 (1.07, 1.14)	1.13 (1.01, 1.27)	1.02 (0.96, 1.07)	0.97 (0.90, 1.05)	0.81 (0.75, 0.89)	1.21 (1.11, 1.31)	1.16 (1.11, 1.20)	0.76 (0.72, 0.82)	0.77 (0.72, 0.81)
Income	Prevalence Ratio (95% confidence interval)**				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)**			
$50k or more	0.62 (0.57, 0.68)	1.05 (1.01, 1.09)	1.16 (1.10, 1.22)	1.16 (1.11, 1.23)	0.99 (0.87, 1.26)	0.99 (0.92, 1.07)	0.89 (0.81, 0.98)	0.96 (0.87, 1.07)	1.18 (1.05, 1.32)	1.21 (1.15, 1.28	0.70 (0.66, 0.76)	0.80 (0.75, 0.86)
$35k - $50k	0.68 (0.55, 0.84)	1.25 (1.13, 1.38)	1.08 (0.96, 1.22)	1.07 (0.95, 1.22)	0.43 (0.24, 0.79)	1.10 (0.88, 1.38)	1.25 (0.99, 1.60)	1.09 (0.83, 1.45)	1.00 (0.76, 1.33)	1.20 (1.05, 1.37)	0.68 (0.57, 0.81)	0.91 (0.77, 1.07)
$25k - $35k	0.60 (0.50, 0.71)	0.93 (0.86, 1.01)	1.23 (1.11, 1.37)	1.18 (1.07, 1.32)	1.08 (0.79, 1.49)	1.04 (0.89, 1.22)	0.62 (0.51, 0.77)	1.04 (0.84, 1.29)	1.64 (1.30, 2.07)	1.19 (1.06, 1.32)	0.68 (0.58, 0.79)	0.69 (0.60, 0.79)
$15k -$25k	0.54 (0.47, 0.62)	1.03 (0.97, 1,09)	1.18 (1.09, 1.28)	1.15 (1.06, 1.25)	1.47 (1.16, 1.85)	0.85 (0.75, 0.95)	0.87 (0.76, 1.00)	0.95 (0.81, 1.11)	1.38 (1.17, 1.62)	1.21 (1.13, 1.29)	0.71 (0.64, 0.80)	0.70 (0.64, 0.78)
$15K or less	0.62 (0.55, 0.71)	1.00 (0.95, 1.06)	1.10 (1.02, 1.19)	1.09 (1.03, 1.15)	1.13 (0.90, 1.42)	0.97 (0.87. 1.07)	1.14 (1.00, 1.30)	0.79 (0.68, 0.91)	1.35 (1.17, 1.57)	1.15 (1.08, 1.23)	0.75 (0.68, 0.83)	0.75 (0.69, 0.82)
Education	Prevalence Ratio (95% confidence interval)**				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)**			
College grad	0.65 (0.61, 0.70)	1.03 (1.00, 1.06)	1.13 (1.08, 1.19)	1.14 (1.09, 1.20)	1.20 (1.07, 1.34)	0.94 (0.89, 1.00)	0.96 (0.90, 1.04)	0.86 (0.79, 0.93)	1.33 (1.23, 1.45)	1.19 (1.15, 1.24)	0.70 (0.66, 0.74)	0.76 (0.72, 0.80)
Some college	0.60 (0.53, 0.68)	1.07 (1.02, 1.14)	1.08 (1.00, 1.16)	1.19 (1.09, 1.29)	1.21 (1.02, 1.46)	0.90 (0.82, 0.99)	0.90 (0.80, 1.02)	0.98 (0.86, 1.13)	1.25 (1.09, 1.44)	1.27 (1.20, 1.37)	0.58 (0.53, 0.64)	0.84 (0.76, 0.91)
High school	0.62 (0.55, 0.70)	1.00 (0.94, 1.05)	1.21 (1.12, 1.30)	1.16 (1.07, 1.25)	1.10 (0.92, 1.32)	0.86 (0.78, 0.94)	1.00 (0.87, 1.14)	1.14 (0.99, 1.30)	1.32 (1.14, 1.52)	1.26 (1.19, 1.34)	0.75 (0.68, 0.83)	0.71 (0.65, 0.77)
Less than HS	0.70 (0.68, 0.86)	1.10 (1.03, 1.18)	1.04 (0.94, 1.14)	1.07 (0.97, 1.17)	1.60 (1.30, 1.97)	1.02 (0.91, 1.13)	1.00 (0.86, 1.14)	0.58 (0.49, 0.68)	1.60 (1.34, 1.89)	1.00 (0.93, 1.07)	0.77 (0.69, 0.86)	0.75 (0.68, 0.83)
Employment	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)**				Prevalence Ratio (95% confidence interval)			
Employed	0.63 (0.58, 0.70)	1.07 (1.02, 1.12)	1.13 (1.06, 1.20)	1.12 (1.05, 1.20)	1.06 (0.90, 1.25)	0.95 (0.87, 1.03)	1.03 (0.92, 1.15)	0.85 (0.76, 0.96)	1.13 (1.00, 1.29)	1.27 (1.20, 1.35)	0.72 (0.66, 0.79)	0.78 (0.72, 0.85)
Unemployed	0.55 (0.44, 0.68)	1.25 (1.12, 1.39)	1.15 (1.01, 1.32)	1.13 (0.97, 1.31)	1.27 (0.94, 1.77)	1.12 (0.95, 1.31)	0.98 (0.79, 1.21)	0.68 (0.54, 0.88)	1.31 (1.02, 1.70)	1.21 (1.07, 1.37)	0.84 (0.71, 0.99)	0.68 (0.56, 0.82)
Homemaker	0.77 (0.66, 0.90)	0.89 (0.82, 0.96)	1.12 (0.99, 1.27)	1.18 (1.04, 1.32)	1.38 (1.06, 1.80)	0.96 (0.83, 1.11)	0.87 (0.70, 1.07)	0.72 (0.58, 0.90)	1.40 (1.18, 1.68)	1.14 (1.04, 1.24)	0.71 (0.62, 0.81)	0.76 (0.66, 0.86)
Student	0.54 (0.41, 0.69)	1.11 (0.97, 1.27)	1.19 (0.98, 1.41)	0.99 (0.79, 1.23)	1.10 (0.63, 1.95)	0.84 (0.63, 1.12)	0.98 (0.67, 1.42)	0.71 (0.45, 1.11)	0.53 (0.33, 0.87)	1.59 (1.30, 1.96)	0.86 (0.63, 1.15)	0.89 (0.65, 1.21)
Retired	0.84 (0.72, 0.99)	0.95 (0.89, 1.03)	0.98 (0.88, 1.11)	1.16 (1.04, 1.29)	1.28 (0.95, 1.71)	1.04 (0.90, 1.19)	0.73 (0.61, 0.89)	0.96 (0.78, 1.18)	1.29 (1.07, 1.54)	1.05 (0.98, 1.14)	0.87 (0.77, 1.00)	0.78 (0.69, 0.88)
Unable to work	0.55 (0.42, 0.71)	1.24 (1.10, 1.39)	1.11 (0.93, 1.33)	1.15 (0.97, 1.36)	0.45 (0.30, 0.68)	0.86 (0.70, 1.03)	2.14 (1.64, 2.80)	1.28 (0.99, 1.64)	1.20 (0.89, 1.59)	1.47 (1.28, 1.69)	0.71 (0.39, 0.61)	0.88 (0.73, 1.07)

*All models were controlled for age, income, sex, education, marital status, and employment status. The pre-disaster period was used as the reference point for all analyses.

** P-value for interaction trend <0.05

Table 7: Stratified log-binomial models of drinking behaviors by outcome and disaster period; Behavioral Risk Factor Surveillance System Respondents from Puerto Rico, 2017-2022.

	Drinking				**Heavy Drinking**			
Effect modifier	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic	Early post-hurricane	Late post-hurricane	Early pandemic	Late pandemic
Sex	Prevalence Ratio (95% confidence interval)**				Prevalence Ratio (95% confidence interval)			
Male	0.99 (0.88, 1.11)	1.07 (1.01, 1.13)	0.98 (0.91, 1.05)	0.92 (0.86, 0.99)	1.06 (0.98, 1.15)	1.01 (0.97, 1.05)	0.98 (0.93, 1.03)	1.02 (0.97, 1.07)
Female	1.01 (0.94, 1,10)	1.04 (1.00, 1.07)	0.89 (0.83, 0.96)	0.95 (0.90, 0.99)	1.19 (1.06, 1.34)	0.97 (0.92, 1.02)	0.93 (0.86, 0.99)	1.08 (1.01, 1.16)
Income	Prevalence Ratio (95% confidence interval)**				Prevalence Ratio (95% confidence interval)**			
$50k or more	0.97 (0.85, 1.10)	1.08 (1.02, 1.15)	0.96 (0.89, 1.03)	0.93 (0.86, 1.00)	1.10 (1.01, 1.20	0.99 (0.95, 1.03)	0.97 (0.92, 1.02)	1.03 (0.97, 1.08)
$35k - $50k	1.07 (0.86, 1.31)	1.07 (0.97, 1.18)	1.03 (0.91, 1.15)	0.86 (0.70, 1.06)	1.49 (1.12, 1.97)	1.00 (0.87, 1.14)	0.81 (0.69, 0.95)	0.99 (0.84, 1.17)
$25k - $35k	0.93 (0.78, 1.12)	1.05 (0.95, 1.13)	0.90 (0.81, 1.01)	1.05 (0.94, 1.18)	0.86 (0.63, 1.18)	0.94 (0.82, 1.08)	0.97 (0.82, 1.15)	1.26 (1.06, 1.47)
$15k -$25k	0.84 (0.73, 0.97)	1.19 (1.11, 1.26)	0.93 (0.85, 1.01)	0.93 (0.85, 1.02)	1.00 (0.81, 1.23)	1.07 (0.98, 1.18)	0.96 (0.85, 1.08)	0.97 (0.84, 1.11)
$15K or less	0.97 (0.85, 1.12)	1.11 (1.04, 1.18)	1.01 (0.92, 1.11)	0.86 (0.79, 0.95)	1.24 (1.02, 1.52)	0.92 (0.83, 1.01)	1.13 (0.99, 1.28)	0.94 (0.82, 1.07)
Education	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)**			
College grad	0.96 (0.84, 1.09)	1.06 (1.00, 1.13)	1.02 (0.95, 1.11)	0.90 (0.83, 0.98)	1.04 (0.95, 1.13)	1.02 (0.98, 1.06)	0.99 (0.94, 1.05)	1.01 (0.95, 1.07)
Some college	1.06 (0.92, 1.22)	1.10 (1.03, 1.18)	1.02 (0.94, 1.11)	0.95 (0.87, 1.05)	1.11 (0.90, 1.35)	0.93 (0.85, 1.02)	0.86 (0.76, 0.96)	1.24 (1.09, 1.40)
High school	1.07 (0.93, 1.23)	0.99 (0.92, 1.05)	0.91 (0.83, 0.99)	0.82 (0.74, 0.90)	1.02 (0.83, 1.25)	1.09 (0.99, 1,19)	1.03 (0.92, 1.16)	0.89 (0.79, 1.02)
Less than HS	0.82 (0.67, 0.96)	1.12 (1.03, 1.23)	1.15 (0.99, 1.34)	0.86 (0.75, 0.96)	1.05 (0.78, 1.40)	0.96 (0.85, 1.09)	1.26 (1.04, 1.51)	0.85 (0.71, 1.03)
Employment	Prevalence Ratio (95% confidence interval)**				Prevalence Ratio (95% confidence interval)			
Employed	0.70 (0.57, 0.86)	1.19 (1.10, 1.29)	1.16 (1.04, 1.30)	0.94 (0.84, 1.06)	0.94 (0.84, 1.05)	1.04 (0.99, 1.09)	1.03 (0.95, 1.11)	1.05 (0.97, 1.13)
Unemployed	0.61 (0.49, 0.76)	1.39 (1.25, 1.55)	1.18 (1.03, 1.36)	0.95 (0.82, 1.10)	1.95 (1.38, 2.75)	0.77 (0.64, 0.92)	0.93 (0.69, 1.23)	1.00 (0.79, 1.27)
Homemaker	0.85 (0.73, 1.00)	0.99 (0.92, 1.07)	1.15 (1.02, 1.30)	0.99 (0.87, 1.11)	1.15 (0.78, 1.68)	0.87 (0.74, 1.04)	1.09 (0.87, 1.38)	0.96 (0.76, 1.22)
Student	0.60 (0.46, 0.77)	1.24 (1.08, 1.42)	1.22 (1.01, 1.45)	0.83 (0.67, 1.03)	1.16 (0.75, 1,80)	1.02 (0.83, 1.25)	0.80 (0.61, 1.04)	1.08 (0.81, 1.46)
Retired	0.94 (0.80, 1.10)	1.06 (0.99, 1.17	1.01 (0.90, 1.14)	0.98 (0.87, 1.08)	0.93 (0.65, 1.33)	1.11 (0.96, 1.29)	0.98 (0.81, 1.18)	0.94 (0.77, 1.12)
Unable to work	0.61 (0.47, 0.79)	1.38 (1.23, 1.55)	1.14 (0.95, 1.37)	0.97 (0.82, 1.14)	0.22 (0.09, 0.47)	1.79 (1.36, 2.33)	1.82 (1.30, 2.55)	1.33 (0.91, 1.96)

*All models were controlled for age, income, sex, education, marital status, and employment status. The pre-disaster period was used as the reference point for all analyses.
** P-value for interaction trend <0.05

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Chapter 3

The Main Effects of Multiple Disaster Exposure on Maternal and Newborn Health and the Role of Colonialism and Place as Determinants of Health in Puerto Rico

3.1 Introduction

3.1.1 Maternal health, pregnancy, and stressors

Disasters with widespread consequences present stressors that disproportionately impact the physical and psychological well-being of socially-made vulnerable populations such as older adults, racial and ethnic minorities, persons experiencing poverty, and women and children.[1-4] Pregnant persons may be particularly vulnerable to disasters since pregnancy is considered an especially sensitive period, and several risks associated with psychosocial, physical, and environmental exposures affect both maternal and child health.[5] Prior studies report that, during pregnancy, people typically experience some form of routine and expected stress from daily or pregnancy-related concerns such as work and childcare, but are also particularly vulnerable to experiencing complications during pregnancy due to unforeseen stress.[6-8] These stressors can seriously impact the health of both the birthing parent and their child, as stress can directly impact the pregnancy through diverse biological mechanisms (e.g., increasing the production of oxytocin and inflammatory markers such as cytokines).[9,10] Attention to psychological and emotional complications during pregnancy is important, since pregnant people with depression and/or anxiety can have more severe pregnancy complications and are at heightened risk for pre-term birth.[11,12] In the context of disasters, these pathways and mechanisms are critical because

disasters can lead to psychological and physiological stress, trauma, reduced access to healthcare services and medication, disruption in prenatal services, and can affect the health of pregnant persons and their unborn children over the course of the pregnancy and post-pregnancy.[13] Research has further established the importance of proper nutrition during pregnancy, and disaster-caused economic insecurity can diminish the quantity and quality of food, as well as decrease food security, with considerable implications for prenatal health and subsequent child development.[14,15] Epidemiologic literature on disasters and their impact on maternal and newborn health is limited, often focusing on singular—rather than cumulative—events and not considering impacts on the parent and child collectively. Prior research from singular events such as ice storms, hurricanes, and earthquakes demonstrates that disasters can adversely impact pregnancy outcomes, including gestation length, birth weight, head circumference, fetal loss, and others.[16-19] Moreover, other widespread socio-structural stressors have also been shown to affect the pregnancy outcomes of socially-made vulnerable pregnant persons, such as studies that have showed that immigration raids and the Muslim ban resulted in higher rates of preterm birth and low birthweight.[20,21] However, more research is needed on these relationships, particularly in the context of multiple (i.e., cumulative, cascading) disaster exposures and in diverse populations.

3.1.2 Colonialism and Disasters

Another neglected issue in the field of reproductive health and disaster epidemiology is colonialism and its potential role as a determinant of health. The U.S. territory of Puerto Rico provides a unique opportunity to build disaster epidemiology research and understand colonialism as a social determinant of health given that Puerto Rico's territorial relationship with the United States has been described by political scientists and historians as colonial.[22] Puerto Rico became a territory of the U.S. following the Spanish-American War of 1898 and Puerto

Ricans have been U.S. citizens since 1917 with the establishment of the Jones Act. However, the U.S. territory has historically had differential access to financial and political resources compared to other U.S. states and jurisdictions. The aforementioned system of colonization has been cited as one of the main drivers of Puerto Rico's financial recession and the resulting economic hardship in recent decades that has driven deindustrialization, high government debt, growing unemployment rates, corruption in the governmental and financial sector, and other social, political, and financial factors that left the island vulnerable prior to, during, and in the aftermath of recent disasters.[23] Although Texas and Florida similarly experienced a hurricane-related disaster event in 2017 and later saw the effects of the COVID-19 pandemic, considerable disparities in Federal disaster response exist between those states and the U.S. territory.[24,25] For example, recovery efforts in Puerto Rico had slower delivery of federally appropriated funds, less Federal staffing, food, water, tarps, and helicopters, and received fewer Federal Emergency Management Agency (FEMA) dollars within the first 6 months post-disaster when compared to Texas and Florida.[24-26]

Colonialism can be considered an important structural predictor of inequities and could be categorized as a social determinant of health—although it has been scarcely examined in the context of U.S. imperialism—and we could expect it to work through similar mechanisms as other socio-structural systems such as racism and sexism.[27] Social and economic research shows that colonialism can lead to draining of wealth, expropriation of land, diminished control over production and trade, exploitation of natural resources, outflow of financial resources, and limitations in social and economic development for the colonized country.[28] Consequently, colonialism can create opportunities for infectious disease proliferation, increased exposure to social and environmental hazards, malnutrition, and adverse behavioral health outcomes.[29-31]

While the consequences of colonialism could be significant, the available literature is mostly anecdotal, qualitative, or from non-public health disciplines, leaving a considerable gap of etiologic studies that consider the potential effects of colonialism on population health outcomes.

3.1.3 The present study

This paper fills some of the aforementioned gaps by examining the intersection of two understudied areas in disaster epidemiology and reproductive health epidemiology: multiple disaster exposure, colonialism, and how these may interact to impact maternal and newborn health in Puerto Rico. Our research addresses these gaps by examining: (1) the main effects of multiple disaster exposure on birthing parent and newborn health and (2) the role of geographic location and colonialism as potential effect modifiers in this relationship. We also explored the possibility of live birth bias affecting the associations with birth outcomes since prior research has found strong potential for bias in these type of studies.[32]

3.2 Methods

3.2.1 Data source

The primary data source for this study was the Vital Statistics Birth Data files from the Center for Disease Control and Preventions' National Center for Health Statistics. This nation-wide system provides the United States' official vital statistics based on the collection and registration of all birth and death events nationwide—inclusive of all states and territories—and provides the most complete and continuous data available to public health officials at the national, state, and local levels. Vital statistics data corresponding to all live births occurring between January 2016 and December 2021 were used for the present analysis. Counties and

municipalities in Puerto Rico, Texas, and Florida affected by multiple disaster events between 2017 and 2022 were selected to examine time trends pre- and post-disaster. Specifically, we used data from counties and municipalities affected by Hurricane Irma in Florida, Hurricane Harvey in Texas, and Hurricane Maria in Puerto Rico in the fall of 2017.

This study focuses on maternal and child health outcomes in Puerto Rico, with Texas and Florida as a basis of comparison with Puerto Rico during the same period to evaluate the role of colonialism. Only counties designated as eligible for individual-level assistance according to FEMA were considered, to focus on the experiences of those most affected by these events (Appendices B-D).

We acquired access to restricted Vital Statistics data files from the National Center for Health Statistics to properly account for geographic-level variables not included in the publicly available datasets. Access to this data reduces the risk for information bias affecting our exposure of interest and allows us to examine effect modification by geographic factors such as proximity to areas more affected by disaster, neighborhood resources, proximity to hospitals and medical care, and other neighborhood and population-level variables. No sensitive information or private information that can be traced back to individual study participants is provided through the publicly available datasets used in this analysis, so the Institutional Review Board at the University of Michigan classified this study as exempt (HUM00229614).

3.2.2 Primary exposure of interest.

Our primary exposure of interest is disaster exposure. Ideally, in a post-disaster scenario one would have data on participants' experiences prior to, during, and following a disaster to properly assign disaster exposure categories. However, the vital statistics record is limited to information about events, dates they occurred, and other relevant sociodemographic and clinical

data. Therefore, pre-/post- disaster variables were created using date variables reported by the vital statistics system, recorded as the time that the event (i.e., birth) occurred. Participants were assigned to disaster periods based on the date that the birth event took place relative to each disaster event in each specific location, always compared to the referent period before any of the disasters occurred (pre-disaster). This approach is used to examine the individual impact of different disaster periods and the potential effect that these have on maternal and newborn health outcomes. Further, given the complex mechanisms that may affect pregnancy in the aftermath of a disaster (e.g., disruptions in nutrition, lack of power, stress) and the fact that many of these disaster-associated exposures are only likely to manifest in adverse maternal and newborn health outcomes after some time has passed, over time, we believe that our analysis is subject to immortal time bias.[33-35] To minimize the possibility of this biasing our results, we evaluated outcomes occurring at least 3 months after each disaster. For example, although in Puerto Rico, Hurricane Maria occurred on September 20, 2017, we will only consider births as occurring during the post-hurricane period if they were born after December 20, 2017.

To properly consider the different stages of the recovery process in Puerto Rico, we divided the hurricane and the pandemic into four key stages, two for each disaster. The early post-hurricane period (0-6 months post-hurricane) was associated with increased suicide rates, psychological distress, and mental and resource scarcity.[36-38] Efforts were focused on cleaning debris, providing food and covering essential needs for affected individuals, and restoring electricity, water, and communications. The late post-hurricane period (6+ months post-hurricane but pre-pandemic) was focused on long-term recovery and coincided with earthquakes occurring in the southwestern region of the island. The pandemic was divided into early pandemic, starting when an emergency declaration was made in Puerto Rico (March 12, 2020), and late pandemic,

starting when vaccine distribution started for the general population (April 15, 2021), due to the differences in terms of lockdowns and understanding of the virus at these time points. The period corresponding to earthquakes was not operationalized as a separate disaster period in the exposure categories for our analysis due to the geographically specific nature of this type of disaster, which mostly affected the south and southwestern regions of Puerto Rico, and limitations with sample size in our data. In summary, the exposure of interest was categorized into the following periods: (1) pre-disaster [unexposed], (2) early post-hurricane [December 20, 2017 to June 20, 2018], (3) late post-hurricane [June 20, 2018 to June 12, 2020], (4) early pandemic[June 12, 2020 to July 15, 2021], and (5) late pandemic [July 15, 2021 to December 2021].

3.2.3 Primary outcome variables.

We considered several variables that correspond to birthing parent and newborn health broadly. Dichotomous variables for newborn health outcomes were pre-term birth, low birthweight, and extreme low birthweight. Pre-term birth is reported through the vital statistics system through two estimates based on ICD-9 and ICD-10 definitions. We defined pre-term birth using the best obstetric estimate of the infant's gestational age based on the clinician's final estimate of gestation, which is determined by the date of the last menstrual period based on self-report if ultrasound is not performed or is unknown. Births were considered preterm (less than 37 weeks) or term (37 weeks or more) based on the obstetric estimate. Birthweight is reported through the vital statistics system as the infant's weight in grams at the time of birth. We categorized term births as low birthweight or normal birthweight based on ICD-19 classification, where low birthweight is less than 2,500 grams.

Variables that correspond to birthing parent health at the time of birth included gestational diabetes, gestational hypertension, and excessive weight gain. Gestational hypertension and gestational diabetes were derived from physician diagnoses of these conditions, and are dichotomous variables. Excessive weight gain was determined based on U.S. Centers for Disease Control and Prevention (CDC) recommendations and women were determined to have gained excessive weight during pregnancy based on their pre-pregnancy body mass index (BMI) and the number of pounds they gained during pregnancy. More information about these classifications can be found on the CDC website.[39]

3.2.4 Covariates.

For the main effects and geographic effect modification analyses, we included the following covariates in our models: maternal age, maternal education, marital status, paternal age, paternal education, birth payment method, BMI, and geographic location in Puerto Rico. For the colonialism effect modification analyses, we included the following covariates in our model: maternal age, maternal education, maternal race, paternal age, paternal education, birth payment method, BMI, and colonialism status. These variables were selected for their potential to confound the association between exposure and outcomes based on prior literature if they met all the following criteria: (1) were considered an independent cause of the outcome, (2) were associated with the exposure of interest, and (3) were not in the causal pathway between exposure and outcome (DAG, Figure 2).

3.2.5 Data analysis

Descriptive statistics were calculated for all outcome variables and covariates. Categorical variables were presented as frequencies with percentages while continuous variables

were reported as means with standard deviations or medians with interquartile ranges. Multivariate regression models were utilized to examine the relationship between disaster exposure and maternal and newborn health outcomes with log-binomial models fit for binary outcomes, controlling for relevant confounders. Prevalence ratios present maternal and child health outcomes in each disaster period compared to baseline. Although we present results with confidence intervals, the vital statistics ideally represent a complete capture of the events occurring within this population and are not actually a sample with the uncertainty inherent to a sample. Missing data patterns were assessed, and the percent of missing data determined. If over 10 percent of data was missing data, multiple imputation techniques were used to complete that data to estimate unbiased statistical parameters. A p-value of 0.05 or less was considered statistically significant; all analyses were conducted using SAS.

3.2.5.1 Effect Modification.

Effect modification was assessed with interaction terms between effect modifiers of interest and exposure categories for all relevant outcomes of interest. Specifically, we tested effect modification for two key variables (1) geographic regions in Puerto Rico and (2) Colonialism. To test for geographic-level effect modification, we utilized regions based on a map from the Puerto Rico Tourism Company (Appendix A) which is based on cultural differences and likely captured differential exposure levels to the various disasters that affected the island. The following 6 regions from Puerto Rico were considered: Western Region, Northern Region, Southern Region, Central Region, Metro Region, & Eastern Region. To test for the modifying effect of colonialism, we compared associations of disaster periods and health outcomes between Puerto Rico (U.S. Colony/Territory) vs Texas and Florida (non-colonies/States). Exposure periods for Texas and Florida, were defined similarly to the approach for Puerto Rico.

Specifically, Hurricane Harvey made landfall in Texas on August 25, 2017, and Hurricane Irma made landfall in Florida on September 10, 2017. The 4th and 5th periods for disasters were based on the dates in which each state declared a Public Health Emergency for the pandemic and the date in which vaccines were made available to all adults state-wide.

3.2.6 Live-birth bias simulation

Prior research has found potentially spurious associations between disaster exposure and reduced rates of preterm birth and low birthweight. According to Harville and colleagues, this could be explained by a reduction in high-risk people giving birth in the region after the disaster, rather than increased positive outcomes among those who did give birth.[32] They attribute this to live-birth bias, a concept first explored by Liew and colleagues, who explained that conditioning on live births in pregnancy cohorts could introduce bias in associations with pregnancy-related outcomes.[40] To address this issue, we followed methods used by Harville and colleagues to simulate counterfactual scenarios to estimate what the effect of disasters on birth outcomes would have been if the number of births had stayed constant in the years following each disaster.[32] Specifically, we used the number of total births in 2017 as the baseline to calculate "missingness" in yearly total births from 2018-2021. The difference in yearly births between each year and 2017 was calculated and was considered as the number of "missing" births. We created a simulated set of these "missing" births, assigned them different rates of the outcome, and then combined these with total number of observed outcomes to estimate risk ratios under different hypothetical scenarios. Further, because it is unclear if these "missing" observations are due to migration or due to births not occurring due to exposure (e.g., decreased sexual activity and/or fertility, increased miscarriages, and/or increased birth control), we simulated two sets of these 'missing' births under two levels of missingness (i.e., 100% and 75%). The results of these

simulations are reported as a supplementary analysis to our main results and colonialism effect modification analysis.

3.3 Results

Our data included 104,560 live births occurring in Puerto Rico as reported by the Vital Statistics System from January 2017 to December 2021. Over 84% of people who gave birth in Puerto Rico during this period used the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) and 67.6% of their birthing costs were paid using Medicaid. This suggests a high level of financial need among people who gave birth during this period in Puerto Rico. 64.4% of people who gave birth in Puerto Rico during this period had at least some college education, 87.6% were between 15 and 34 years old, 69% were unmarried, and 54.6% had a BMI that could be considered as overweight or obese. Additionally, 76% of fathers represented in Puerto Rico were between 15 and 34 years old, while 53.8% had at least some college education. Full sociodemographic information can be found on Tables 8 and 11.

3.3.1 Main effects: Newborn Health

Multivariate log-binomial models were run including data only in Puerto Rico, adjusting for maternal age, maternal education, marital status, paternal age, paternal education, birth payment method, BMI, and geographic location in Puerto Rico. The pre-disaster period was used as the reference point for all analyses. Estimates from the log-binomial model output were exponentiated and presented as prevalence ratios with 95% confidence intervals (CIs) for ease of interpretation. Overall, across outcomes of interest (i.e., pre-term birth, low birthweight, and term low birthweight), regression model estimates for child health did not show statistically significant differences across disaster periods (Table 9). Notably—contrary to our hypothesis—

the direction of association for low birthweight and term low birthweight was consistently protective in the early post-hurricane, late post-hurricane, and early pandemic periods for low birthweight and term low birthweight. Only the late post-hurricane period was associated with term low birthweight (PR=0.90, 95% CI: 0.83, 0.98).

3.3.2 Main effects: Maternal Health

Multivariate log-binomial models were run considering only data in Puerto Rico, adjusting for maternal age, maternal education, marital status, paternal age, paternal education, birth payment method, BMI, and geographic location in Puerto Rico. The pre-disaster period was the reference point for all analyses. Overall, across outcomes of interest (i.e., gestational hypertension, gestational diabetes, and excessive weight gain), estimates for maternal health consistently showed that disaster periods were associated with elevated prevalence ratios (Table 10). Notably, the early post-hurricane period was the only period not significantly associated with elevated rates of gestational hypertension (PR=1.05, 95% CI: 0.93, 1.19), gestational diabetes (PR=1.09 , 95% CI: 0.95, 1.25), or excessive weight gain (PR= 1.01, 95% CI: 0.97, 1.05)—although the point estimate of association was consistently harmful. The late post-hurricane period saw elevated rates of gestational hypertension (PR= 1.19, 95% CI: 1.10, 1.29), gestational diabetes (PR= 1.19, 95% CI: 1.08, 1.31), and excessive weight gain (PR= 1.07, 95% CI: 1.04, 1.10). The early pandemic period was associated with increased rates of gestational hypertension (PR= 1.30, 95% CI: 1.18, 1.42), gestational diabetes (PR= 1.38, 95% CI: 1.24, 1.54), and excessive weight gain (PR= 1.15, 95% CI: 1.11, 1.18). Lastly, the late pandemic period was associated with elevated rates of gestational hypertension (PR= 1.21, 95% CI: 1.07, 1.36), gestational diabetes (PR= 1.37, 95% CI: 1.20, 1.56), and excessive weight gain (PR= 1.13, 95% CI: 1.09, 1.17).

3.3.3 Effect modification: Geographic location

Interaction terms were used in the multivariate log-binomial models to assess effect modification based on geographic location. All models were adjusted for maternal age, maternal education, marital status, paternal age, paternal education, birth payment method, BMI, and geographic location in Puerto Rico. The San Juan metro area was selected as the reference point since it is the capital of Puerto Rico and has historically had more resources and lower poverty rates than other parts of the island.

Overall, our results suggest that living in the San Juan metro area was not protective of maternal and child health—as hypothesized—compared to other regions in Puerto Rico (Tables 10 and 11). Compared to those born in the metro area, newborns in other parts of Puerto Rico mostly did not have increased rates of preterm birth and low birthweight across disaster period, regardless of proximity to disaster epicenters. Notably, newborns in the Central, Eastern, and Northern regions of Puerto Rico had reduced rates of term low birthweight across several disaster periods. Most strikingly, in the early post-hurricane period, reduced rates of term low birthweight were seen in the Central (PR= 0.65, 95% CI: 0.41, 1.01), Eastern (PR= 0.71, 95% CI: 0.49, 1.03), and Northern (PR= 0.62, 95% CI: 0.40, 0.98) regions of Puerto Rico compared to the metro region. Moreover, during the post-hurricane period children born in the Northern region had lower rates of term low birthweight (PR= 0.71, 95% CI: 0.54, 0.93) and the direction of association was protective —although not significant—for all other regions, compared to the Metropolitan area. Similarly, lower rates of term low birth weight occurred in all regions versus the metro area during the late pandemic period, but these differences were not statistically significant. For all other outcomes and periods, regions outside of the Metropolitan area had mostly protective—although not statistically significant—directions of association compared to

the Metropolitan area, except for preterm birth during the late pandemic, in which the outlying geographic areas had worse, although non-significant outcomes.

Results were mixed for maternal health outcomes. During the early post-hurricane and late post-hurricane period, geographic locations across Puerto Rico did not have statistically significant differences compared to the Metropolitan area for gestational hypertension and excessive weight gain. However, women in the Central region had elevated rates of gestational diabetes during both the early post-hurricane (PR= 1.48, 95% CI: 0.86, 2.54) and the late post-hurricane (PR= 1.57, 95% CI: 1.07, 2.30) periods, compared to those in the Metropolitan area. Moreover, during the early pandemic we found elevated levels of gestational hypertension among women in the Eastern (PR= 1.40, 95% CI: 1.04, 1.84), Southern (PR= 1.57, 95% CI: 1.16, 2.10), and Western (PR= 1.27, 95% CI: 0.88, 1.68) regions. However, this difference was not noted for gestational diabetes and excessive weight gain during the same period. Gestational hypertension was also higher among those in the Southern region (PR=1.72, 95% CI: 1.19, 2.49) during the late pandemic period, compared to those in the Metropolitan region.

3.3.4 Effect modification: Colonialism

Multivariate log-binomial models—inclusive of Texas and Florida—were run for outcomes of interest and interaction terms were used to assess effect modification based on colonialism. All models were adjusted for maternal age, maternal education, maternal race, paternal age, paternal education, birth payment method, BMI, and colonialism status, with the pre-disaster period as the reference point for all analyses. Estimates from the log-binomial model output were exponentiated and presented as prevalence ratios with 95% confidence intervals (CIs) for ease of interpretation. To test for effect modification, Puerto Rico was classified as a

"U.S. Colony", Texas and Florida were classified as "non-U.S. Colony", and non- U.S. Colony was used as the reference point for all analyses.

Overall, our results suggest that living in a U.S. colony was not consistently associated with elevated levels of adverse maternal and child health as hypothesized (Table 13). The association between all child health outcomes and disaster exposure was not modified due to colonialism status. However, results on effect modification by colonialism for the association between maternal health outcomes and disaster exposure were mixed. The relationship between gestational hypertension and disaster periods was not modified by colonialism status in any of the disaster periods. However, for gestational diabetes and excessive weight gain, living in a U.S. Colony was consistently associated with higher rates across disaster periods, compared to non-U.S. Colonies. Specifically, Puerto Rico consistently had slightly higher—although not statistically significant—rates of gestational diabetes in the early post-hurricane, late post-hurricane, and early pandemic periods, and statistically higher rates in the late pandemic period (PR=1.17, 95% CI: 1.00, 1.31) than the states. Moreover, colonialism was associated with higher excessive weight gain in the late post-hurricane (PR= 1.10, 95% CI: 1.07, 1.13), early pandemic (PR= 1.15, 95% CI: 1.12, 1.19), and late pandemic (PR= 1.20, 95% CI: 1.15, 1.24).

3.3.5 Live-birth bias supplemental analysis

We explored multiple simulations to estimate potential associations between disaster periods and maternal and child pregnancy outcomes if yearly birth rates had stayed constant in Puerto Rico. We found that these were appropriate, since the total number of yearly live births in Puerto Rico was reduced between 12 and 22 percent in every year following the first disaster event. For consistency with prior studies, we present these simulations as yearly effects (i.e., 2018-2021 vs 2017), rather than period effects (e.g., early post-hurricane vs pre-disaster).

Overall, our results suggest that live-birth bias is likely driving and underestimating the results of our main effects and colonialism effect modification analyses. While the potential magnitude of bias varies by outcomes, our results suggest that risk ratios for our main effect analysis could range from 0.92 to 2.86 for newborn health outcomes and 1.04 and 8.10 for maternal health outcomes. Similarly, our results suggest that live-birth bias is likely impacting our colonialism effect modification results, with newborn health outcomes being underestimated and maternal health outcomes presenting mixed results. Complete results from these simulations can be found in Tables 14-16.

3.4 Discussion

3.4.1 Summary of research findings

This study examined the association between multiple disaster exposure and maternal and child health among all 104,560 live births in Puerto Rico from 2017 to 2022 based on vital records. It also considered effect modification based on geographic location—as a proxy for proximity to disaster epicenters—in Puerto Rico and colonialism by comparing associations in Puerto Rico to those in Texas and Florida.

Firstly, disaster periods were consistently associated with adverse maternal health across all outcomes of interest, with particularly strong impacts in the early and late pandemic periods. Secondly, child health outcomes were not significantly impacted by disaster exposure in Puerto Rico and these associations did not vary based on colonialism and proximity to disaster epicenters. Thirdly, although results on geographic effect modification were mixed, rates of gestational diabetes were higher in the early post-hurricane and late post-hurricane period in Central and Eastern Puerto Rico compared to the Metropolitan region, and rates of gestational hypertension were higher in the early pandemic and late pandemic periods, in Southern Puerto

Rico compared to the Metropolitan region. These results are particularly notable given that those two regions were considered the most affected by Hurricane Maria (Central and Eastern regions) and the earthquake events that happened during the early pandemic (Southern region). Lastly, colonialism modified the effect of disasters on gestational diabetes in the late pandemic period and on excessive weight gain during the late post-hurricane, early pandemic, and late pandemic periods, with Puerto Rico seeing greater impacts of these periods on outcomes than the two states.

3.4.2 Main discussion and contextualization of results

Overall, our results differ from those of other studies. While disaster exposure was associated with adverse maternal health outcomes, research has scarcely considered these associations and it remains unclear if the associations we observed would be replicable in other populations. Nonetheless, our results in Table 9 indicate that pregnant women in Puerto Rico experienced heightened rates of post-disaster gestational hypertension, gestational diabetes, and excessive weight gain. Notably, the early pandemic period was associated with the most significant increases in adverse maternal health outcomes across all outcomes of interest. Given our study's limitations in terms of exposure classification, we cannot definitively attribute this observed surge exclusively to the pandemic versus the cumulative effects of multiple disaster exposure.

Prior studies report associations between the COVID-19 pandemic and increased pregnancy stress and anxiety due to social isolation, increased unemployment rates, poverty, and intimate partner violence.[41-43] These psychosocial considerations, combined with potentially increased food insecurity and/or disruption in food systems during the COVID-19 pandemic,[44,45] could be drivers of the heightened rates of adverse maternal health outcomes we observed.

Additionally, it is plausible that these associations reflect cumulative disaster exposure, particularly since Hurricane Maria was similarly associated with adverse mental health outcomes and disruptions in food systems in Puerto Rico.[36,37,46-49]

Notably, our main effects results examining potential impacts on newborn health (Table 9) are inconsistent with our hypothesis and have mixed consistency with prior studies. While our study did not yield significant post-disaster differences in terms of preterm birth, low birthweight, and term low birthweight, other studies have found adverse impacts among children born in post-disaster settings. In particular, studies exploring the effects of disasters such as hurricanes, wildfires, and floods had found associations with increased rates of preterm birth and low birthweight among women who were exposed to disasters and those who identified as racial and ethnic minorities.[50-54] However, as noted in our methods, prior research has established that these type of analyses can be misleading and could be driven by live-birth bias. For example, Hamilton and colleagues, who examined official birth records post-hurricane Katrina, found apparent reductions in preterm birth and low birthweight following the hurricane.[55] These findings were contested by other researchers who estimated what the effect of the storm would have been if the number of births had stayed constant and found that Hurricane Katrina would have been associated with worse outcomes, with an estimated risk ratio of 1.30 and 1.35 for low birthweight, contrary to the findings from Hamilton and colleagues.[32,55,56] Our supplemental live-birth bias analysis (Tables 14 and 15) showed that this was also the case in our data, with a reduction in the number of live births in Puerto Rico following each year after Hurricane Maria, down from 24,373 births in 2017, to 19,332 births in 2021, a 21% reduction in births. More on this trend is shown in table 3.6. Similar to studies conducted by Harville and other researchers, we found that, if births had stayed constant in post-disaster periods, we would have observed

harmful associations across all newborn outcomes of interest. These supplemental live-birth bias analyses are meant to be a counterfactual thought experiment to simulate what risk ratios could look like if births stayed constant among high-risk women in future disasters. More research would be needed to better assess how likely it is that this bias is distorting the results of the main effects analysis presented in Table 9.

To the best of our knowledge, our study is one of the first epidemiologic studies to consider the impact of multiple disasters in a population as well as the role of colonialism in this association. While our results were mixed, the direction of association of multiple disasters for gestational diabetes and excessive weight gain was consistently harmful, and stronger associations in Puerto Rico versus the two states suggests that colonialism increased the risk for disaster-associated adverse maternal health outcomes. Moreover, it is possible that the previously mentioned problems with our study design—particularly conditioning on live births—could be significantly underestimating the modifying effect of colonialism on maternal and child health in Puerto Rico. Although Puerto Rico saw a yearly reduction of 12 to 22 percent in total births in post-disaster periods, Texas and Florida only saw a 1 to 6 percent reduction (Table 13), suggesting that colonialism and its social, political, and economic pathways might be driving a differential reduction in live births under multiple disaster scenarios. Further, our supplemental analysis simulating potential risk scenarios if births had remained constant (Table 16) also suggests that live-birth bias might significantly underestimate the true role of colonialism in modifying the relationship between multiple disaster exposure and newborn health. However, the true magnitude of this association remains unclear given that these simulations only consider the effect modification effect of colonialism and cannot consider its role as a confounder.

Largely, we did not find that different geographic locations throughout Puerto Rico were associated with greater risk for maternal and newborn health outcomes. Regarding geographic-level effect modification, some of the observed effect estimates presented in Table 10 suggest that proximity to disaster epicenters and more severe disaster experiences may be associated with adverse maternal health outcomes. In particular, gestational diabetes was higher among those in the Central region during the early post-hurricane (PR=1.48, 95% CI: 0.86, 2.54) and late post-hurricane periods (PR=1.57, 95% CI: 1.07, 2.30), compared to those in the Metropolitan region. Further, gestational hypertension was higher in the Southern region during the early pandemic (PR=1.57, 95% CI: 1.16, 2.10) and late pandemic (PR=1.72, 95% CI: 1.19, 2.49), compared to in the Metropolitan region. These results are particularly notable since the Central region was reportedly associated with more significant hurricane-related complications due to resource scarcity while the Southern region was the epicenter for the earthquakes that occurred during the early pandemic period.[57,58] These results are consistent with a prior study that found that living in areas closer to earthquake epicenters was associated with stronger adverse mental health associations among pregnant women in China.[59]

3.4.3 Limitations

This study has some limitations. Firstly, data from the vital statistics system can be considered as a repeated cross-sectional design as it does not follow individuals longitudinally. In other words, it does not represent the health and exposure trajectories of the same individuals, although it is representative of the target population over time. This issue could have been partially addressed with more detailed information about individual mothers and multiple births in our periods of study; however, the vital statistics record does not provide unique identifiers to protect participant confidentiality. Notwithstanding, the richness of the vital statistics datasets

avoid some of the common pitfalls of cross-sectional study designs due to representing the official records of health conditions prior to birth, including date of last menstrual period, pre-pregnancy risk factors, and other maternal and paternal characteristics. Secondly, it is possible that selection bias is affecting our results due to several key factors. For example, several sources have documented significant population out-migration because of disasters in Puerto Rico and it is therefore possible that our sample would not appropriately represent the experiences of those who were affected by disasters in the island. It is also likely that pregnancies that were most affected by disaster experiences could be more likely to result in miscarriages, stillbirths, and/or that women who were most affected decided to not have children and thus our data may not entirely represent the association between disaster exposure and maternal and child health.[60] Both of these scenarios are examples of how live-birth bias mechanisms can impact our results and our supplementary analysis supports that this form of selection bias is underestimating the true effect of disaster exposure and biasing our results towards the null. Thirdly, we can also expect unmeasured confounding due to relying on limited data from vital records. For example, vital records do not report information about income, employment status, food security, and other relevant social and behavioral factors that may impact pregnancy and that may be associated with disaster exposure. Fourthly, information bias with respect to our exposure variable may be influencing our results due to relying on disaster periods, rather than individual disaster experiences. While considering geographic location as an effect modifier helps provide better understanding about the severity of disaster exposure, it does not account for the individual-level variability that can exist in disaster experiences and may bias our results towards the null. Fifthly, we also would like to recognize that most of the effect modification analyses presented in this paper utilize multiple comparisons due to these variables having multiple levels.

Specifically, our geographic-level effect modification variable has 6 levels, while our exposure categories have 5 levels. Based on mathematical principles, these types of simultaneous statistical analyses may widen confidence intervals.[61-63] Therefore, it is possible that some of the observed associations could be due to chance. This could be addressed using a Bonferroni correction; however, this was not incorporated to our analysis since it can become overly conservative and lead to type II errors.[61,64] Future research could benefit from incorporating false discovery rates to deal with multiple comparisons of this nature since it deals better with an increasing number of hypothesis tests.[65] Sixthly, we should recognize that our live birth bias simulation is significantly limited through several assumptions. For example, it inadvertently makes assumptions about the fraction of "missing births", such as assuming that women did not migrate or were not captured by vital records. It is possible that there are several complex factors driving a reduction in yearly live births that we cannot fully account for. Finally, we operationalized colonialism based only on someone living in a U.S. colony versus not living in a U.S. colony, but we also recognize that individual, community, political, and economic factors can affect how people experience colonialism. We expect that factors such as generational trauma, structural inequities, racism, indigenous identity, and other factors may affect how an individual experiences colonialism and how colonialism can impact maternal and child health, but the limitations in our data limit our ability to fully consider these pathways. Further, our colonialism analysis is limited by only having one example of one "colonized" and two "non-colonized" states, and does not necessarily capture the colonialism experiences of other unincorporated territories of the United States and their non-colonized counterparts.

3.4.4 Strengths

Several key strengths should be highlighted. Firstly, colonialism as an effect modifier of compounding disasters on health is understudied and therefore observational and exploratory approaches are appropriate to begin to understand these associations and inform future research. Similarly, while cross-sectional study designs traditionally have limitations establishing causality, our approach helps mitigate some of the common pitfalls of this design. For example, due to having official records of date of birth and time of the disaster events, we reduce the risk of temporal ambiguity and reverse causation bias. Secondly, the Vital Statistics System provides the official record of all live births nationwide, meaning that our data is fully representative of all live births in our population of interest. Thirdly, the use of geographic-level zip code data, combined with official FEMA disaster declarations helps us include only areas that were affected by disasters, reducing the risk for exposure misclassification. Lastly, the use of clinical outcomes certified and diagnosed by physician reduces the possibility for information bias with respect to outcomes.

3.4.5 Conclusion

Overall, our results reveal important insights about the association between multiple disaster exposure and their implications for maternal and child health. Consistent with our hypothesized associations, maternal gestational hypertension, gestational diabetes, and excessive weight gain were adversely impacted in post-disaster periods. We also found that geographic location and colonialism modified the association between disaster exposure and maternal health for some outcomes and periods. Our main effects analysis suggests no associations between disaster exposure and newborn health (i.e., preterm birth, low birthweight, and term low birthweight) and that this association was not significantly modified by colonialism. However, these results are likely impacted by live-birth bias and our supplementary simulation analysis

suggests that our results are likely significantly underestimated and that the true association between newborn health and multiple disaster exposure is likely to be harmful and that living in a colony is likely to present greater risk for newborn health. Moreover, our results also suggest that colonialism and multiple disaster exposure are also likely drivers of significant reductions in live births among socially disadvantaged populations.

Overall, our findings suggest that disasters can have harmful impacts on maternal health and likely newborn health when live birth bias is corrected for, and that colonialism may be an underlying social determinant of health that could amplify the adverse consequences of compounding disasters related to epidemics and climate change. Future research could benefit from more refined exposure assessment and retrospective designs that more carefully consider individual exposure levels, disaster experiences, and other maternal and child endpoints across multiple disaster events.

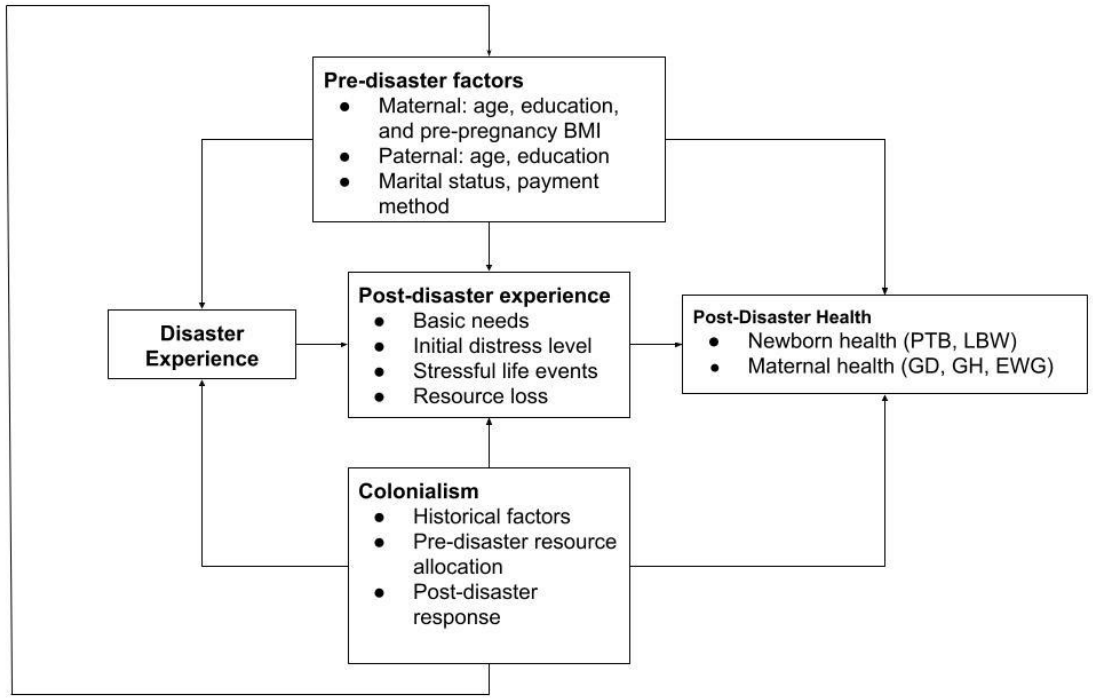

Figure 2: Chapter 3 Conceptual Model

Table 8: Sociodemographic characteristics and distribution of key covariates among births in Puerto Rico; U.S. Vital Statistics Records, 2017-2021.

	Pre-Disasters	Early Post-Hurricane	Late Post-Hurricane	Early pandemic	Late pandemic	p-value*
Maternal Age						<0.0001
<15	0.1%	0.06%	0.06%	0.02%	0.02%	
15-24	43.7%	40.0%	40.0%	38.2%	36.8%	
25-34	45.1%	47.7.%	47.5%	49.0%	50.4%	
35-44	11.0%	12.2%	12.6%	12.6%	12.7%	
45-54	0.1%	0.1%	0.1%	0.1%	0.1%	
Maternal education						<0.0001
High School or less	37.0%	35.6%	35.3%	34.4%	35.3%	
Some College	35.0%	33.0%	33.3%	33.5%	32.0%	
Bachelor's or higher	28.0%	31.4%	31.4%	32.1%	32.7%	
Paternal Age						<0.0001
<15	0.0%	0.0%	0.0%	0.02%	0.0%	
15-24	28.6%	25.8%	25.9%	25.4%	24.5%	
25-34	49.0%	49.7%	49.5%	50.4%	51.1%	
35-44	19.2%	21.4%	21.1%	20.7%	20.9%	
45-54	3.1%	3.1%	3.5%	3.6%	3.4%	
Paternal education						<0.0001
High School or less	47.6%	45.3%	45.8%	45.9%	46.2%	
Some College	35.1%	35.6%	34.7%	34.1%	34.0%	
Bachelor's or higher	17.3%	19.1%	19.5%	20.0%	19.8%	
Payment Method						<0.0001
Self-pay	1.6%	1.5%	2.0%	2.2%	2.3%	
Private insurance	28.7%	31.5%	30.7%	30.7%	30.4%	
Medicaid	69.5%	66.9%	67.2%	66.8%	67.1%	
Other	0.2%	0.1%	0.2%	0.3%	0.2%	
Marital status						0.0071
Single	69.4%	68.5%	69.4%	70.5%	69.5%	
Married	30.6%	31.5%	30.6%	29.5%	30.50%	
Body Mass Index						<0.0001
Normal Weight	42.0%	41.2%	39.8%	38.1%	37.4%	
Underweight	6.3%	6.2%	5.8%	5.5%	5.0%	
Overweight	26.9%	27.8%	27.2%	27.7%	27.5%	
Obesity	20.7%	21.0%	22.5%	23.6%	24.7%	
Extreme Obesity	4.1%	3.8%	4.6%	5.1%	5.4%	
Geographic Location in Puerto Rico						0.0038
Metro	28.2%	27.7%	28.5%	28.1%	27.7%	
Eastern	17.3%	17.9%	17.6%	18.3%	18.6%	
Central	12.2%	11.9%	11.9%	12.0%	11.4%	
Northern	13.0%	12.5%	13.0%	13.1%	12.3%	
Western	15.8%	16.5%	16.2%	15.9%	17.1%	
Southern	13.6%	13.6%	13.0%	12.6%	13.0%	

Table 9: Results of multivariate log-binomial regression models for reproductive outcomes in Puerto Rico by disaster categories; U.S. Vital Records, 2017-2021.

Outcome	**Disaster Period**	**Adjusted Prevalence Ratio**
Child Outcomes		**PR (95% CI)**
Pre-term birth		
	Early post-hurricane	1.01 (0.94, 1.09)
	Late post-hurricane	1.01 (0.96, 1.07)
	Early pandemic	1.00 (0.94, 1.06)
	Late pandemic	1.03 (0.95, 1.11)
Low birthweight		**PR (95% CI)**
	Early post-hurricane	0.97 (0.90, 1.05)
	Late post-hurricane	0.95 (0.90, 1.01)
	Early pandemic	0.98 (0.91, 1.05)
	Late pandemic	1.03 (0.95, 1.12)
Term low birthweight		**PR (95% CI)**
	Early post-hurricane	0.90 (0.80, 1.02)
	Late post-hurricane	0.90 (0.83, 0.98)
	Early pandemic	0.96 (0.87, 1.06)
	Late pandemic	1.02 (0.91, 1.16)
Maternal outcomes		
Gestational Hypertension		**PR (95% CI)**
	Early post-hurricane	1.05 (0.93, 1.19)
	Late post-hurricane	1.19 (1.10, 1.29)
	Early pandemic	1.30 (1.18, 1.42)
	Late pandemic	1.21 (1.07, 1.36)
Gestational Diabetes		**PR (95% CI)**
	Early post-hurricane	1.09 (0.95, 1.25)
	Late post-hurricane	1.19 (1.08, 1.31)
	Early pandemic	1.38 (1.24, 1.54)
	Late pandemic	1.37 (1.20, 1.56)
Excessive Weight Gain		**PR (95% CI)**
	Early post-hurricane	1.01 (0.97, 1.05)
	Late post-hurricane	1.07 (1.04, 1.10)
	Early pandemic	1.15 (1.11, 1.18)
	Late pandemic	1.13 (1.09, 1.17)

*Regression models were controlled for maternal age, maternal education, paternal age, paternal education, birth payment method, marital status, and pre-pregnancy body mass index.

Table 10: Prevalence ratios for effect modification in maternal and newborn birth outcomes in log-binomal models by outcome and disaster from births in Puerto Rico; U.S. Vital Statistics Records, 2017-2021.

Effect Modifier	**Child Health Outcomes**											
	Pre-term birth				**Low birthweight**				**Term low birthweight**			
	Early Post Hurricane	**Late Post Hurricane**	**Early Pandemic**	**Late Pandemic**	**Early Post Hurricane**	**Late Post Hurricane**	**Early Pandemic**	**Late Pandemic**	**Early Post Hurricane**	**Late Post Hurricane**	**Early Pandemic**	**Late Pandemic**
Location	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
Metro	ref	ref	ref	ref	ref	ref	ref	ref	ref	Ref	ref	Ref
Central	0.95 (0.72, 1.24)	1.01 (0.84, 1.21)	0.96 (0.77, 1.19)	1.13 (0.86, 1.50)	0.80 (0.60, 1.07)	0.93 (0.77, 1.13)	0.83 (0.66, 1.04)	0.89 (0.66, 1.19)	0.65 (0.41, 1.01)	0.83 (0.62, 1.09)	0.80 (0.57, 1.13)	0.72 (0.46, 1.12)
Eastern	0.96 (0.76, 1.21)	0.96 (0.82, 1.12)	0.96 (0.80, 1.15)	1.15 (0.91, 1.46)	0.77 (0.60, 0.98)	0.89 (0.75, 1.04)	0.87 (0.72, 1.05)	0.86 (0.67, 1.10)	0.71 (0.49, 1.03)	0.92 (0.72, 1.18)	1.01 (0.76, 1.34)	0.83 (0.57, 1.19)
Northern	0.87 (0.67, 1.13)	0.96 (0.81, 1.14)	0.91 (0.74, 1.12)	1.04 (0.80, 1.36)	0.79 (0.59, 1.05)	0.89 (0.74, 1.08)	0.88 (0.70, 1.09)	0.82 (0.61, 1.09)	0.62 (0.40, 0.98)	0.74 (0.56, 0.99)	0.80 (0.57, 1.12)	0.66 (0.42, 1.04)
Southern	1.04 (0.81, 1.34)	0.98 (0.82, 1.16)	0.98 (0.79, 1.20)	1.03 (0.79, 1.35)	1.01 (0.79, 1.33)	0.83 (0.69, 1.00)	0.90 (0.72, 1.12)	0.92 (0.70, 1.22)	1.08 (0.74, 1.57)	0.81 (0.61, 1.06)	1.01 (0.73, 1.39)	0.85 (0.57, 1.28)
Western	1.01 (0.79, 1.28)	1.05 (0.89, 1.24)	1.02 (0.84, 1.24)	1.13 (0.88, 1.46)	0.99 (0.77, 1.27)	0.96 (0.81, 1.14)	0.95 (0.78, 1.17)	0.98 (0.76, 1.27)	0.95 (0.65, 1.38)	0.90 (0.70, 1.17)	1.06 (0.78, 1.43)	0.96 (0.66, 1.39)
Effect Modifier	**Maternal Health Outcomes**											
	Gestational Hypertension				**Gestational Diabetes**				**Excessive Weight Gain**			
	Early Post Hurricane	**Late Post Hurricane**	**Early Pandemic**	**Late Pandemic**	**Early Post Hurricane**	**Late Post Hurricane**	**Early Pandemic**	**Late Pandemic**	**Early Post Hurricane**	**Late Post Hurricane**	**Early Pandemic**	**Late Pandemic**
Location	Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)				Prevalence Ratio (95% confidence interval)			
Metro	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref	ref
Central	0.68 (0.43, 1.08)	0.89 (0.67, 1.18)	0.84 (0.59, 1.18)	0.95 (0.61, 1.49)	1.48 (0.86, 2.54)	1.57 (1.07, 2.30)	0.91 (0.58, 1.43)	1.16 (0.67, 2.03)	0.98 (0.85, 1.12)	0.98 (0.89, 1.07)	0.96 (0.86, 1.06)	1.00 (0.88, 1.14)
Eastern	1.09 (0.76, 1.55)	1.09 (0.86, 1.39)	1.40 (1.06, 1.84)	1.08 (0.75, 1.55)	0.83 (0.54, 1.26)	0.89 (0.68, 1.18)	0.89 (0.65, 1.22)	1.13 (0.77, 1.66)	0.98 (0.87, 1.11)	0.97 (0.90, 1.05)	0.97 (0.89, 1.07)	0.97 (0.87, 1.09)
Northern	0.75 (0.46, 1.23)	0.80 (0.59, 1.10)	1.04 (0.73, 1.49)	0.80 (0.48, 1.31)	0.89 (0.52, 1.52)	0.66 (0.46, 0.95)	0.80 (0.53, 1.19)	0.91 (0.54, 1.51)	0.95 (0.83, 1.09)	0.96 (0.88, 1.04)	1.00 (0.91, 1.10)	1.00 (0.89, 1.13)
Southern	1.06 (0.72, 1.56)	1.04 (0.80, 1.35)	1.57 (1.16, 2.10)	1.72 (1.19, 2.49)	1.13 (0.74, 1.71)	0.87 (0.65, 1.17)	0.92 (0.66, 1.28)	1.02 (0.67, 1.55)	0.98 (0.87, 1.12)	0.95 (0.87, 1.04)	0.95 (0.86, 1.05)	0.95 (0.83, 1.08)
Western	1.04 (0.72, 1.49)	1.00 (0.79, 1.28)	1.27 (0.95, 1.68)	1.27 (0.88, 1.89)	0.77 (0.51, 1.16)	0.76 (0.58, 1.00)	0.92 (0.67, 1.24)	0.92 (0.63, 1.35)	1.00 (0.88, 1.13)	0.94 (0.86, 1.02)	0.95 (0.87, 1.05)	1.00 (0.90, 1.14)

*Regression models were controlled for maternal age, maternal education, paternal age, paternal education, birth payment method, marital status, geographic location, and pre-pregnancy body mass index.

Table 11: Sociodemographic characteristics and distribution of key covariates by colonialism status in Florida, Texas, and Puerto Rico; U.S. Vital Statistics Records, 2017-2021.

	Texas and Florida	Puerto Rico	p-value*
Maternal Age			<0.0001
<15	0.1%	0.1%	
15-24	23.5%	40.1%	
25-34	57.3%	47.5%	
35-44	18.9%	12.2%	
45-54	0.3%	0.1%	
WIC Use			<0.0001
Uses WIC	40.2%	83.6%	
Payment Method			<0.0001
Self-pay	5.5%	1.9%	
Private Insurance	43.1%	30.3%	
Medicaid	48.7%	67.6%	
Other	2.7%	0.2%	
Marital Status			<0.0001
Single	45.4%	69.5%	
Married	54.6%	30.5%	
Maternal Education			<0.0001
High school or less	42.2%	35.6%	
Some college	28.2%	33.6%	
Bachelor's or higher	29.7%	30.8%	
Body Mass Index			<0.0001
Normal Weight	40.9%	39.9%	
Underweight	3.3%	5.9%	
Overweight	27.8%	27.3%	
Obesity	23.0%	22.4%	
Extreme obesity	5.0%	4.6%	

Table 12: Effect modification from colonialism by maternal and newborn pregnancy outcomes and disaster periods in Florida, Texas, and Puerto Rico; U.S. Vital Statistics Records, 2017-2021.

Outcome	**Disaster Period**	**Colony Effect (PR)**	**Non-Colony(TX & FL)**
Child Outcomes		**PR (95% CI)**	
Pre-term birth			
	Early post-hurricane	1.00 (0.92, 1.08)	ref
	Late post-hurricane	0.97 (0.92, 1.03)	ref
	Early pandemic	0.94 (0.89, 1.01)	ref
	Late pandemic	0.96 (0.89, 1.04)	ref
Low birthweight		**PR (95% CI)**	
	Early post-hurricane	0.96 (0.89, 1.05)	ref
	Late post-hurricane	0.95 (0.90, 1.01)	ref
	Early pandemic	0.97 (0.91, 1.04)	ref
	Late pandemic	0.99 (0.91, 1.08)	ref
Term low birthweight		**PR (95% CI)**	
	Early post-hurricane	0.92 (0.80, 1.05)	ref
	Late post-hurricane	0.92 (0.85, 1.01)	ref
	Early pandemic	0.97 (0.87, 1.08)	ref
	Late pandemic	1.00 (0.87, 1.14)	ref
Maternal outcomes			
Gestational Hypertension		**PR (95% CI)**	
	Early post-hurricane	0.93 (0.82, 1.05)	ref
	Late post-hurricane	1.00 (0.92, 1.09)	ref
	Early pandemic	0.94 (0.86, 1.03)	ref
	Late pandemic	0.91 (0.80, 1.03)	ref
Gestational Diabetes		**PR (95% CI)**	
	Early post-hurricane	1.05 (0.92, 1.21)	ref
	Late post-hurricane	1.06 (0.97 1.17)	ref
	Early pandemic	1.06 (0.96, 1.18)	ref
	Late pandemic	1.17 (1.00, 1.31)	ref
Excessive Weight Gain		**PR (95% CI)**	
	Early post-hurricane	1.01 (0.97, 1.05)	ref
	Late post-hurricane	1.10 (1.07, 1.13)	ref
	Early pandemic	1.15 (1.12, 1.19)	ref
	Late pandemic	1.20 (1.15, 1.24)	ref

*Regression models were controlled for maternal age, maternal education, maternal race, paternal age, paternal education, birth payment method, marital status, colonialism, and pre-pregnancy body mass index.

Table 13: Total births by year and percent reduction in total live births in Florida, Texas, and Puerto Rico; U.S. Vital Statistics Records, 2017-2021.

Year	Puerto Rico	Texas	Florida
2017	24,373 (baseline)	115,449 (baseline)	206,031 (baseline)
2018	21,482 (12% reduction)	114,336 (1% reduction)	204,991 (1% reduction)
2019	20,408 (16% reduction)	113,226 (2% reduction)	203,259 (1% reduction)
2020	18,965 (22% reduction)	109,301 (5% reduction)	193,538 (6% reduction)
2021	19,332 (21% reduction)	109,760 (5% reduction)	199,602 (3% reduction)
Total	104,560	562,072	1,007,421

Table 14: Live-birth bias health supplemental analysis. Simulation of hypothetical risk scenarios assuming births stayed constant (100%) in PR; U.S. Vital Statistics Records, 2017-2021.

Year	Risk of outcome among "missing" births	Corrected Relative Risk and 95% CI for PTB	Corrected Relative Risk and 95% CI for LBW	Corrected Relative Risk and 95% CI for GH	Corrected Relative Risk and 95% CI for GD
2018	100%	1.94 (1.85, 2.04)	1.99 (1.89, 2.09)	3.96 (3.66, 4.23)	5.06 (4.70, 5.44)
	50%	1.43 (1.36, 1.50)	1.43 (1.35, 1.50)	2.48 (2.30, 2.68)	3.08 (2.85, 3.33)
	20%	1.12 (1.06, 1.18)	1.09 (1.03, 1.15)	1.60 (1.48, 1.74)	1.90 (1.74, 2.06)
	18%	1.10 (1.04, 1.16)	1.07 (1.01, 1.13)	1.55 (1.42, 1.68)	1.82 (1.67, 1.98)
	15%	1.07 (1.01, 1.13)	1.03 (0.97, 1.09)	1.46 (1.34, 1.59)	1.70 (1.56, 1.85)
	12%	1.04 (0.98, 1.10)	1.00 (0.94, 1.06)	1.37 (1.26, 1.49)	1.58 (1.45, 1.72)
	10%		0.98 (0.92, 1.03)	1.31 (1.21, 1.43)	1.50 (1.37, 1.64)
	8%			1.25 (1.15, 1.37)	1.42 (1.30, 1.56)
	5%			1.05 (0.96, 1.15)	1.31 (1.19, 1.43)
	3%			1.04 (0.95, 1.13)	1.23 (1.12, 1.35)
2019	100%	2.27 (2.16, 2.38)	2.34 (2.23, 2.46)	4.97 (4.63, 5.34)	6.40 (5.96, 6.87)
	50%	1.56 (1.48, 1.65)	1.57 (1.49, 1.66)	2.98 (2.76, 3.21)	3.70 (3.43, 3.99)
	20%	1.14 (1.08, 1.20)	1.11 (1.05, 1.17)	1.78 (1.65, 1.93)	2.08 (1.92, 2.26)
	18%	1.11 (1.05, 1.17)	1.08 (1.02, 1.14)	1.70 (1.57, 1.85)	1.98 (1.82, 2.15)
	15%	1.07 (1.01, 1.13)	1.03 (0.97, 1.09)	1.58 (1.46, 1.72)	1.81 (1.67, 1.97)
	12%	1.03 (0.97, 1.08)	0.99 (0.93, 1.04)	1.46 (1.35, 1.59)	1.65 (1.52, 1.80)
	10%		0.96 (0.90, 1.01)	1.38 (1.27, 1.51)	1.54 (1.41, 1.69)
	8%			1.30 (1.20, 1.42)	1.44 (1.31, 1.57)
	5%			1.18 (1.09, 1.29)	1.28 (1.19, 1.37)
	3%			1.11 (1.01, 1.21)	1.17 (1.06, 1.28)
2020	100%	2.72 (2.59, 2.85)	2.86 (2.72, 3.00)	6.56 (6.12, 7.03)	8.57 (7.99, 9.20)
	50%	1.75 (1.66, 1.84)	1.80 (1.71, 1.90	3.79 (3.53, 4.08)	4.83 (4.49, 5.20)
	20%	1.17 (1.11, 1.24)	1.17 (1.11, 1.24)	2.14 (1.98, 2.31)	2.58 (2.39, 2.80)
	18%	1.13 (1.07, 1.20)	1.13 (1.07, 1.19)	2.02 (1.87, 2.19)	2.43 (2.25, 2.64)
	15%	1.07 (1.02, 1.13)	1.07 (1.01, 1.13)	1.86 (1.72, 2.01)	2.21 (2.04, 2.40)
	12%	1.02 (0.96, 1.07)	1.00 (0.95, 1.06)	1.69 (1.56, 1.84)	1.98 (1.83, 2.16)
	10%		0.96 (0.91, 1.02)	1.58 (1.46, 1.72)	1.83 (1.69, 2.00)
	8%			1.47 (1.35, 1.60)	1.69 (1.55, 1.84)
	5%			1.31 (1.20, 1.42)	1.46 (1.34, 1.60)
	3%			1.20 (1.10, 1.31)	1.31 (1.20, 1.44)
2021	100%	2.63 (2.51, 2.76)	2.75 (2.62, 2.89)	6.16 (5.75, 6.61)	8.10 (7.55, 8.69)
	50%	1.73 (1.64, 1.82)	1.77 (1.68, 1.87)	3.61 (3.36, 3.88)	4.64 (4.31, 5.00)

	20%	1.19 (1.13, 1.26)	1.18 (1.12, 1.25)	2.08 (1.92, 2.25)	2.57 (2.37, 2.78)
	18%	1.15 (1.09, 1.22)	1.14 (1.08, 1.21)	1.98 (1.83, 2.14)	2.43 (2.24, 2.63)
	15%	1.10 (1.04, 1.16)	1.09 (1.03, 1.15)	1.82 (1.68, 1.97)	2.22 (2.05, 2.41)
	12%	1.05 (0.99, 1.11)	1.03 (0.97, 1.09)	1.67 (1.54, 1.81)	2.01 (1.85, 2.19)
	10%		0.99 (0.93, 1.05)	1.57 (1.44, 1.70)	1.87 (1.72, 2.04)
	8%			1.46 (1.35, 1.59)	1.74 (1.59, 1.89)
	5%			1.31 (1.20, 1.43)	1.53 (1.40, 1.67)
	3%			1.21 (1.11, 1.32)	1.39 (1.27, 1.52)

* 2017 (pre-disaster) is used as the reference point for all comparisons

** PTB = Preterm birth, LBW = Low birthweight, GH = Gestational Hypertension, GD = Gestational Diabetes

*** Starting point for simulation "risk" was based on baseline (i.e., 2017) risk for outcome. PTB was 11.5%, LBW was 10.0%, GH was 4%, and GD was 3%.

Table 15: Live-birth bias health supplemental analysis. Simulation of hypothetical risk scenarios assuming births stayed constant (75%) in PR; U.S. Vital Statistics Records, 2017-2021.

Year	Risk of outcome among "missing" births	Corrected Relative Risk and 95% CI for PTB	Corrected Relative Risk and 95% CI for LBW	Corrected Relative Risk and 95% CI for GH	Corrected Relative Risk and 95% CI for GD
2018	100%	1.69 (1.60, 1.77)	1.71 (1.62, 1.80)	3.21 (2.98, 3.45)	4.07 (3.78, 4.38)
	50%	1.30 (1.23, 1.37)	1.29 (1.22, 1.36)	2.11 (1.96, 2.29)	2.59 (2.39, 2.80)
	20%	1.07 (1.01, 1.13)	1.03 (0.97, 1.09)	1.46 (1.34, 1.59)	1.70 (1.56, 1.85)
	18%	1.05 (1.00, 1.11)	1.02 (0.96, 1.08)	1.41 (1.30, 1.54)	1.64 (1.50, 1.79)
	15%	1.03 (0.97, 1.09)	0.99 (0.93, 1.05)	1.35 (1.24, 1.47)	1.55 (1.42, 1.69)
	12%	1.01 (0.95, 1.06)	0.96 (0.91, 1.02)	1.28 (1.18, 1.40)	1.46 (1.34, 1.60)
	10%		0.95 (0.89, 1.00)	1.24 (1.14, 1.35)	1.40 (1.28, 1.53)
	8%			1.20 (1.10, 1.30)	1.34 (1.23, 1.47)
	5%			1.03 (0.95, 1.13)	1.26 (1.15, 1.38)
	3%			1.03 (0.94, 1.13	1.20 (1.09, 1.31)
2019	100%	1.92 (1.82, 2.01)	1.96 (1.86, 2.06)	3.97 (3.70, 4.27)	5.05 (4.70, 5.43)
	50%	1.39 (1.32, 1.46)	1.38 (1.31, 1.46)	2.48 (2.30, 2.68)	3.03 (2.80, 3.27)
	20%	1.07 (1.01, 1.13)	1.03 (0.97, 1.09)	1.58 (1.46, 1.72)	1.81 (1.67, 1.97)
	18%	1.05 (0.99, 1.11)	1.01 (0.95, 1.07)	1.52 (1.40, 1.65)	1.73 (1.59, 1.89)
	15%	1.02 (0.96, 1.07)	0.97 (0.92, 1.03)	1.43 (1.32, 1.56)	1.61 (1.48, 1.76)
	12%	0.98 (0.93, 1.04)	0.94 (0.89, 1.00)	1.34 (1.24, 1.46(	1.49 (1.36, 1.63)
	10%		0.92 (0.86, 0.97)	1.28 (1.18, 1.40)	1.41 (1.29, 1.54)
	8%			1.22 (1.12, 1.33)	1.33 (1.21, 1.45)
	5%			1.14 (1.04, 1.24)	1.21 (1.13, 1.30)
	3%			1.08 (0.98, 1.17)	1.13 (1.03, 1.24)
2020	100%	2.23 (2.13, 2.34)	2.33 (2.22, 2.45)	5.18 (4.82, 5.56)	6.70 (6.24, 7.20)
	50%	1.51 (1.43, 1.59)	1.54 (1.46, 1.62)	3.10 (2.88, 3.34)	3.89 (3.61, 4.20)
	20%	1.07 (1.02, 1.13)	1.07 (1.01, 1.13)	1.86 (1.72, 2.01)	2.21 (2.04, 2.40)
	18%	1.05 (0.99, 1.10)	1.03 (0.98, 1.09)	1.78 (1.64, 1.92)	2.10 (1.93, 2.28)
	15%	1.00 (0.95, 1.06)	0.99 (0.93, 1.05)	1.65 (1.52, 1.79)	1.93 (1.77, 2.10)
	12%	0.96 (0.91, 1.01)	0.94 (0.89, 1.00)	1.53 (1.41, 1.66)	1.76 (1.62, 1.92)
	10%		0.91 (0.86, 0.96)	1.44 (1.33, 1.57)	1.65 (1.51, 1.80)
	8%			1.36 (1.25, 1.48)	1.54 (1.41, 1.68)
	5%			1.24 (1.14, 1.35)	1.37 (1.25, 1.50)
	3%			1.16 (1.06, 1.26)	1.25 (1.14, 1.38)
2021	100%	2.18 (2.07, 2.29)	2.26 (2.15, 2.38)	4.89 (4.55, 5.25)	6.37 (5.93, 6.84)
	50%	1.50 (1.43, 1.58)	1.53 (1.45, 1.61)	2.97 (2.76, 3.20)	3.78 (3.50, 4.07)

	20%	1.10 (1.04, 1.16)	1.09 (1.03, 1.15)	1.82 (1.68, 1.97)	2.22 (2.05, 2.41)
	18%	1.07 (1.02, 1.13)	1.06 (1.00, 1.12)	1.75 (1.61, 1.89)	2.12 (1.95, 2.30)
	15%	1.03 (0.98, 1.09)	1.01 (0.95, 1.07)	1.63 (1.50, 1.77)	1.96 (1.80, 2.13)
	12%	0.99 (0.94, 1.05)	0.97 (0.91, 1.03)	1.52 (1.40, 1.65)	1.81 (1.66, 1.96)
	10%		0.94 (0.88, 0.99)	1.44 (1.32, 1.56)	1.70 (1.56, 1.85)
	8%			1.36 (1.25, 1.48)	1.60 (1.46, 1.74)
	5%			1.25 (1.14, 1.36)	1.44 (1.32, 1.58)
	3%			1.17 (1.07, 1.28)	1.34 (1.22, 1.46)

* 2017 (pre-disaster) is used as the reference point for all comparisons

** PTB = Preterm birth, LBW = Low birthweight, GH = Gestational Hypertension, GD = Gestational Diabetes

*** Starting point for simulation "risk" was based on baseline (i.e., 2017) risk for outcome. PTB was 11.5%, LBW was 10.0%, GH was 4%, and GD was 3%.

Table 16: Live-birth bias colonialism supplemental analysis. Simulation of hypothetical risk scenarios assuming births stayed constant in PR; U.S. Vital Statistics Records, 2017-2021.

Year	Risk of outcome among "missing" births	Corrected Relative Risk and 95% CI for PTB	Corrected Relative Risk and 95% CI for LBW	Corrected Relative Risk and 95% CI for GH	Corrected Relative Risk and 95% CI for GD
2018	100%	2.42 (2.39, 2.45)	2.76 (2.72, 2.79)	2.57 (2.53, 2.60)	2.62 (2.59, 2.66)
	50%	1.66 (1.62, 1.69)	1.77 (1.73, 1.81)	1.45 (1.40, 1.49)	1.58 (1.54, 1.63)
	20%	1.25 (1.21, 1.29)	1.30 (1.26, 1.34)	0.93 (0.87, 0.98)	0.97 (0.92, 1.03)
	18%	1.22 (1.18, 1.26)	1.27 (1.26, 1.34)	0.89 (0.84, 0.95)	0.93 (0.87, 0.99)
	15%	1.18 (1.14, 1.22)	1.22 (1.18, 1.26)	0.84 (0.79, 0.90)	0.87 (0.81, 0.93)
	12%	1.14 (1.10, 1.18)	1.18 (1.13, 1.22)	0.79 (0.73, 0.85)	0.81 (0.75, 0.87)
	10%		1.15 (1.10, 1.19)	0.76 (0.70, 0.81)	0.77 (0.71, 0.83)
	8%			0.72 (0.66, 0.78)	0.73 (0.66, 0.79)
	5%			0.60 (0.54, 0.66)	0.67 (0.60, 0.74)
	3%			0.60 (0.53, 0.66)	0.63 (0.56, 0.70)
2019	100%	2.87 (2.84, 2.90)	3.44 (3.41, 3.47)	2.68 (2.65, 2.72)	2.93 (2.90, 2.97)
	50%	1.80 (1.76. 1.83)	2.10 (2.06, 2.14)	1.62 (1.58, 1.66)	1.73 (1.69, 1.78)
	20%	1.24 (1.20, 1.28)	1.41 (1.37, 1.45)	0.98 (0.93, 1.03)	1.00 (0.94, 1.05)
	18%	1.21 (1.17, 1.25)	1.36 (1.32, 1.40)	0.94 (0.89, 0.99)	0.95 (0.89, 1.00)
	15%	1.16 (1.12, 1.20)	1.30 (1.26, 1.34)	0.87 (0.82, 0.93)	0.87 (0.82, 0.93)
	12%	1.10 (1.06, 1.14)	1.23 (1.19, 1.28)	0.81 (0.75, 0.86)	0.80 (0.74, 0.86)
	10%		1.19 (1.15, 1.23)	0.77 (0.71, 0.82)	0.75 (0.68, 0.81)
	8%			0.72 (0.66, 0.78)	0.70 (0.63, 0.76)
	5%			0.66 (0.60, 0.72)	0.62 (0.55, 0.69
	3%			0.61 (0.55, 0.68)	0.57 (0.50, 0.64)
2020	100%	3.77 (3.74, 3.80)	4.57 (4.54, 4.60)	2.33 (2.30, 2.36)	2.48 (2.45, 2.51)
	50%	2.16 (2.13, 2.20)	2.57 (2.54, 2.60)	1.54 (1.51, 1.58)	1.65 (1.61, 1.68)
	20%	1.36 (1.32, 1.40)	1.57 (1.53, 1.61)	0.98 (0.94, 1.03)	1.02 (0.98, 1.07)
	18%	1.31 (1.27, 1.35)	1.51 (1.47, 1.55)	0.94 (0.89, 0.99)	0.98 (0.93, 1.03)
	15%	1.24 (1.20, 1.28)	1.42 (1.37, 1.46)	0.88 (0.83, 0.93)	0.90 (0.93, 1.03)
	12%	1.16 (1.12, 1.21)	1.32 (1.28, 1.37)	0.81 (0.76, 0.86)	0.83 (0.77, 0.88)
	10%	1.12 (1.07, 1.16)	1.26 (1.22, 1.31)	0.77 (0.71, 0.82)	0.77 (0.72, 0.88)
	8%		1.20 (1.16, 1.25)	0.72 (0.67, 0.77)	0.72 (0.66, 0.78)
	5%			0.65 (0.59, 0.71)	0.64 (0.57, 0.70)
	3%			0.60 (0.54, 0.66)	0.58 (0.51, 0.65)
2021	100%	3.42 (3.39, 3.44)	4.13 (4.10, 4.16)	2.46 (2.42, 2.49)	2.73 (2.70, 2.76)
	50%	2.00 (1.97, 2.03)	2.37 (2.34, 2.40)	1.54 (1.50, 1.58)	1.72 (1.68, 1.76)

	20%	1.29 (1.26, 1.33)	1.49 (1.45, 1.53)	0.95 (0.90, 0.99)	1.04 (0.99, 1.09)
	18%	1.25 (1.21, 1.29)	1.43 (1.39, 1.47)	0.91 (0.86, 0.95)	0.99 (0.94, 1.04)
	15%	1.18 (1.15, 1.22)	1.35 (1.31, 1.39)	0.84 (0.79, 0.89)	0.92 (0.86, 0.97)
	12%	1.12 (1.08, 1.16)	1.27 (1.23, 1.31)	0.78 (0.73, 0.83)	0.84 (0.79, 0.89)
	10%		1.22 (1.18, 1.26)	0.73 (0.68, 0.79)	0.79 (0.73, 0.84)
	8%			0.69 (0.64, 0.74)	0.74 (0.68, 0.79
	5%			0.62 (0.57, 0.68)	0.65 (0.59, 0.72)
	3%			0.58 (0.52, 0.64)	0.60 (0.54, 0.66)

* Living in a non-U.S. colony is used as the reference point for colonialism effect modification analyses

** PTB = Preterm birth, LBW = Low birthweight, GH = Gestational Hypertension, GD = Gestational Diabetes

*** Starting point for simulation "risk" was based on baseline (i.e., 2017) risk for outcome. PTB was 11.5%, LBW was 10.0%, GH was 4%, and GD was 3%.

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Chapter 4
Puerto Rican Experiences with Health, Equity, and Colonialism in Times of Social and Environmental Disasters

4.1 Introduction

Since Hurricane Katrina, a significant body of research has explored the relationship between living through disasters and consequent adverse mental and physical health endpoints. Most notably, catastrophic events such as hurricanes, earthquakes, tornadoes, floods, and epidemics have been found to lead to short and long-term psychological and psychosocial distress. Disasters have been associated with mental and behavioral consequences due to the disruptive, life-threatening, and potentially violent nature of these events. Individuals who had more severe and potentially traumatic experiences—such as loss of home, death of a loved one, or displacement from community—are particularly at risk for adverse mental health outcomes. Most of the available literature has found that disaster experiences can lead to post-traumatic stress disorder (PTSD), depression, sleep disturbances, irritability, cognitive dysfunction, behavioral reactions, and other psychopathological conditions.[1-4] A more limited body of research has also found associations between disaster exposure and physical health outcomes such as asthma attacks, infectious disease incidence, and long-term chronic disease development.[5-7] While studies have established associations between living through disaster events and consequent health and wellness, opportunities to advance disaster and health research remain.

A significant gap is that limited research has examined the impact of living through multiple and/or cascading disasters, the potential for cumulative impacts on health, and specific pathways and mediating factors. Some studies have observed high rates of psychological distress, acute stress disorder, PTSD, depression, panic disorder, and/or suicidal ideation in individuals who experienced multiple disasters.[8-13] Other studies have found that, compared to those who experience a singular disaster events, individuals who experienced multiple disasters had more significant risks to mental health.[2,14-16] However, most of these studies focused on cascading disasters (i.e., a disaster that leads to another disaster) or similar disasters that happened years–or even decades—apart from each other (e.g., Hurricane Katrina and Hurricane Gustav in Louisiana). A recent systematic literature review on multiple disaster exposure and their public health implications conducted by Leppold and colleagues found that multiple disasters may have direct and indirect effects on physical and mental health, but found significant gaps in terms of consecutive disasters with different hazard types (e.g., hurricane and pandemic), how previous disaster exposure affects the experience of subsequent disasters, and the physical health effects of multiple disasters.[15,17] The need to examine the health impacts of multiple disaster events has become increasingly evident as disasters associated with climate change and natural hazards are increasing in frequency, intensity, and duration, and can co-occur with other disasters such as pandemics, oil spills, biologic attacks, and other natural and/or human-made hazards.

Further, another significant gap in knowledge of multiple disaster exposures, supported by Leppold and colleagues,[17] is a lack of qualitative research providing additional insights into these complex relationships.[17] These applications are particularly important since much is still not understood about these phenomena and information on experiences of directly-impacted

people can guide research on etiologic pathways, facilitate the development of scales to assess the severity of multiple disaster exposure, and explore new associations informed by affected communities. In Puerto Rico—a U.S. territory that has been recently ravaged by multiple disasters—research has established that multiple disaster experiences have resulted in adverse mental health, increased mortality, reduced healthcare access, and a disproportionate burden on geriatric health.[18-20] However, these few studies have been primarily based on the effects of Hurricane Maria and used quantitative analysis, leaving knowledge gaps about the implications of the earthquakes and the COVID-19 pandemic that could be filled through qualitative research.

Prior research from our group—as presented in chapters 2 and 3—has underscored the need to explore these issues beyond the limitations of statistical analysis. In chapter 2, we found that disaster exposure was associated with adverse physical and mental health during the early post-hurricane period, but this relationship did not persist in subsequent periods. Most notably, the early and late pandemic periods were protective for mental health, exercise, and participant health perceptions, while the early pandemic was linked with improved physical health. These results are opposite to our hypothesized associations and may be the result of measurement bias, selection bias, social desirability, and/or other analytical and theoretical considerations that cannot be accounted for given the limitations in our data. Similarly, results from chapter 3 show that disaster periods were consistently associated with harms to maternal health, but no significant associations were found with newborn health. While we theorize that the latter results may be explained by live birth bias, particularly since yearly pregnancy rates in Puerto Rico are steadily declining since Hurricane Maria, data from vital records cannot fully explain our observations. More refined in-depth analyses may help address the limitations in these chapters,

answer lingering questions, and enhance our understanding of how multiple disaster exposure can affect health.

This study aims to address current gaps in multiple disaster and health literature and address the questions raised by chapters 2 and 3 of this dissertation by conducting an in-depth exploration of multiple disaster exposure and consequent health trajectories of residents of Puerto Rico affected by disasters from 2017 to 2021. More specifically, we describe the experiences of residents of Puerto Rico who were exposed to Hurricane Maria, earthquakes, and the COVID-19 pandemic, specifically regarding health and wellness (e.g., mental, physical, and reproductive health), barriers and protective factors to disaster adjustment, and the contrast between different disaster hazard experiences. We also further explore participants' perception about colonialism and how Puerto Rico's territorial status may have driven disaster effects and consequent health endpoints. The findings from our study can help inform future etiologic studies that aim to understand the impact of cumulative disaster experiences on population health outcomes and address the root causes of adverse health during the climate crisis.

4.2 Methods

4.2.1 Data source

We gathered data through in-depth qualitative interviews with Puerto Ricans currently living in the island who lived through all 3 disaster periods. To enhance relevance of findings to our prior quantitative aims, study participants were limited to adults in the younger range of reproductive age (i.e., between 15-35 years-old)—inclusive of all gender identities—to understand both general health trajectories and their experiences with reproductive health. We utilized a purposive convenience sampling approach and interviewed 30 participants living in diverse geographical locations throughout Puerto Rico. Specifically, after consulting with local

researchers, we utilized a regional map from the Puerto Rican Tourism Company—based on its ability to represent different disaster experiences and proximity to disaster epicenters—to divide Puerto Rico into 6 regions (Appendix A). These were the following: Western, Northern, Central, Southern, Metropolitan, and Eastern Puerto Rico. Five participants were sampled from each of these regions to capture diverse experiences in disaster periods and their health trajectories from 2017 to 2022.

4.2.2 Recruitment and enrollment

Recruitment activities were primarily conducted through social media due to high activity in this medium from our target population. We created the Estudio Clima, Ambiente, Bienestar, y Equidad en Puerto Rico (CABE-PR; Study of Climate, Enviroment, Wellness, and Equity in Puerto Rico) Facebook and Instagram pages and developed multimedia promotional materials to encourage enrollment in the study. These recruitment materials required individuals to be between 18 to 35 years old, communicate in Spanish and/or English, and have lived in Puerto Rico between 2017 and 2021. We also paid for advertisements directed at our targeted population and participants were compensated $50 for their time. These promotional efforts resulted in 150 followers and over 8000 individuals reached with our posts on Facebook. Recruitment flyers were also distributed by e-mail to nonprofit, governmental, and community-based organizations and they forwarded our materials.

Interested participants were asked to fill out a participant interest form in Qualtrics to be considered for invitation in our study. This form asked respondents sociodemographic information, including their name, age, gender, education, occupation, self-described socioeconomic status, marital status, if they had children, dates of residence in Puerto Rico, geographical location, and contact information. This information was used to screen participants

for inclusion and exclusion criteria and to purposively select participants into our study. Specifically, we wanted to ensure that 5 participants from each geographic location were represented and that we had diversity in terms of gender, socioeconomic status, marital status, and parental status. To achieve this, we developed a system to screen participants from the interest form and select 5 participants per region based on their sociodemographic characteristics. Generally, these 5 participants were diverse in terms of their gender identity, socioeconomic status, marital status, and if they were parents. We attempted to contact participants several times through e-mail, text messages, and phone calls, based on their preferred method of communication. If we were unable to establish communication after 3 attempts or if participants no longer wanted to participate in the study, we attempted to replace them with someone with similar sociodemographic characteristics. Overall, 250 individuals filled out the participant interest form, 39 were invited for interviews, and we completed 30 interviews. We were not able to establish communication with 6 prospective participants and 3 did not show up for their scheduled interviews.

4.2.3 Data collection

Interviews were conducted through non-video teleconference programs and telephone, based on participant preference. After individual participants joined the call, the interviewer explained the project objectives and participants gave informed consent. Interviews were conducted in Spanish based on participant preference, were audio recorded, and transcribed verbatim by 3 research assistants who were fully bilingual, Puerto Rican, and native Spanish speakers. No personally identifiable information was collected, and transcriptions were secured in an encrypted folder, only accessible to members of our research team. Interviews were conducted between May 2023 and August 2023 by the primary author of this paper, who is fully

bilingual, a Native Puerto Rican, and has extensive training in qualitative research methods. Interviews lasted between 30 minutes to 2 hours. We used a semi-structured interview protocol which adapted questions to suit the particular experiences of each interviewee.

We developed questions based on dimensions of disaster exposure and health, informed by the findings from the first two dissertation aims. Interview protocols explored participants' experiences with the hurricane, earthquakes, and pandemic, their physical and mental health trajectories during these periods, reproductive health, and their view on the role of colonialism in the relationship between disaster exposure and health. We also asked participants for sociodemographic information, barriers and facilitators to health, their views on disaster resilience, and some of the strengths and limitations of recovery efforts. All members of our academic team were trained in ethical principles and are committed to the ethical conduct of research. All participants provided consent to participate following proper linguistic, cultural, and ethical guidelines and procedures. The study was approved by the University of Michigan Institutional Review Board (HUM00229812).

4.2.4 Data analysis

Sociodemographic information was double-entered, reviewed, and reconciled for quality control by the primary author. We calculated descriptive statistics of sociodemographic information to characterize the study sample. We analyzed the interview transcripts in the original language, to avoid losing the cultural richness of the language when translating information. Only quotes used in the present manuscript were translated to English. We utilized a framework analysis approach for qualitative data by working individually with each transcript and using Dedoose software.[21,22] Specifically, the analysis used a systematic process with the following key stages: (1) reading each transcript entirely one at a time, (2) documenting

emerging themes, (3) developing coding categories and sorting data into categories based on the interview, (4) documenting the range of responses for each code category, (5) searching for meaningful patterns in the data, (6) reviewing transcripts to ensure full report of all responses, and (7) summarizing the range of responses for each category. The principal author trained and worked together with research assistants who developed thematic summaries of individual interviews and identified emerging themes. These narrative summaries, interview field notes, and several analyses meetings were used to develop a codebook and apply codes to transcripts using Dedoose. Twenty initial codes were included in the codebook, but additional subcodes were iteratively developed by the primary author as we coded interviews. After transcripts were coded, coding outputs were examined to better understand the various perspectives of participants related to our research questions. When examining these outputs, the primary author wrote memos on emerging key themes that were salient to the objectives of our study. Results are presented with illustrative quotes of participants and are de-identified to protect participant confidentiality.

4.3 Results

We interviewed a total of 30 participants, 5 from each of the 6 geographic regions in Puerto Rico (i.e., Western, Eastern, Northern, Southern, Metropolitan, and Central). Participants were largely single (80%), employed (57%), and identified as female (77%). The average participant age was 27 and participants spent an average of 13 years in their current residence. All participants identified as Latinx and Puerto Rican, and were raised in Puerto Rico. The majority of participants still had their extended family living in Puerto Rico, but 5 participants reported that their extended family had moved to the continental United States. The overwhelming majority of participants (93.3%) had some level of college education. The

currently employed participants had a wide range of professional careers, including lawyers, teachers, healthcare workers, nurses, administrative assistants, and researchers but 43 percent of inteviewees were unemployed (inclusive of homemakers and students). Participants represented munincipalities from Southern (Ponce, Villalba, Arroyo), Western (Aguada, Cabo Rojo, San Germán, San Sebastián, Guánica), Central (Utuado, Adjuntas, Jayuya, Corozal), Northern (Arecibo, Hatillo, Barceloneta, Vega Baja), Metropolitan (San Juan, Toa Baja), and Eastern (Caguas, San Lorenzo, Juncos, Humacao, Loiza) Puerto Rico. No participants came from the offshore islands of Vieques and Culebra. Key findings are presented using illustrative quotes and participant information is de-identified to protect confidentiality. The themes presented in this manuscript include individual disaster experiences, physical health and mental health trajectories, reproductive health, barriers and protective factors, and colonialism.

4.3.1 Experiences during Hurricane Maria

Interview participants recounted experiences and challenges during and in the aftermath of Hurricane Maria. Broadly, participants described structural damages to their homes and communities, loss or interruption of employment and job insecurity, displacement from their homes, death of loved ones, outward migration of family and friends, significant financial loss, interruption in essential services, and other hazardous living conditions. Participants also experienced unique mental health stressors during the hurricane, including anxiety, depression, stress, substance use, trauma, suicidal ideation, worsening of prior mental health conditions, fear of future storms, and feelings of hopelessness. One male participant from the Central region described his thoughts on the experiences lived and post-hurricane mental health and how this relates to commonly-held feelings of post-disaster trauma:

"In terms of mental health in Puerto Rico, Hurricane Maria formulated a perpetual post-traumatic stress that has not dwindled amidst the pandemic. People are waiting for the next horrible event to happen. Whenever there's a storm warning, people run to supermarkets. People are on edge. They feel more anxious. We lived through experiences that we don't want to happen again, and, with even the smallest prospect of threat, people overreact. But in some ways, it is justified due to the severity of what we lived."

The hurricane brought significant financial impacts to many participants and their loved ones, with several participants reporting reductions in work hours, job loss, interruption in government benefit programs (e.g., food stamps), and other financial stressors. This resulted in significant financial stress and led to participants pulling from their savings, having to borrow money, and/or taking out loans. A female participant from Northern Puerto Rico recounted how this financial stress affected her and her children:

"During Hurricane Maria, my children also suffered a lot because we spent that time with no food stamps, and we were close to my daughter's second birthday. Honestly, knowing that I wasn't going to be able to buy her a cake was very difficult. I'm very grateful that my sister-in-law let me borrow her food stamps and I was able to buy food… afterwards, during a few months, we were battling daily so we could have something to eat. It was very difficult."

Participant recollection of events post-hurricane also focused heavily on interruption in essential services and extended periods without electricity, running water, and communication. They also explained that it was difficult to access gasoline, drinking water, food, and that there were significant challenges with transportation. The most significant service interruption for the majority of participants was power and electricity interruption, with all participants spending at

least one month with no power, and some participants spending as much as one year without electricity. A female participant from the Central Region recounted her experience with service interruptions:

> *"Our family learned to not depend on public services. We knew that we couldn't count on electricity being restored for a very long time. Therefore, we invested in power generators. Water, it was the same thing. We knew we couldn't depend on having any water in our house because we get water through a pump that works with electricity. If there's no power, there's no water. We had to look for ways to fend for ourselves, getting power generators, investing in a cistern, storing drinking water, and always taking care of those things."*

Participants who invested in generators still struggled daily to access gasoline due to shortages and prolonged wait times. Some participants reported going to gas stations as early as 4 am and spending close to 7 hours in the line. However, for many participants, the financial investment required to access a generator or a cistern was not feasible, and they had to spend extended periods without access to these services. This resulted in excessive heat exposure, food being spoiled, complications for individuals who needed their medication properly refrigerated, and other negative consequences.

4.3.2 Experiences during the Earthquakes

Interview participants recounted experiences during the late 2019 and early 2020 period when multiple earthquake events affected Southwestern Puerto Rico. Broadly, participants reported electricity loss and structural impacts in their home; however, most participants reported more minimal damages from the earthquakes compared to Hurricane Maria, particularly among participants in Northern, Metropolitan, and Eastern Puerto Rico. These earthquakes are viewed

among participants as a Southern and Western Puerto Rico-specific disaster, and participants in other regions felt that the impact from these was mostly psychological due to constant fear of stronger earthquakes or shockwaves triggering earthquakes in other parts of the island. One female participant from the Metropolitan area expressed her experience during the earthquakes:

> *"During Hurricane Maria, the interruption in electricity was much more significant. I don't remember many interruptions in services during the earthquakes. Maybe we lost power, but it wasn't for a prolonged time, we spent maybe 5 days with no power. Water service had some interruptions. At least where I was living at in San Juan, there were some interruptions during the earthquakes and it was kind of on and off, but there weren't many problems with electricity. In terms of the earthquakes, I feel that the Metropolitan region wasn't very affected. It was more of an emotional impact."*

Participants with closer proximity to earthquake epicenters—primarily those in Southern and Western Puerto Rico—had different experiences. Many reported prolonged loss of electricity and other essential services, had considerable infrastructure damage in their homes, had interruptions in their employment, and had significant psychological distress. Several participants from these regions felt that the earthquake was the worst disaster in terms of mental health impact due to the unpredictability of these events and the constant fear of seismic activity. A male participant from Southern Puerto Rico shared his experience during the earthquakes:

> *"I feel that earthquakes affected people psychologically more than anything. It was something that, anywhere you went to in the South, there was always fear, especially inside of buildings. It affected a lot. After the first big earthquake, we were sleeping in the living room for basically two or three days with the aftershocks. I feel like that affected people a lot… in places like Ponce, you would often drive through the city, and you saw*

buildings about to collapse. You didn't feel comfortable going inside of buildings, you didn't trust going to the supermarket. Everyone was reclusive and stayed locally. People were cautious about where they went. If there was an aftershock, people would call to see where you were, if you were okay. I remember that there was a lot of fear around going to the beach. With a hurricane, you know more or less what to expect. But with earthquakes, there was so much uncertainty anywhere you went. My sister was so affected that she ended up moving to the United States. She didn't feel safe here."

4.3.3 Experiences during the COVID-19 pandemic

Participants recollected their experiences during the COVID-19 pandemic in Puerto Rico. Broadly, participants reported disruptions in employment, or unemployment, significant financial impact at the individual and community levels, social isolation, constant uncertainty and confusion about the virus, infection anxiety, limited access to healthcare and food, and confusing or ineffective policies by the local government. Participants largely reported feeling isolated, leading more sedentary lifestyles, gaining weight, and feeling psychological impacts. One male participant from Southern Puerto Rico recounted his experience with social isolation:

"The pandemic was different because it had its advancements in terms of learning how to work remotely, which persists. But what affected me the most was not having any social contact for so long. I went through at least 31 days just seeing my mom, my girlfriend, or my roommate. The depression this caused is something I've never felt, because there's never been anything that isolated you so much from other people. That was a very challenging time psychologically for me. I missed talking with other people, being able to go out, share a space outside of these 4 walls. It got to the point where I felt desperation. You were a prisoner of your own home."

While participants broadly reported little-to-no service interruptions in terms of electricity, water, and communications during the pandemic, they highlighted that it was more difficult to access things like health insurance and food. According to participants, particular governmental and private industry policies contributed to these challenges with access, including the local government-imposed curfew, being able to drive on certain days based on if you had even/odd numbers in your car license plate, and restrictions inside of supermarkets. A female participant from the Metropolitan area recounted her experiences with food access:

> *"What caused the most uncertainty in terms of daily life during the pandemic was the guidelines, which changed frequently. In Puerto Rico we had a curfew, we had several phases of restrictions, there was the restriction in which you could only drive based on your plate. There were several changes in terms of the time of the curfew, in what you could or could not do. That affected schedules and, since people worked, it was complicated because many places were not operating at full capacity. If you spent all day in class or at work, you had a very limited timeframe to go to the supermarket or to run errands. Everything felt very unsteady."*

Healthcare and food access was also hindered by COVID-19 infection anxiety. Many participants reported feeling discouraged from leaving their house, even if they were sick or needed medical attention, to avoid infection. Participants admitted to delaying needed medical care, reducing visits to the supermarket, and avoiding running errands. A female participant from Southern Puerto Rico shared her experience with fear of infection during pregnancy:

> *"The pandemic was very difficult because it was the earthquakes and the pandemic at the same time. Protecting your children was the most important thing. You feared going outside, that anxiety, that stress, I say we lived in a bubble. That's when I lost my baby.*

Also going to the hospital was very difficult because you had those restrictions at the start, and medical evaluations. It was very difficult to live through both the pandemic and earthquakes at the same time. It was a very difficult pregnancy. That's when I thought if I went to the hospital, I'll get COVID, and I'm pregnant. Fear was really intensified. Often I had severe pain and I didn't go to the hospital because I was going to get COVID. But I ended up losing my baby anyway."

4.3.4 Physical Health

Participants highlighted diverse experiences regarding their post-disaster trajectories with physical health. These included complications with healthcare, medication, and food access throughout disaster periods, development of disease, physical strain and fatigue, reduction in exercise and physical activity, weight gain, and impaired respiratory health. In terms of healthcare access, participants reported the most significant complications during Hurricane Maria and the pandemic. According to participants, during the COVID-19 pandemic healthcare access was limited due to fear of infection, long wait times and lack of availability of medical appointments, and logistical challenges due to the government policies mentioned above. Hurricane Maria saw limited healthcare access due to the closure of clinics and doctors' offices, power and electricity, structural damages and challenges with transportation, and participants being overburdened with daily responsibilities due to the disaster. A female participant from Eastern Puerto Rico shared her experience with healthcare access during the hurricane:

"In terms of healthcare services, I'd say they were affected especially after Hurricane Maria because there was no way to communicate. For example, in my case, I had an intrauterine device and, because I had to carry heavy water bottles and exerting a lot of physical strain, the device moved, and I had no way to contact my gynecologist. There

was no service during that time because it was all chaos. I had no other choice but to take it out myself and let God decide what happens."

Similarly, other participants reported extreme levels of physical strain and constant fatigue during the early post-hurricane period. They had to spend considerable time cleaning and throwing things away, walk significant distances while carrying water and gasoline, wash clothes by hand, and were at risk for injury due to accidents while moving antennas or cleaning debris from the hurricane. Several participants also reported developing respiratory infections during the early stages of the post-hurricane period. One male participant from Southern Puerto Rico shared his experience with physical health:

"During Hurricane Maria, there was a lot of physical strain. Every day you had to wake up to clean, pick-up debris, throw away things that no longer worked or that broke. That's what I remember in terms of physical health. I remember having a lot of allergies after Maria. The environment, the wind, there was a lot in the air. There was a lot of contamination and a lot of allergies, there was a lot of people getting sick."

One of the most significant challenges with physical health highlighted by participants was disruptions in nutrition and physical activity throughout disaster periods. After Hurricane Maria, participants had less access to food, with participants often feeling hungry, having to eat reduced portions, and generally eating food of lower nutritional quality since they had to rely on nonperishable items and/or fast food. This was particularly prevalent among individuals who experienced prolonged interruptions of power and electricity services. On the other hand, while the pandemic saw some limitations in terms of food access due to scarcity of food and limited access to supermarkets, some participants also reported stress eating. The pandemic also largely saw participants having more sedentary lifestyles and exercising less, although it had the

opposite effect on a smaller number of participants who became more health conscious and reportedly started exercising more during the pandemic. A female participant from Northern Puerto Rico recounted how living without power for a year affected her nutrition:

> *"It affected me a lot because everything I had to eat was canned food. It was difficult for my family and I to spend money on gasoline, food, candles… and then you go to work and spend on gas. That all led to having to spend more excessively. If you bought meat, you couldn't store it. You had to eat it that same day. My nutrition was literally based on rice, quinoa, cereal, and canned food. We ate no protein, we had to eat nonperishable food. Prior to the hurricane, we had a vegetable patch and we lost it. My mother loved eating lettuce and organic food, so we lost that too. A lot of the food in supermarket was… well, questionable. It didn't look fresh, in a bad state."*

4.3.5 Mental Health

Mental health was by far the most pervasive topic of discussion throughout our interviews. Participants largely outlined their experiences with disasters and connected these with mental health impacts and psychological well-being. Among mental health endpoints discussed by participants were the following: anxiety, depression, social isolation, stress, trauma, suicidal ideation, substance use, emotional problems, lack of mental stimulation, and others. Participants largely felt that each disaster uniquely impacted their mental health.

According to participants, Hurricane Maria was a source of psychological distress due to widespread damages, the disruption in daily activities and essential services, structural damages and financial impact, traumatic experiences, and a general sense of hopelessness. Participants also reported that the hurricane led to decreased mental stimulation and sources of entertainment due to lack of power, which was a significant source of psychological distress. A male

participant from Western Puerto Rico expressed the mental toll that Hurricane Maria had on him and his view on how other Puerto Ricans were affected:

> *"In terms of mental health, I would say it has been horrible. Hurricane Maria, without a doubt in my mind, has left a mark in everyone that was here during the recovery process. I'd say that people have at the very least developed anxiety. Speaking for myself, I felt anxiety, depression, I felt powerless to help other people who had needs during that time. It brings me more anxiety that I lived through that and could potentially live it again during hurricane season. I feel like I've been feeling constant anxiety since Hurricane Maria. I have this constant feeling that we are extremely vulnerable in Puerto Rico."*

The earthquakes also caused significant psychological distress, particularly for those closer to Southwestern Puerto Rico, primarily due to the unexpected nature of these events and the prospect of a more significant earthquake or a tsunami. Several participants reported sleeping outside in tents or in their living room due to constant fear of earthquakes. A female participant from Western Puerto Rico who lost her home during the earthquakes recounted the mental toll of this experience:

> *"The earthquakes were the worst experience I've lived through. I lost everything and I spent some time living in a park with my child. It was difficult, something I'll never forget. When I lost my apartment, I fell into a deep depression, and it wasn't easy for me. I saw that there were security guards looking out for us, helping us. People that came from other parts of Puerto Rico to bring supplies for my kid. It wasn't easy. I had to go through a lot that wasn't easy. I ended up going to a psychologist because I needed to get one for my kid. The only thing is that it can take a while to get appointments."*

The pandemic also led most participants to experience some form of psychological distress across all geographic regions in Puerto Rico. They reported that this period was psychologically challenging due to constant fear of infection, social isolation and disruptions in daily life, loss of employment and financial impacts, uncertainty about the virus and prevention, and constantly evolving government policies and recommendations. A female participant from Western Puerto Rico explained why the pandemic was distressing for her:

> *"In my case, the worst disaster for mental health was the pandemic because of the confinement. At least during the hurricane, independently of everything else that was happening, we could go out. We could spend time with loved ones, talk with our neighbor who we perhaps had never met. We would spend hours on the mile-long lines to get food or gasoline. However, with the lockdown, everything was different. There was a new reality that you had to adapt to and we are social beings. I am bipolar and have a personality disorder. I suffer from panic attacks. For me, everything has been up and down with my emotions, especially with the pandemic. I feel like this exacerbated my symptoms and doubled them; I ended up having a partial psychiatric hospitalization."*

Collectively, these disasters have meant a persistent source of psychological distress and have exacerbated pre-existing mental health conditions. Several participants feel that living through multiple disaster events over the course of 5 years has delayed their personal, professional, and financial development and caused emotional distress and frustrations. Several participants reported feeling hopeless and depressed, and developing unhealthy coping mechanisms (e.g., anxious eating, alcohol consumption, and tobacco smoking).

4.3.6 Reproductive Health

Participants discussed their experiences with reproductive health during the interview. Conversations focused on participants' desire to have children, access to reproductive care, experiences having children during disaster periods, sexually transmitted infections, and other relevant topics. Participants largely discussed their thoughts on the prospect of having children in the near future and potential concerns with childbearing in post-disaster Puerto Rico. Most participants expressed reservations about having children, with a significant number expressing they did not want to have children due to the social, economic, and political conditions in Puerto Rico. Reasons for not wanting to have children included availability and quality of employment opportunities, cost of living and current financial situation, poor educational system and poor quality of life, safety concerns, mistrust in the availability and consistency of essential services, and fear of future disaster events. Some participants even noted that they still desired to have children but had abandoned the idea of having them in Puerto Rico. A male participant from Southern Puerto Rico touched on this during his interview:

> *"While these [disaster] situations have not changed my perspective about wanting to have children, what they've made me think about is having children in Puerto Rico. I think it is complicated to raise kids here and I'm not sure I want that. In some ways, I would like to have my kids here because its where I was born, where I grew up. However, at the same time, I'm sure it isn't the best option. I don't like how the government handled the pandemic, how they handled the hurricane, the aftermath of the earthquakes, and everything. I'm scared because, wow, a hurricane can come, and I can spend 8 months without electricity. What if I have a baby? What if the baby has some kind of medical condition? Even worse."*

These feelings were echoed by participants who previously had children or who gave birth during the post-disaster period. A female participant who had a child gave her thoughts about what she believed it would have been like to have been pregnant during these disasters:

> *"I feel that being pregnant during that period would've been a traumatic experience. Especially during Hurricane Maria, because you couldn't even say that you were living under appropriate circumstances. Without services, with no access to doctors, it would have been very traumatic. I think that would affect the health of the mother and the baby, because obviously nutrition isn't the same and neither is quality of time. Even with COVID, a pregnant woman is much more susceptible to these types of things. I definitely think that pregnancy during any of these emergencies is scary."*

4.3.7 Barriers and Facilitators to Health

While discussing their experiences in post-disaster periods and their consequent health trajectories, participants outlined several factors that they believed were protective or harmful determinants of health amidst disaster exposure. Protective factors included community resilience and mobilization, family connections and social support, socioeconomic status and savings, geographic location, help from neighbors, social networks and connections, and access to power generators, solar panels, and cisterns. Largely, participants felt that support from family, loved ones, and neighbors helped minimize the potential impacts of disasters. A female participant from the Metropolitan Area explained that her family and neighbors were a significant support system during the pandemic:

> *"I never had challenges accessing food during the pandemic because what I did was, I would drive my mother to the supermarket, and she would buy groceries while I worked. I spent most of the time working and my family, specifically my mother and my brother,*

they were a bit more stressed because they weren't working, and we didn't have a generator back home. However, we had neighbors who had a generator and they ran an extension cord from their house to ours. At least that way we could use the fan and not be overburdened with heat. But we had to depend on someone else to help."

On the other hand, participants highlighted several factors that they perceived as barriers to health and wellness during these events. Participants mostly highlighted structural barriers such as government disaster response mismanagement, individual-level lack of financial resources, lack of investment in disaster preparedness and response, instability of essential services, and policies by health insurance companies. Specifically, participants expressed that they felt that both the local and federal government should have responded to disasters more swiftly and with more appropriate resources, paying specific attention to more geographically and financially vulnerable communities, such as those living in the Central regions or in rural communities across the islands.

4.3.8 Perspectives on Colonialism and Government

Participants shared their perspective about Puerto Rico's relationship with the United States and how this territorial history might have impacted disaster preparedness and recovery efforts. During the interviews, several participants did not want to speak about politics and/or felt uninformed about the relationship between Puerto Rico and the United States. Nonetheless, many participants recognized the colonial relationship and current and historical differences in terms of resources, unequal treatment, and disaster management. A female participant from Central Puerto Rico shared her perspective on colonialism and how it has affected recovery:

"Puerto Rico receives unequal treatment because we aren't part of the U.S., and they treat us accordingly. We are treated as a colony. They treat us like we're not part of them

until it is convenient for them. When natural disasters occur in the U.S., they're addressed promptly. In Puerto Rico, recovery efforts are a mess."

While participants largely felt that Puerto Rico received unequal treatment compared to U.S. states, participants were more critical about how the local government managed disasters, rather than the federal government. A male participant from Western Puerto Rico argued that the issues in disaster response were a byproduct of both local and federal mismanagement:

"I feel like it is a combination of both things. Without a doubt, we are treated differently than the United States. But they have responded to some of the needs we've had in times of crisis, and the local government has influenced things a lot. We know that there's corruption and nepotism in the government. We have an electric system that hasn't been updated, hasn't been maintained, and is fragile. If that wasn't the case, I'm sure Hurricane Maria would not have been so traumatic. In summary, we're treated differently by the United States, but the local government has been inept in preparing us for these events."

4.4 Discussion

4.4.1 Summary of research findings

We interviewed 30 residents of Puerto Rico and described their experiences with hurricanes, earthquakes, and the pandemic from 2017-2021, and their consequent physical, mental, and reproductive health trajectories. This qualitative study illustrates the adverse and traumatic experiences lived by Puerto Ricans through the five-year period associated with Hurricane Maria, earthquakes, and the COVID-19 pandemic. Individual-level experiences included structural damages to homes and neighborhoods, prolonged service interruptions, occupational layoffs and financial loss, displacement and housing insecurity, social isolation, and

other potentially traumatic disaster experiences. Participants consequently faced problems with physical health (e.g., weight gain, respiratory disease, poor nutrition, sedentary behavior), mental health (e.g., hopelessness, depression, anxiety), and reproductive health (e.g., pregnancy loss, infant mortality, reduced access to perinatal services, increased perceived stress), and highlighted different structural barriers and individual-level protective factors. We also found that—although there were common threads across disasters—each disaster presented unique physical and mental stressors, which varied based on individual characteristics, community resources, and geographic location.

4.4.2 Main discussion and contextualization of results

Our findings build on prior research that explores associations between individual and multiple disaster exposure and consequent health outcomes. In terms of adverse experiences during individual disaster events, our results are consistent with data from populations that were impacted by hurricanes, floods, and the COVID-19 pandemic. Prior research in populations affected by Hurricane Katrina and other tropical cyclones also found structural damages, power and communication interruptions, financial impact, death of loved ones, and other hazardous post-disaster living conditions.[2,23-26] However, the widespread prevalence of these experiences and the prolonged extension of service interruptions—with all participants experiencing prolonged power outages and some spending up to a year without electricity—seems to be unique to this population. Another key difference between Hurricane Maria—based on statistics from our sample—and other hurricanes in the United States is the incidence of displaced households and the consequent exodus of the population. While Katrina and Hurricane Maria had similar impacts in terms of magnitude of the storm and population health impacts, more affected locations like New Orleans saw its population decline to as much as one-third of the pre-

Katrina population, compared to our data which showed that participants were extremely hesitant to leave their homes and communities.[27-29] Participants in our sample were therefore much more likely to report consistent physical strain due to their domestic responsibilities, active participation in community clean-ups, and the need to walk long distances to acquire water and gasoline.

Consistent with other studies, our participants had adverse experiences during the pandemic, including unemployment, social isolation, infection anxiety, and limited access to healthcare.[30-33] However, the experiences of our participants were more severe than in prior studies given that the earlier part of the pandemic coincided with the period with more significant seismic activity in Puerto Rico, and recovery efforts from the hurricane were still ongoing. As a result, participants who lived near Southwestern Puerto Rico often experienced power outages and service interruptions during the pandemic, were displaced or had household structural damages, and faced the double burden of COVID infection anxiety and constant fear of a potential earthquake. Altogether, these experiences from compounding and overlapping disasters caused a consistent feeling of hopelessness and led to pervasive anxiety and depressive symptoms among participants.

Psychological distress and poor mental health were a persistent theme throughout all our interviews. Participants felt anxiety, depression, stress, emotional distress, suicidal ideation, and had reportedly developed trauma and substance use, and needed to receive mental health services. While they had diverse opinions about which disaster affected them most in terms of mental health, they all agreed that the severity of these events coupled with them occurring in succession led to a cumulative mental health impact and feelings of hopelessness. Although these are self-reported experiences of mental health and not clinical diagnoses, these results suggest

significant concern for mental health during multiple disaster events, and underscore the need for persistent monitoring of psychological symptoms and mental health resources in multi-hazard settings. Further, these results are consistent with studies that suggest that multiple disaster exposure is associated with increased risk to mental health and can result in various psychological impacts.[8,10-12,16,17,34] Future research should consider the long-term implications of multiple disaster exposure and monitor mental health endpoints beyond the traditional psychological conditions explored in disaster research (i.e., depression, PTSD, and suicide), including anxiety and adoption of health-damaging habits, whether by necessity or as a maladaptive coping strategy.

Our results highlight the prolonged disruptions in terms of food access and lower nutritional quality during the aftermath of Hurricane Maria and during the COVID-19 pandemic. Participants often had to rely on nonperishable items, military-provided food, and fast-food restaurants for months due to lack of electricity in the early post-hurricane period. The early pandemic and early post-hurricane periods also saw food scarcity, and the pandemic was characterized by participants foregoing supermarket visits due to fear of crowds, confusing policies in supermarkets, and time limitations because of the government curfew. Similar factors also reportedly hindered access to healthcare, medication, and financial resources. Our results are consistent with other studies that have found reduced healthcare and food access amidst other disasters.[35-40] However, more research is needed to properly understand the long-term implications of these prolonged interruptions in food and healthcare.

Although nutritional disruptions, sedentary behavior, and foregoing medical attention may result in long term physical health consequences, participants reportedly developed adverse physical health outcomes during this period. Specifically, participants reported respiratory health

problems, persistent fatigue, excessive weight gain or loss, exacerbation of prior health concerns, and chronic disease development. Several interviewees reported having family members who passed away due to complications with pre-existing chronic conditions that did not receive proper medical attention, while others attribute the development of diabetes, hypertension, asthma, and other diseases to disaster exposure. While these reports are anecdotal and disease onset may have been caused by pre-disaster conditions, plausible biologic mechanisms for disease incidence include persistent disruptions in nutritional quality, food access, and regular exercise, and adoption of other behaviors such as smoking and alcohol consumption. Singular disaster research corroborates the plausibility of these claims; for example, a cross-sectional study of Hurricane Katrina found that survivors of the storm suffered from upper and lower respiratory symptoms due to roof damage, outside mold, dust, and flood damage caused by the storm.[41] Furthermore, prior studies have also found that singular disaster events can lead to exacerbation of prior chronic disease and development of new disease.[42-44] However, more research is needed to fully understand these pathways and to determine if living through multiple disaster experiences puts individuals at greater risk of chronic disease development than singular disasters.

Our research also highlights important findings in terms of reproductive health and pregnancy amidst multiple disaster exposure. Conversations about reproductive health in Puerto Rico provided an opportunity for participants to share their thoughts on declining birth rates and their perspectives about having children. While several participants desired to have children, most had strong concerns about the prospect due to the significant challenges presented by these disaster experiences and the pre-existing economic crisis which was exacerbated during this period. To the best of our knowledge, this is one of the first studies to explore how multiple

disaster exposure can impact decision-making about having children, and our study can help guide programs and policies to address the concerns of prospective parents in post-disaster contexts. Further, we can extrapolate from our findings that the significant decrease in birth rates can be partially explained by migration and pregnancy loss, since some participants reportedly lost their pregnancy, while others had family and friends that moved to the continental United States seeking better perinatal care.

4.4.3 Limitations

This study has several limitations. Firstly, we used a purposive convenience sampling approach to recruit participants, and this could have resulted in self-selection bias. Those who were interested in participating in the study may have had an invested interest in the research questions. Specifically, we could expect that those who participated are those most affected by these disasters in significant ways. We do not expect that this possibility negates the value of the questions addressed in our study since our interest was primarily exploratory, and we did not set out to establish causal relationships. Secondly, another limitation is a smaller sample size, since we only interviewed 30 participants in Puerto Rico, and only 5 participants per region. The experiences of our participants may not represent those of all adults of reproductive age in Puerto Rico, hampering generalizability of our findings to the larger population. Nonetheless, the in-depth interviews allowed us to explore the complexities of these public health issues and will provide important insight to inform studies that can incorporate larger sample sizes. Importantly, we did not ask participants solely about their experiences, but also about family, friends, and the broader community. Additionally, we quickly reached saturation of research themes and themes often overlapped between participant interviews, suggesting that most experiences were shared

among the broader community. Thirdly, another limitation was the significant challenges we had in recruiting men and participants with children in our study. Specifically, we were not able to identify any fathers and were not able to capture their perspectives about physical, mental, and reproductive health. Their perspectives might provide valuable insight into childbearing, childcare, and reproductive health during disasters. Fourthly, conversations about colonialism proved to be difficult since participants viewed them as overly political and did not want to spend much time on them. While many participants believed that Puerto Rico received unfair or unequal treatment from the United States, they were not always able to articulate why or how. Participants felt much more comfortable discussing local politics and how local government mismanagement affected disaster recovery. Perspectives from political and community-based leaders, researchers, and experts with more familiarity with these topics might provide greater insight into the etiologic connections between colonialism and adverse health outcomes during these disasters. Lastly, another key limitation is that our analysis does not allow us to establish causal relationship or measure true health impacts. While participants reported several physical, mental, and reproductive health endpoints that they believed were the result of multiple disaster exposure, we could not validate their reports and we need to take them at face value. Due to the scarcity of research on this area, our results still provide an important framework to develop future research that can more appropriately establish causal links between multiple disaster exposures, and health outcomes.

4.4.4 Strengths

This study has several key strengths. First, we are exploring an understudied area of research that can benefit significantly from the detailed contextual information gained through qualitative data. Importantly, the findings from chapters 2 and 3 of the dissertation yielded

unexpected results that cannot be explained through quantitative data alone; therefore, the in-depth data presented in this chapter helps us understand those results and can help inform future projects on multiple disaster exposure and population health outcomes. Importantly, the themes presented by participants in terms of their specific disaster experiences and their perceived barriers and protective factors provide important insight into disaster and health pathways. These themes can be used to develop multiple disaster experience severity scales, mediation analyses, and help inform more robust epidemiologic studies. Secondly, while our data collection took place approximately 6 years after Hurricane Maria and 3 years after the earthquakes and early pandemic period, it is unlikely that recall bias would influence our results given that disasters are considered seriously disruptive experiences that are unlikely to be forgotten. Our participants all had very vivid and detailed recollections of their disaster experiences and delay between disaster experience and data collection may prove beneficial to minimize psychological risk and give participants more time to reflect on their experiences. Thirdly, our analysis followed a systematic and theory driven approach to qualitative analysis by incorporating Framework Analysis and using a professional qualitative analysis software program. These approaches help support the validity of our results and minimize the risk for researcher bias. Finally, the flexibility of qualitative methods and the use of semi-structured interviews allowed us to explore areas that could have been missed by quantitative approaches. In other words, while we had particular questions in our interview protocol, we were able to adapt interviews according to the context of the interview, emerging themes, and individual participant experiences. As a result, we were able to capture themes that we did not originally anticipate when developing the interview protocol.

4.4.5 Conclusion

Our study reveals important insights about the lived experiences of a population impacted by multiple disaster exposure and their physical, mental, and reproductive health trajectories. Consistent with prior research, we found that participants had unfavorable experiences throughout each disaster and faced consequent adverse health outcomes. Participants talked extensively about mental health outcomes, including depression, anxiety, and a persistent feeling of hopelessness. Interviewees believed that living through multiple disaster events in a short period resulted in cumulative physical and mental health impacts. Importantly, participants highlighted community resilience and mobilization, family support, socioeconomic status, geographic location, social networks, and access to power generators and cisterns as protective factors in times of disaster. Future research could benefit from longitudinal designs—with greater sample sizes for more statistical power—that more appropriately consider participant health trajectories and have more refined health outcome assessment methods.

4.5 References

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Chapter 5
Conclusion

5.1 Dissertation overview

The present dissertation reported three analytical examples of the physical, mental, and reproductive health implications of living through multiple disasters. Collectively, the three aims explored in the dissertation aimed to understand the public health implications of multiple disaster exposure and how these relationships are modified by individual and community-level characteristics, geographic location, and colonialism. Chapter 2 used self-reported data from the Behavioral Risk Factor Surveillance System to understand the physical and mental health implications of multiple disaster exposure and potential individual-level protective factors. Chapter 3 used vital records from the National Center for Health Statistics to understand the maternal and newborn health implications of multiple disaster exposure and potential geographic and structural-level protective factors. Chapter 4 used primary data from participants who lived through multiple disasters to understand their physical, mental, and reproductive health trajectories, and further contextualize and understand the questions explored in the first two aims. Findings from these chapters can inform the development of individual, community, and structural level interventions to address disaster preparedness, mitigation, and recovery among historically oppressed populations.

5.2 Summary of Research Findings

Aim 1 examined the association between multiple disaster exposure and the physical, mental, and behavioral health of a sample of 35,517 adults living in Puerto Rico between 2017 and 2022 who participated in the Behavioral Risk Factor Surveillance System. We specifically considered days of poor physical and mental health, self-reported general health status, and health modifying behaviors, and how these varied over multiple disaster periods. The early post-hurricane period showed particularly strong associations with adverse health since our main effects analysis showed that all of our outcomes—except for drinking and heavy drinking—had consistently harmful directions of association among participants, compared to pre-disaster levels. We also saw that post-pandemic periods were associated with an apparent improvement in health outcomes, with participants having fewer days of poor mental health in the early and late pandemic periods, less heavy drinking episodes in the early pandemic period, less smoking in the late pandemic, and more positive perceptions of their general health status in both the early and late pandemic. Finally, sex, income, education, and employment status modified the association between our exposure and outcomes of interest, but the extent and direction of modification varied across disaster and outcome.

Aim 2 examined the association between multiple disaster exposure and maternal and newborn health among all 104,560 live births in Puerto Rico from 2017 to 2022 based on vital records. It also considered how this relationship could vary based on 1) geographic location in Puerto Rico—as a proxy for proximity to disaster epicenters—and 2) colonialism by comparing associations in Puerto Rico to those in Texas and Florida, two states that had multiple disasters in the same period. We found that newborn outcomes were not significantly impacted by disaster exposure in Puerto Rico and that these associations did not vary based on colonialism and

proximity to disaster epicenters. However, disaster periods were consistently associated with adverse mental health across all outcomes of interest, with particularly strong impacts in the early and late pandemic periods, and colonialism modified the relationship with maternal health outcomes. However, we found significant potential for bias due to live birth bias a product of a 12 to 21 percent reduction in the number of yearly live births in Puerto Rico across disasters.

Aim 3 explored and described the multiple disaster experiences of 30 residents of Puerto Rico and their consequent physical, mental, and reproductive health trajectories. Our findings illustrate the adverse and traumatic experiences lived by Puerto Ricans through the 5-year period associated with Hurricane Maria, earthquakes, and the COVID-19 pandemic. Individual-level experiences included structural damages to homes and neighborhoods, prolonged service interruptions, occupational layoffs and financial loss, displacement and housing insecurity, social isolation, and other potentially traumatic disaster experiences. These led to participants having adverse physical health (e.g., weight gain, respiratory disease, poor nutrition, sedentary behavior), mental health (e.g., hopelessness, depression, anxiety), and reproductive health (e.g., pregnancy loss, infant mortality, reduced access to perinatal and reproductive health services, increased perceived stress during pregnancy), and highlighted different structural barriers and individual-level protective factors. We also found that, although there were common threads across disasters, each disaster presented unique physical and mental stressors, and these varied based on individual-level characteristics, community resources, and geographic location.

5.3 Triangulation of Research Findings

Collectively, the results of all three aims suggest widespread adverse health impacts from multiple disaster exposure in Puerto Rico and socio-structural inequities due to colonialism, individual-level vulnerabilities, and government mismanagement of pre- and post-disaster

conditions. While these analyses deal with different outcomes, apply diverse analytical methodologies, and pull from different data sources, they are bound by common threads that highlight the importance of improved disaster preparedness and response.

All three aims identified Hurricane Maria as a driver of adverse physical and emotional health. While Aim 1 showcased the storm's impact on days of poor mental health and substance use behaviors, Aim 3 further validated these claims through participants' lived experience. To some extent, all 30 participants interviewed for Chapter 4 reported psychological distress, and feelings of anxiety, depression, stress, trauma, and hopelessness. Clarity on how these outcomes might translate to clinical diagnoses of adverse mental health is lacking, but our findings suggest that mental health should be closely monitored in post-hurricane settings, particularly with disasters of the magnitude of Hurricane Maria.

Aim 1 also showed that individuals from lower income levels were much more likely to experience poor mental health in the early post-hurricane period. Specifically, compared to those earning more than $50k a year, individuals in the lowest and second lowest income category had 1.24 and 1.18 more days of poor mental health respectively. Participants from these groups also had significantly higher prevalence of smoking and greater negative general health perceptions in the early post-hurricane period, compared to their wealthier counterparts. These findings are supported by Chapter 4, where participants reported that the hurricane brought significant financial impacts and service interruptions, which could have been ameliorated with greater financial safety nets. For example, several participants expressed that one of the most significant sources of mental distress was prolonged lack of power and running water; however, wealthier participants could minimize the impact of this by investing in power generators and cisterns.

One key difference between our findings in Aim 1 and Aim 3 pertains to the apparent improvement in health outcomes observed during the pandemic in Chapter 2. Specifically, Aim 1 showed that participants had fewer days of poor mental and physical health, less heavy drinking episodes, less smoking, and more positive perceptions of their general health status, compared to the pre-disaster period. However, the narratives from participants in Chapter 4 suggested adverse cumulative physical and mental health impacts from the hurricane, earthquakes, and pandemic. Specifically, participants largely described their health—especially their mental health—worsening over time due to the persistence of stress fueled by multiple disaster exposure and its implications on their finances and disruptions in daily life. Many participants described feeling "hopeless" and "waiting for the next disaster to happen."

Several plausible factors may explain this discrepancy, including the specific measurement approaches used by the BRFSS, differences in the nature of these disasters, and interviewer bias. In terms of measurement, it is likely that the mental health measurements used by the BRFSS cannot fully capture post-disaster psychological distress since they only ask participants for days of poor health in the past 30 days and prior clinical diagnoses. Based on our interviews with participants in Chapter 4, their post-disaster psychological condition is much more complex and includes anxiety, depression, hopelessness, trauma, suicidal ideation, and isolation. Moreover, while participants all recognized that they experienced psychological distress during the pandemic, they argued that these feelings were different than during the hurricane. Specifically, the pandemic brought more significant feelings of isolation and disconnection from loved ones, infection anxiety, and anxiety, largely due to stay-at-home mandates; on the other hand, participants argued that the hurricane provoked trauma, depression, and suicidal ideation due to the interruption in services, structural damages to their homes and

communities, and lack of mental stimulation. It is important to note than when asked about mental and physical health, participants we interviewed for Aim 3 would often compare themselves to others who they viewed as "more affected" from a disaster. For example, participants often expressed that they were not significantly impacted from the pandemic in terms of physical health because they were not hospitalized or did not die from infection, even if they were suffering from another ailment. This suggests that, in the context of disasters, participants may self-report their health as better than it actually is because they are comparing themselves to others—who they view as more affected—during a disaster, rather than to themselves before a disaster.

While the results presented in Chapter 4 cannot fully explain the lingering questions from Chapter 3, they help provide context. Specifically, our analysis in Chapter 3 showed that, although there were significant impacts on maternal health across disaster periods, these associations did not persist for newborn health. Moreover, Chapter 3 also highlighted a significant reduction in the total number of live births in Puerto Rico, down from 24,373 in 2017 to 19,332 in 2021, a 21% reduction. Findings from the in-depth interviews helped to explain that the reduction in live births may largely be due to migration and young adults having concerns with childbearing. Specifically, participants believed that the social, economic, and political conditions in Puerto Rico—coupled with climate change and recent disasters—discouraged people from having children since these conditions greatly hinder quality of life. Participants who had children echoed these sentiments, with many expressing that living through disasters has changed their perspective about having children, and several abandoning the idea of raising their children in Puerto Rico.

5.4 Future Research Directions

There are many opportunities to expand research that examines the health consequences of multiple disaster exposure and the role of colonialism as a social determinant of health. While Chapter 2 and 3 leverage publicly available data to explore associations between physical, mental, and reproductive health outcomes, future research could benefit from longitudinal designs that more appropriately consider health trajectories and establish causal links. Specifically, there are opportunities for ongoing cohort studies in areas affected by multiple disasters to retrospectively assess exposure to disasters and prospectively follow disease onset. These would help establish clearer causal associations, since we could therefore have certainty that disaster exposure precedes disease onset. Longitudinal studies would have the added benefit of having access to individual participants and inquiring about individual-level disaster experiences. This could enhance understanding of the role of severity of multiple disaster experiences, consequent health outcomes, and could help us understand the cumulative effect of disaster exposure by comparing experiences of individuals who had more severe experiences in multiple disasters compared to those who had severe experiences in one or less disasters. Another opportunity for observational studies is more refined health outcome assessment methods, particularly relying on different psychological distress scales, and clinically diagnoses physical and mental health endpoints. Due to the possibility of reverse causation—since there is no way to ascertain when a diagnosis took place relative to a disaster—and the self-reported nature of data from the BRFSS, we were not able to rely on the reported clinical diagnoses from this dataset. In terms of maternal and child health outcomes, there could be promising opportunities to employ longitudinal, case-crossover, and case-control designs. Longitudinal designs would be helpful to understand pregnancy loss amidst multiple disaster exposure,

particularly since this would be difficult to document in other observational study designs. Moreover, case-control studies comparing maternal severity of disaster exposure among children who were born term and preterm could present valuable findings to understand how multiple disaster exposure may drive reproductive health outcomes. Similarly, case-crossover designs, comparing multiple pregnancies of women who had children both pre- and post-disaster and their consequent reproductive outcomes might provide valuable insights.

Importantly, public health research should more carefully consider the role of colonialism as a determinant of health. As discussed in Chapter 3, we believe that colonialism could affect health through similar pathways as other socio-structural determinants of health such as racism, sexism, and xenophobia. However, colonialism has largely been understudied and underdeveloped as a construct that can be applied in epidemiologic studies. The present dissertation attempted to consider the role of colonialism in shaping public health amidst multiple disaster exposure and found implications for maternal health. Nonetheless, given that our analysis conceptualizes colonialism as living in a U.S. colony vs not living in a U.S. colony, it fails to capture the complexities of this important social, political, and economic phenomenon. Future research—particularly epidemiologic studies collecting primary data—should have analyses that incorporate more refined assessments of colonialism.

5.5 Public Health Significance

The research presented in this dissertation is critical to understanding and addressing emerging issues in social and environmental epidemiology and has important implications for public health research and practice. Importantly, the possibility of compounding and simultaneous disasters has become increasingly likely worldwide given the intensification of climate change leading to more frequent and severe weather-related disasters. At the same time,

globalization is increasing human travel and international interaction, thereby increasing the likelihood of infectious disease propagation and the consequent risk for pandemics to emerge. These social and environmental factors, combined with social inequities and the ongoing threat of other natural and man-made disasters, create significant risk for multiple disaster events to co-exist and impact human life in catastrophic ways. However, there is still scarce research that examines how disasters interact with each other and how these interactions can affect human health and wellness.

The need to understand these events and their potential impacts is particularly important among historically marginalized and oppressed populations such as women, communities of color, persons experiencing poverty, and communities and nations that have been subjected to colonization. The historical disenfranchisement of these communities has resulted in long standing health disparities that continue to perpetuate generational inequities which can only worsen in the face of climate change and multiple disaster exposure. The results from Chapter 2 of this dissertation help us understand the physical, mental, and behavioral implications of multiple disaster exposure and how these associations can vary based on individual-level characteristics. These findings can be used to inform targeted interventions in the context of multiple disaster exposure. The results from Chapter 3 of this dissertation helps us understand the maternal and newborn health implications of multiple disaster exposures and raises important considerations about how these events can affect pregnancy. This is particularly important since prior research has established that pregnancy is a critical period, and that adverse experiences during pregnancy can have lasting effects on the health of both the mother and child. Finally, the results from Chapter 4 of this dissertation have important theoretical and contextual implications that build on the findings from previous chapters. Specifically, our findings help add context to

multiple disaster exposure and consequent health trajectories, increasing our understanding of specific causal pathways that drive physical, mental, and reproductive health amidst multiple disasters. Collectively, the findings from this dissertation can be used to help inform the development of individual, community, and structural level interventions and research to further understand and address disaster preparedness, mitigation, and recovery among historically oppressed populations.

Appendices

Appendix A: Regional Map of Puerto Rico used in Chapter 3 and 4

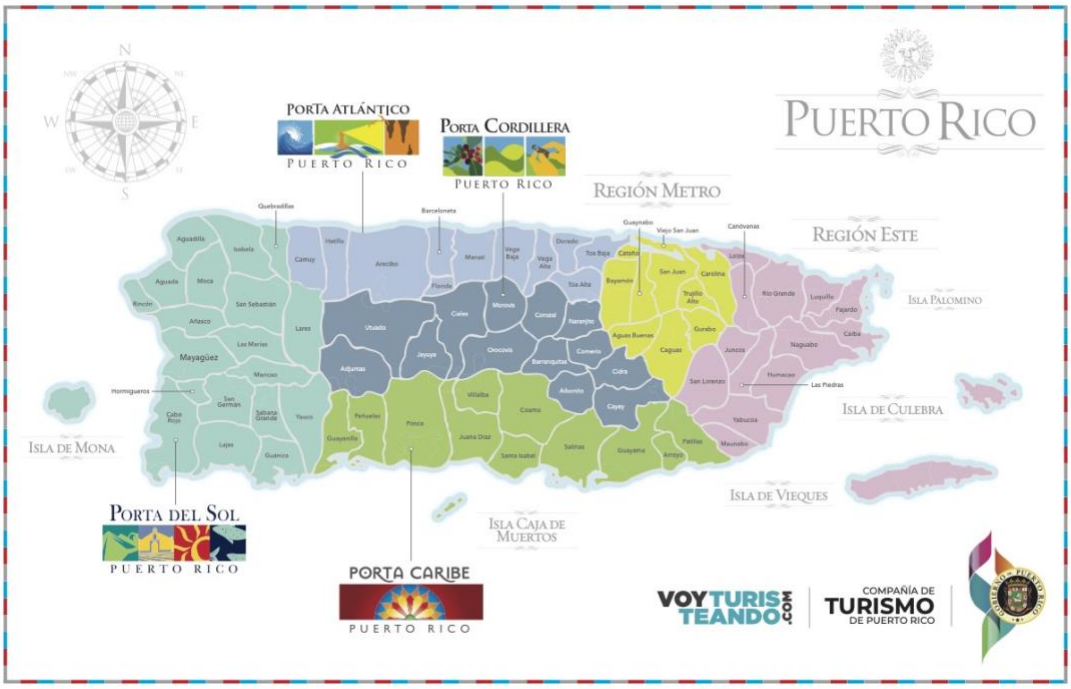

Figure 3: Regional Map of Puerto Rico, divided by Western, Northern, Central, Southern, Metropolitan, and Eastern Regions.

Appendix B: Puerto Rico Zip Codes Included in Chapter 3 Analysis

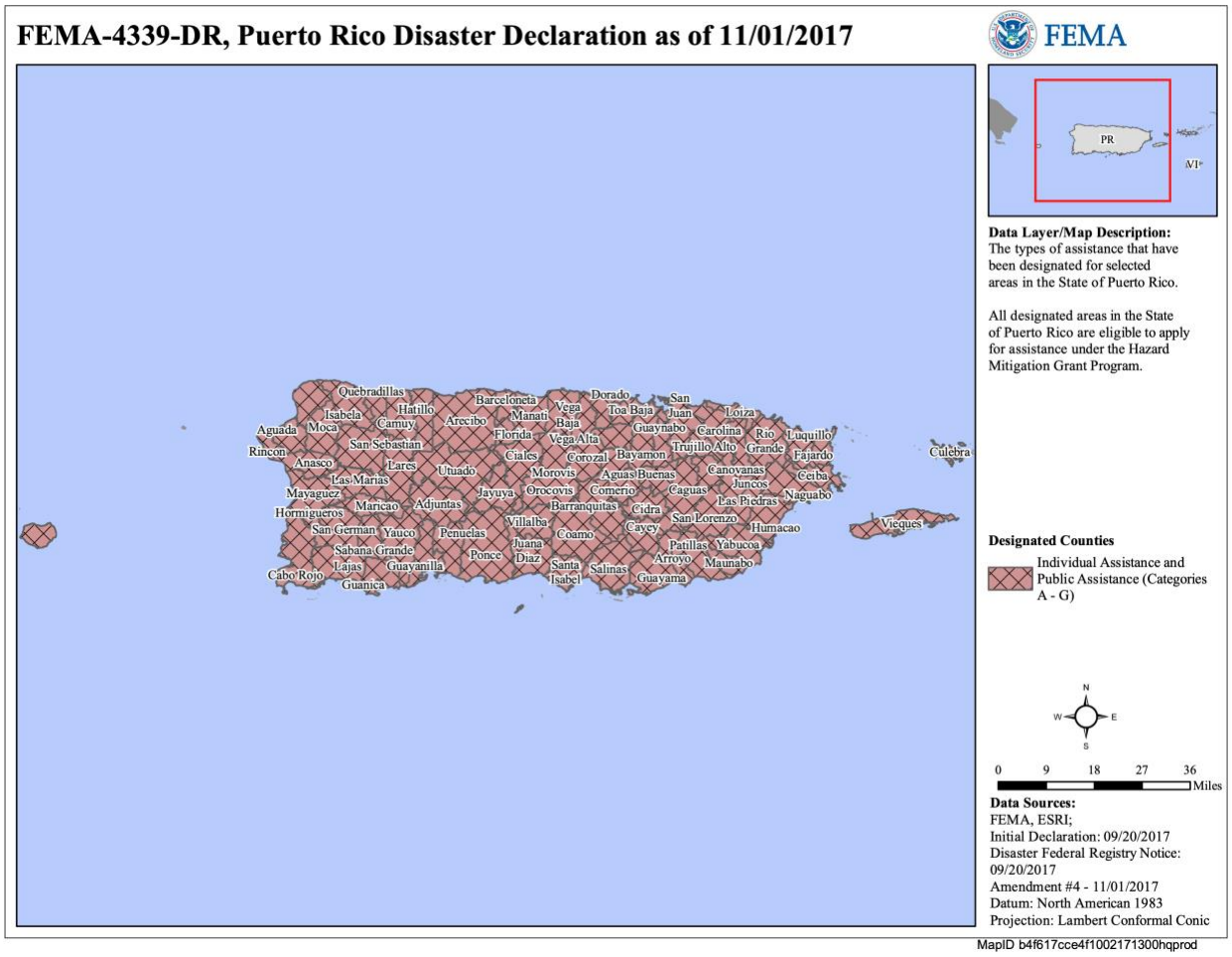

Figure 4: Map of Puerto Rico documenting counties that were designated as eligible for Individual Assistance and Public Assistance during Hurricane Maria

Appendix C: Florida Zip Codes Included in Chapter 3 Analysis

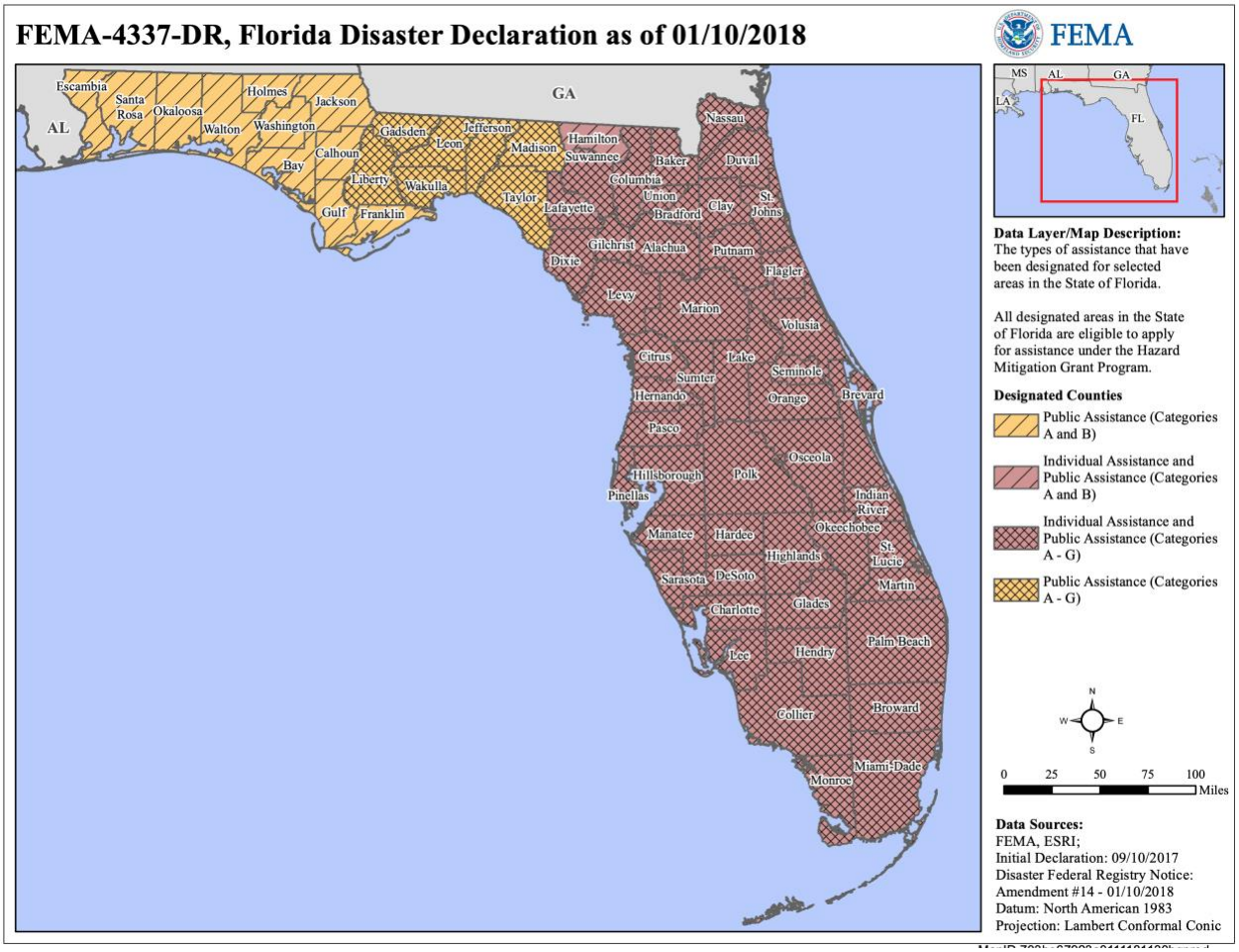

Figure 5: Map of Florida documenting counties that were designated as eligible for Individual Assistance and Public Assistance during Hurricane Irma

Appendix D: Texas Zip Codes Included in Chapter 3 Analysis

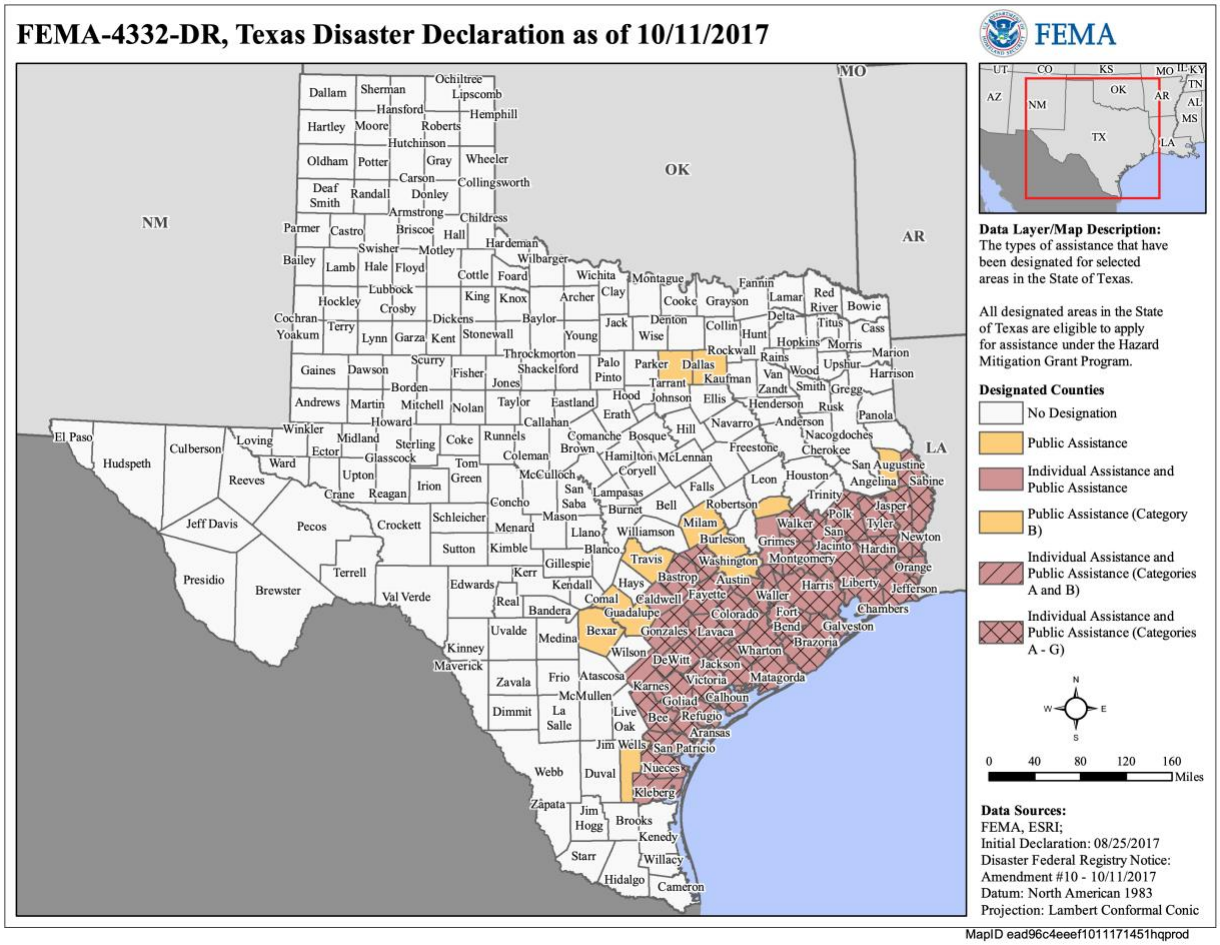

Figure 6 Map of Texas documenting counties that were designated as eligible for Individual Assistance and Public Assistance during Hurricane Harvey

Appendix E: Detailed Information about Zip Codes used in Chapter 3

Puerto Rico			Texas		Florida	
Municipio	Area	FIPS code	County	FIPS code	County	FIPS Code
Utuado	Centro	72141	Aransas	48007	Alachua	12001
Adjuntas	Centro	72001	Austin	48015	Baker	12003
Jayuya	Centro	72073	Bastrop	48021	Bradford	12007
Ciales	Centro	72039	Bee	48025	Brevard	12009
Morovis	Centro	72101	Brazoria	48039	Broward	12011
Orocovis	Centro	72107	Caldwell	48055	Charlotte	12015
Corozal	Centro	72047	Calhoun	48057	Citrus	12017
Barranquitas	Centro	72019	Chambers	48071	Clay	12019
Naranjito	Centro	72105	Colorado	48089	Collier	12021
Comerio	Centro	72045	DeWitt	48123	Columbia	12023
Aibonito	Centro	72009	Fayette	48149	DeSoto	12027
Aguas Buenas	Centro	72007	Fort Bend	48157	Dixie	12029
Cidra	Centro	72041	Galveston	48167	Duval	12031
Cayey	Centro	72035	Goliad	48175	Flagler	12035
Caguas	Este	72025	Gonzales	48177	Gilchrist	12041
Gurabo	Este	72063	Grimes	48185	Glades	12043
San Lorenzo	Este	72129	Hardin	48199	Hamilton	12047
Maunabo	Este	72095	Harris	48201	Hardee	12049
Loíza	Este	72087	Jackson	48239	Hendry	12051
Juncos	Este	72077	Jasper	48241	Hernando	12053
Las Piedras	Este	72085	Jefferson	48245	Highlands	12055
Yabucoa	Este	72151	Karnes	48255	Hillsborough	12057
Canovanas	Este	72029	Kleberg	48273	Indian River	12061
Río Grande	Este	72119	Lavaca	48285	Lafayette	12067
Naguabo	Este	72103	Lee	48287	Lake	12069
Humacao	Este	72069	Liberty	48291	Lee	12071
Luquillo	Este	72089	Matagorda	48321	Levy	12075
Fajardo	Este	72053	Montgomery	48339	Manatee	12081
Ceiba	Este	72037	Newton	48351	Marion	12083
Culebra	Este	72049	Nueces	48355	Martin	12085
Vieques	Este	72147	Orange	48361	Miami-Dade	12086

Toa Baja	Metro	72137	Polk	48373	Monroe	12087
Catano	Metro	72033	Refugio	48391	Nassau	12089
Bayamón	Metro	72021	Sabine	48403	Okeechobee	12093
Guaynabo	Metro	72061	San Jacinto	48407	Orange	12095
San Juan	Metro	72127	San Patricio	48409	Osceola	12097
Carolina	Metro	72031	Tyler	48457	Palm Beach	12099
Trujillo Alto	Metro	72139	Victoria	48469	Pasco	12101
Camuy	Norte	72027	Walker	48471	Pinellas	12103
Hatillo	Norte	72065	Waller	48473	Polk	12105
Arecibo	Norte	72013	Wharton	48481	Putnam	12107
Barceloneta	Norte	72017			Sarasota	12115
Florida	Norte	72054			Seminole	12117
Manati	Norte	72091			St. Johns	12109
Vega Baja	Norte	72145			St. Lucie	12111
Vega Alta	Norte	72143			Sumter	12119
Dorado	Norte	72051			Suwannee	12121
Toa Alta	Norte	72135			Union	12125
Aguadilla	Oeste	72005			Volusia	12127
Aguada	Oeste	72003				
Rincón	Oeste	72117				
Añasco	Oeste	72011				
Mayagüez	Oeste	72097				
Hormigueros	Oeste	72067				
Cabo Rojo	Oeste	72023				
Isabela	Oeste	72071				
Moca	Oeste	72099				
San Sebastián	Oeste	72131				
Quebradillas	Oeste	72115				
Las Marías	Oeste	72083				
Maricao	Oeste	72093				
Sabana Grande	Oeste	72121				
San Germán	Oeste	72125				
Lajas	Oeste	72079				
Guánica	Oeste	72055				
Lares	Oeste	72081				
Yauco	Oeste	72153				
Guayanilla	Sur	72059				
Peñuelas	Sur	72111				
Ponce	Sur	72113				
Villalba	Sur	72149				
Juana Diaz	Sur	72075				

Coamo	Sur	72043				
Santa Isabel	Sur	72133				
Salinas	Sur	72123				
Guayama	Sur	72057				
Patillas	Sur	72109				
Arroyo	Sur	72015				

Table 17: Detailed information about zip codes used in Chapter 3

Appendix F: Promotional Flyer used for Participant Recruitment in Chapter 4

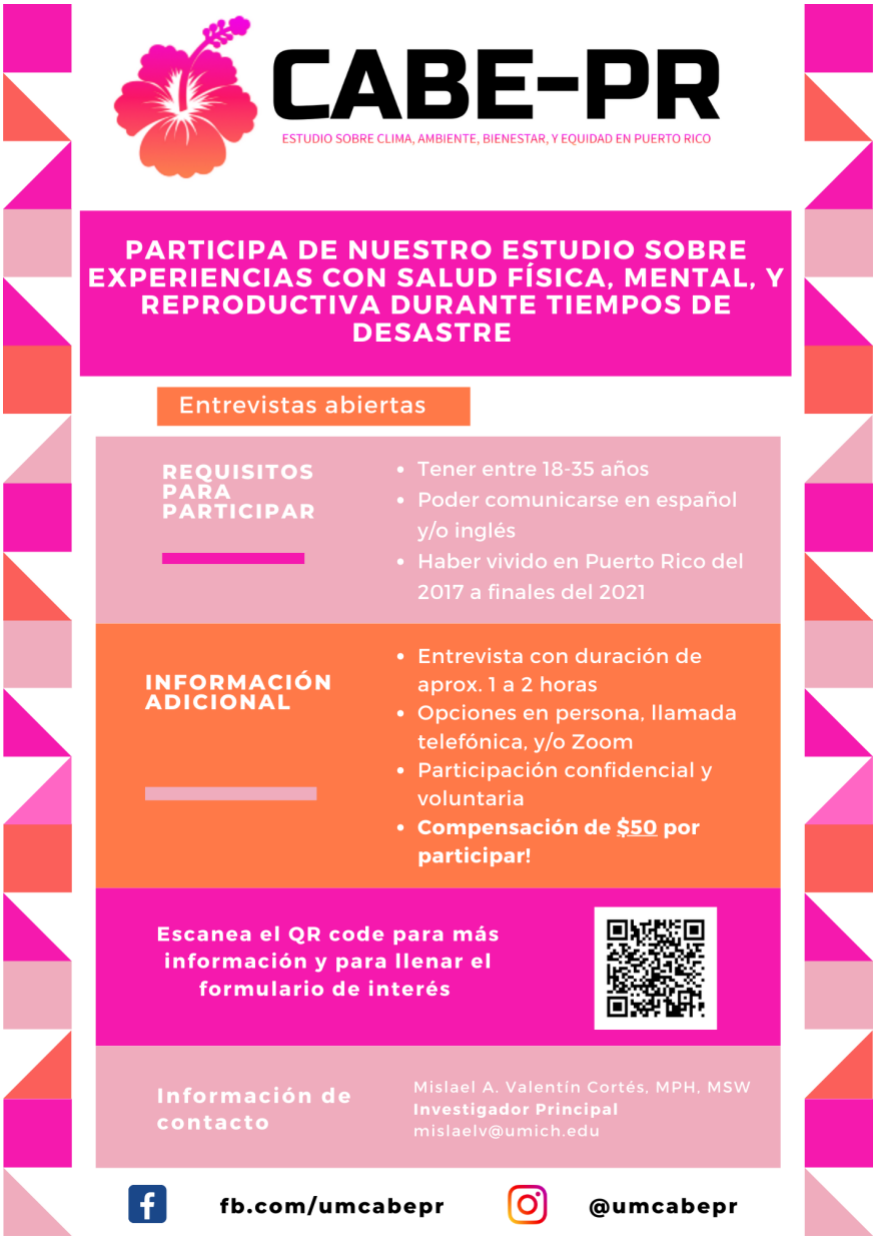

Figure 7: CABE-PR promotional flyer

Appendix G: Chapter 4 Interview Guide

<u>INSTRUCCIONES PARA EL ENTREVISTADOR:</u> (Sigue el protocolo del IRB para explicar este estudio y explicar procedimientos para la protección de confidencialidad.)

1. Número de participante (orden cronológico): _____
2. Fecha de la entrevista: _____ (mm/dd/aaaa)
3. Localización o método de entrevista: _____
4. Iniciales del entrevistador: _____
5. Hora de la entrevista (comienzo): _____

¡Gracias por tu disponibilidad para participar en nuestro estudio!

LEER: El propósito de la entrevista en el día de hoy es conocer sobre tu experiencia durante los pasados 5 a 7 años con los diferentes eventos que hemos tenido en Puerto Rico; es decir, el huracán María, los terremotos, y la pandemia. Además, queremos conocer tu perspectiva sobre cómo estos eventos posiblemente han afectado la salud física, mental, y reproductiva de las personas afectadas.

[PREGUNTA: ¿Tienes alguna pregunta hasta el momento?]

LEER: Bien, quiero tomar la oportunidad para recordarte que la entrevista es confidencial. Puedes rehusarte a contestar cualquier pregunta que no te sientas cómodo/cómoda contestando. Si no quieres o no puedes contestar una pregunta, solo dímelo y podemos seguir a la siguiente pregunta. Al finalizar la entrevista, recogeremos tu información para enviarte el incentivo de 50 dólares a donde mejor te convenga.

[PREGUNTA: ¿Podemos comenzar con el proceso de entrevista?]

LEER: Si te parece bien, ahora voy a prender la grabadora. Esto lo hacemos principalmente para poder enfocarnos más en la conversación y poder capturar tu perspectiva en vez de estar tomando notas. Solo recuerda que no debemos mencionar tu nombre ni nombres de familiares o seres queridos durante la entrevista para que pueda permanecer anónima. Gracias, ahora comenzamos.

<u>INSTRUCTIONS TO THE INTERVIEWER:</u> Turn on the recorder.

<u>NOTES TO THE INTERVIEWER</u>: *[Por favor que las preguntas no necesariamente deben ser preguntadas en el orden que se presentan. Hasta la medida posible, sigue el ritmo del participante y pregunta las preguntas cuando te parezca más apropiado. Los "probes" se*

incluyen debajo de cada pregunta para guiar la conversación, pero no es necesario preguntar todo. Utiliza los que tengan más sentido en la conversación con el participante.]

Pregunta #1: Para empezar, nos gustaría conocer un poco sobre ti para poder contextualizar el resto de las preguntas. Para esto, te haré unas preguntas cortas sociodemográficas. [Short sociodemographic questionnaire].

- ¿A qué te dedicas?
  - _____ [type of job]
- ¿Part-time vs full-time (horas trabajadas)? [Circle the option]
  - _____ [# de horas]
- ¿Qué edad tienes?
  - _____ [edad en años]
- ¿Cuál es tu sexo o identidad de género?
  - Mujer
  - Hombre
  - No binario
- ¿Cómo describirías tu estado socioeconómico? [read options to participant]
  - Clase baja
  - Clase media baja
  - Clase media
  - Clase media alta
  - Clase alta
- ¿Cuál es tu nivel de educación más alto? [read options to participant]
  - Grados 1 a 11 completados
  - Grado 12 o GED completados
  - Universidad 0 a 3 años
  - Universidad completada (grado de bachillerato)
  - Maestría o doctorado
- ¿Cuál es tu estado marital? [read options to participant]
  - Casado/a
  - Divorciado/a
  - Viudo/a
  - Separado/a
  - Soltero/a
  - Unión libre o pareja conviviendo pero no casados
- ¿Te criaste en Puerto Rico?
  - Sí
  - No
    - If no, ¿dónde? _____
- ¿En qué municipio vives o viviste durante tu tiempo en Puerto Rico?
  - _____ [nombre de municipio]
- ¿Aproximadamente, cuánto tiempo has vivido en tu residencia actual?
  - _____ [tiempo en años]
- ¿Viviste en el mismo lugar durante el periodo de desastres (es decir, 2017 a 2022)?
  - Sí

    - No
- ¿Dirías que la mayoría de tu familia extendida todavía vive en Puerto Rico?
    - Sí
    - No
- ¿Tienes hijos?
    - Sí
        - If yes, ¿cuántos? _____
        - If yes, ¿viven contigo? _____
    - No

Pregunta #2: Como te mencioné durante el principio de la entrevista, este estudio trata con los diferentes desastres que hemos tenido en Puerto Rico durante los pasados 5-7 años. En otras palabras, el huracán María, los terremotos, y la pandemia. ¿Cuál ha sido tu experiencia con estos desastres? ¿Cómo te afectaron a ti y a tus seres queridos?

NOTE TO THE INTERVIEWER: *[Asegúrate que los participantes hablen de todos los desastres y la experiencia de ellxs y sus seres queridos. Si no contestan sobre su experiencia con la pregunta inicial, dale seguimiento y pregúntale directamente sobre el desastre que no habló]*.

[Prompts for question #2]

- ¿Cuál ha sido tu experiencia con los servicios de electricidad, agua potable, y/o comunicaciones durante estos tiempos de desastre? Si hubo interrupción, ¿por cuánto tiempo duró?
- ¿Cuál ha sido tu experiencia con el acceso a comida, agua limpia para tomar, y servicios de salud durante tiempos de desastres?
- ¿Cuál dirías que fue el impacto de estos desastres en la región de Puerto Rico en la que vives? [**Note to interviewer:** piensa en el área que vive: i.e., área oeste, área sur, área norte, área central, área metro, área este]
- En lo personal, ¿tu trabajo el trabajo de algún familiar o ser querido se vio afectado por alguno de los desastres? ¿Cuál fue el impacto si alguno?
- ¿Cómo comparas el efecto de los diferentes desastres? ¿Crees que un desastre afectó más que otro? ¿por qué? **[sub aim 3]**
- ¿Qué dirías que fue lo peor o lo más que recuerdas de cada desastre? **[Note to interviewer: participante debe decir por lo menos una cosa de cada desastre] [sub aim 3]**

Pregunta #3a: Uno de los temas más importantes cuando pensamos en estos diferentes desastres en como potencialmente han afectado la salud y el bienestar de las personas. Nos gustaría saber tu perspectiva sobre salud física, mental, y reproductiva y como estas se han visto afectadas por los desastres. Vamos a tocar todas estas individualmente pero primero nos gustaría saber tu perspectiva sobre salud física. Salud física la podemos considerar como el funcionamiento del cuerpo, enfermedades, y condiciones físicas como la presión, el azúcar, la nutrición, hábitos de ejercicio, y simplemente como uno se siente físicamente, entre otras cosas. Tomando eso en consideración, ¿Cuál ha sido tu experiencia con como estos desastres han afectado tu salud física y/o la salud física de tus seres queridos? **[sub aim 1]**
[Prompts for question 3a]

- ¿Crees que alguno de estos desastres tuvo mayor impacto en tu salud física o la salud física de tus seres queridos? ¿por qué?
- ¿Cómo describirías la salud física de la gente en Puerto Rico tras el impacto de estos desastres?
- ¿Crees que la habilidad de las personas de adoptar estilos de vida saludable (i.e., alimentación, ejercicio, fumar, ingerir alcohol, etc.) se ha visto afectada por estos desastres?

Pregunta #3b: Gracias por compartir tu perspectiva sobre salud física, ahora nos gustaría conversar un poco sobre salud mental. Esto lo podemos considerar como estrés, depresión, ansiedad, problemas con las emociones, y otra serie de condiciones relacionadas. Tomando eso en consideración, ¿Cuál ha sido tu experiencia con como estos desastres han afectado tu salud mental y/o la salud mental de tus seres queridos? **[sub aim 1]**

[Prompts for question 3b]

- ¿Crees que alguno de estos desastres tuvo mayor impacto en tu salud mental y/o en la salud mental de tus seres queridos? ¿por qué?
- ¿Cómo describirías la salud mental de la gente en Puerto Rico tras el impacto de estos desastres?

Pregunta #3c: Gracias por compartir tu perspectiva sobre salud mental, ahora nos gustaría conversar un poco sobre salud reproductiva. La salud reproductiva la podemos considerar como la salud del sistema reproductivo, salud sexual, el embarazo, la fertilidad, y la salud de madres y niños. Tomando eso en consideración, ¿Cuál ha sido tu experiencia con como estos desastres han afectado la salud reproductiva tuya o de tus seres queridos?

[Prompts for question 3c]

- Desde tu perspectiva, ¿Cómo crees que estos fenómenos de desastre han afectado el proceso y el cuidado del embarazo en Puerto Rico?
- **[INSTRUCTIONS TO THE INTERVIEWER:** Solo preguntar si respondieron que tienen hijos en el principio de la entrevista] ¿Tuviste hijos durante los pasados 5 años?
    - **Si responde que sí**: ¿Cuál fue tu experiencia durante ese tiempo con tu embarazo o el embarazo de tu pareja? ¿Qué dificultades encontraste o encontraron? ¿Cómo piensas que la experiencia hubiera sido diferente si los desastres no hubieran ocurrido?
    - **Si responde que no**: que todos sus hijos fueron antes de este periodo: ¿Cómo crees que tu experiencia con tu embarazo en aquel momento fue diferente de lo que hubiera sido si hubieras tenido hijos en estos tiempos de desastre?
- ¿Piensas tener hijos en los próximos 5 a 10 años? ¿Por qué?
- ¿Cómo piensas que vivir estos tiempos de desastre han cambiado tu perspectiva sobre tener hijos o no tenerlos?

- ¿Qué crees que es necesario para que en Puerto Rico se pueda tener una buena salud reproductiva y las personas se sientan cómodas teniendo hijos?

Pregunta #3d: Ahora, tomando todo lo que hemos hablado sobre salud y en cómo nos podemos preparar para futuros eventos de desastre, nos gustaría saber qué cosas ayudan a las personas durante estos tiempos o qué cosas complican la situación durante estos eventos.

[Prompts for question 3d]

- ¿Qué factores o barreras piensas que complicaron la situación en Puerto Rico para poder tener buen estado de salud en tiempos de desastre?
- ¿Qué factores o facilitadores piensas que ayudaron a algunas personas en puerto a tener buen estado de salud en tiempos de desastre?
- ¿Qué cosas te gustaría ver o te gustaría que existieran para que en un futuro los desastres no tengan el impacto que han tenido en Puerto Rico en términos de salud?
- De forma general y basado en tu experiencia en Puerto Rico durante estos tiempos, ¿Crees que vivir una experiencia de desastre te ayuda a enfrentar otra en el futuro o piensas que por pasar tantas cosas en tan poco tiempo el bienestar ha estado deteriorando? **[sub aim 3]**

Pregunta #4: Para finalizar la entrevista, uno de los temas que más hemos discutido en Puerto Rico durante estos tiempos es sobre cómo las condiciones sociales, políticas, y económicas en la isla afectaron la preparación y la respuesta a estos desastres. También se ha hablado mucho de la relación entre Puerto Rico y los Estados Unidos y muchas personas opinan que Puerto Rico recibe un trato diferencial en comparación a otros estados y territorios. ¿Cuál dirías que es tu perspectiva sobre esto? ¿Sientes que Puerto Rico recibe un trato diferencial? ¿Por qué?

[Prompts for question 4]

- ¿Cómo crees que esta relación entre Puerto Rico y Estados Unidos ha afectado la preparación y la recuperación de los desastres?
- ¿Cómo comparas la respuesta federal entre estos diferentes desastres? (i.e., Maria vs COVID vs terremotos) Si hubo una diferencia, ¿a qué crees que se debe?
- ¿Cómo te sientes sobre la respuesta del gobierno de Estados Unidos a la situación que tenemos en Puerto Rico? ¿Cuál crees que debe ser el rol del gobierno federal en Puerto Rico para la preparación y/o recuperación de estos eventos?
- ¿Sientes que hay áreas geográficas o grupos en Puerto Rico que recibieron diferentes niveles de ayuda o reconstrucción? ¿Por qué?

Pregunta #5: Para finalizar, ¿hay alguna pregunta que te hubiera gustado que hubiera preguntado? ¿Hay alguna información adicional que te gustaría compartir?

¡Gracias por compartir tus experiencias!

INSTRUCTIONS TO THE INTERVIEWER: Apaga la grabación.

Hora de la entrevista (fin): _____

<u>INSTRUCTIONS TO THE INTERVIEWER</u>: Pregúntale al participante la mejor forma para mandarle por correo el incentivo debido.

1. Dirección postal a mandar el incentivo: _____
   _____
2. Preferencia de cómo recibir el incentivo (circula la que aplique):
   a. Cheque por $50
   b. Tarjeta VISA por $50