Impacts of Disaster-Induced Death and Destruction on Health and Mortality over the Longer-Term

Elizabeth Frankenberg
Department of Sociology and the Carolina Population Center,
University of North Carolina at Chapel Hill

Nicholas Ingwersen
Carolina Population Center,
University of North Carolina at Chapel Hill

Rene Iwo
Department of Sociology and the Carolina Population Center,
University of North Carolina at Chapel Hill

Cecep Sumantri
SurveyMETER, Indonesia

Duncan Thomas
Department of Economics, Duke University

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Abstract

Extreme events causing death and property destruction are on the rise across the globe. We document the long-term consequences for population health of exposure to an extreme event, the 2004 Indian Ocean Earthquake and Tsunami, which killed an estimated quarter of a million people worldwide. Using data from an extremely rich population-representative longitudinal survey, the Study of the Tsunami Aftermath and Recovery (STAR), we explore how this major natural disaster affected survival and psychosocial health of adults in the fifteen years after the tsunami. Leveraging the unanticipated nature of the tsunami, contrasts between those who were directly affected by the disaster and those who were not can plausibly be interpreted as causal. We also investigate the impacts of specific exposures and stressors. Results for mortality and post-traumatic stress reactivity establish that a large-scale natural disaster exerts enduring impacts on health and well-being. In communities that were directly affected by the tsunami, survivors are positively selected with respect to characteristics associated with longevity. For some, this advantage dissipates over time as the deleterious effects of their experiences during the tsunami and in its aftermath emerge over the long-term, both in terms of subsequent survival rates and psycho-social health.

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Climate change is increasing the frequency and intensifying the force of natural disasters at the same time that populations in vulnerable areas are growing in size. Projections that take the combination of these forces into account indicate that relative to their parents and grandparents, today's children and young adults will experience a four- to seven-fold increase in the number of extreme events they live through (Thiery et al., 2021). Understanding the sustained impacts of these events on health and well-being is critically important, but a key constraint is the paucity of high quality longitudinal data that can advance the science.

In this paper we use data from an extremely rich population-representative longitudinal survey, the Study of the Tsunami Aftermath and Recovery (STAR) to explore how both longer-term survival and psychosocial health of individuals who experienced a natural disaster are affected by various types of exposure in the fifteen years after the event, in comparison to individuals who were not directly exposed. We study the 2004 Indian Ocean Earthquake and Tsunami. The disaster, which killed an estimated quarter of a million people worldwide, is one of the most devastating natural disasters in recorded history. Nowhere was hit harder than coastal Aceh, Indonesia. The tsunami completely destroyed some communities but left other comparable communities untouched. STAR is uniquely well-suited for this research: the baseline was conducted 10 months before the tsunami and we have followed survivors for 15 years post-tsunami. The tsunami was completely unanticipated and the location of the communities that sustained damage is a complex function of the location of the precipitating earthquake and the topography of the sea floor and coastline. Leveraging the natural experiment of the tsunami we provide evidence that credibly identifies the causal impact of the disaster on mortality and psycho-social health over the longer-term.

CONTEXT OF THE DISASTER

At 8 a.m. on Sunday, December 26, 2004, one of the most powerful earthquakes in recorded history occurred some 150 miles from the coast of the island of Sumatra, Indonesia. The earthquake displaced a trillion tons of water, which formed a series of tsunami waves that hit the northern coast of Sumatra about 15 minutes later and eventually reached across the entire Indian Ocean. The tsunami was completely unexpected. Geological records indicate that the last tsunami to hit mainland Sumatra was over 600 years ago (Monecke et al., 2008).

Aceh, the northern most province on the island of Sumatra, was hardest hit. Along 800 kilometers of the coast communities experienced varying degrees of inundation, resulting in destruction of the built and natural environment and the deaths of more than 170,000 people.

Impacts varied considerably even between areas quite close to one another. The water's height and inland reach were a function of slope, water depth, and coastal topography (Ramakrishnan et al., 2005). Along parts of the west coast of Aceh, trees up to 13 meters tall lost their bark (Borrero, 2005). At the beachfront in Banda Aceh, the province's capital and largest city, the water was as deep as 9 meters; though rarely exceeded the height of a two story building (Borrero, 2005). Low-lying communities within a few kilometers of the coast were largely destroyed and many of their residents perished. River basins allowed the waves to move inland as much as 9 kilometers in some areas, whereas in other locations they encroached only 3-4 kilometers (Kohl et al., 2005; Umitsu et al., 2007). Areas sheltered by altitude, distance from the coast, or other topographical features sustained damage to structures and deposition of sediment and debris, but larger proportions of the population survived. For some communities the tsunami had few if any direct effects, although the earthquake was felt throughout Aceh and damaged property and infrastructure in some areas that the water never reached. The tsunami affected the transportation network along the coast and some communities were cut off from the main roads connecting major population centers. In some cases, residents of communities that were not directly impacted by the tsunami saw increased demand for their goods and services, particularly food and housing.

DATA

The STAR baseline consists of respondents who participated in a large, population-representative socioeconomic survey (SUSENAS) conducted by Statistics Indonesia in February/March 2004, ten months before the tsunami. SUSENAS is representative at the *kabupaten* (regency) level. We worked with Statistics Indonesia to select all 11 districts in the province of Aceh that had coastlines which were potentially vulnerable to inundation by a tsunami. Within each selected district we included all SUSENAS enumeration areas, regardless of distance from the coast. All members of all households enumerated in these districts in the 2004 SUSENAS form the STAR baseline study population.

SUSENAS, a long-standing government survey that is well-known in Indonesia, achieves participation rates that exceed 97%. The survey, which most closely parallels a combination of the Consumer Expenditure Survey and Current Population Survey in the U.S., collects information on demographic and socioeconomic characteristics of household members from a key household member. The first STAR follow-up survey took place between May 2005 and July 2006. Four annual follow-ups were conducted thereafter, with additional follow-ups roughly ten and fifteen years after the event.

We triangulated across multiple sources of information to establish survival status for 99% of the baseline (pre-tsunami) respondents. Information comes from interviews with household and family members (whose reports we consider most reliable), community leaders, and neighbors. Information from the latter two sources is critical for households for in which no members could be located. In each follow-up, every household member is interviewed. Parents or caregivers provide information about children age 11 years or younger, proxy respondents provide information for adults unable to answer for themselves. The first two follow-up surveys collected detailed information on experiences at the time of the tsunami from each respondent. All surveys include questions on physical health, psycho-social well-being, and behavioral responses to the event, including displacement and migration, as well as information about individual and household demographics and socioeconomic status.

MEASURES

In this paper we investigate links between multiple indicators of exposure to the tsunami and two post-tsunami measures of health—mortality for those who survived the tsunami and post-traumatic stress reactivity (PTSR). Frankenberg et al. (2011) describe mortality at the time of the tsunami and Frankenberg et al. (2008) describe (PTSR) in the year after the tsunami. See, also, Ho et al. (2017) and Frankenberg et al. (2020) for studies of mortality. This research builds on those studies. Our data on mortality derive from our household rosters, which we update at each wave to track survival status and movement across locations (and of household members across households).

Following the literature, we summarize the impact of the stressors using an index of the incidence and severity of symptoms of PTSR, based on seven items from the PTSD Checklist Civilian Version (Weathers et al., 1993). For example, respondents are asked whether they have had "repeated, disturbing memories, thoughts, dreams or relived experiences of the tsunami" and "felt very upset when something reminded you of the tsunami." If the respondent did experience the feelings, they are asked, for the period when the feelings were most severe, whether they felt them rarely (coded as 1), sometimes (coded as 2) or often (coded as 3). Respondents who did not experience the feelings are coded as 0. Summing the responses to each of the seven items creates a 21-point scale. As our measure of elevated PTSR, an indicator is defined as 1 for respondents whose score was above 11 and 0 otherwise.

These questions were assessed in the first post-tsunami survey, which was conducted 5 to 16 months after the tsunami, except for a small fraction of respondents (less than 3%), whose first post-tsunami interview took place during the second follow-up, 18 to 24 months after the tsunami.

Exposure to the tsunami is measured at both the community and individual level. At the community level, two classes of measures of exposure are operationalized. Our first measure is an indicator of exposure based on the geographic location of the community where each respondent resided at the time of the tsunami. This measure, in recognition that characteristics of the tsunami wave and coastline topography were key determinants of death and destruction at the time of the tsunami, combines information on that community's elevation above sea level, proximity to the coastline, and tsunami wave height at the closest coastal point to the community. In the analyses this indicator allows us to distinguish respondents who were living in communities that were directly affected by the 2004 tsunami ("tsunami-affected") from respondents who were living in communities at similar risk of exposure to a tsunami but were not directly affected by the 2004 tsunami ("other") at the time of the tsunami. Our second measure of exposure at the community level is the percentage of baseline respondents in the community who died in the tsunami. It is designed to reflect intensity of exposure and varies from no deaths to a staggering three-quarters of the community residents perishing in the tsunami.

Turning to individual-level measures, we asked each surviving respondent about their own experiences of the tsunami. The first set of individual-specific measures reflects experiences that may generate a sense of helplessness or horror (which have been linked with symptoms of post-traumatic stress; Dalgleish, 1999). Specifically, we ask whether the respondent was caught up in the water, was injured at the time of the tsunami, or watched friends or family struggle or disappear in the waves. Any affirmative answer is classified as direct exposure. We also construct exposure measures that capture loss of family: whether the tsunami killed an individual's spouse, or whether it killed an individual's parent, sibling, or child (regardless of whether the family member was co-resident). These individual-specific indicators of exposure complement the community-level measure of damage, providing more fine-grained indicators of tsunami-related stresses experienced by the respondent. As with PTSR, the individual-specific questions are asked at the first post-tsunami follow-up except for those respondents whose first post-tsunami individual interview took place during the second follow-up.

Finally, to address post-tsunami displacement during the 24 months after the disaster, we develop an indicator identifying respondents who lived in temporary housing during this period: a tent, camp, or barracks. This measure draws on data collected in the first three annual post-tsunami follow-ups.

Our community-level and individual-level direct exposure measures are plausibly exogenous because they depend primarily on characteristics that were outside the control of the respondents at the time of the tsunami. While the exact locations of tsunami impact are reasonably treated as random, residential location is a choice and it is possible that those who were living in areas that were inundated are different from those who were living elsewhere. To address this concern, we examine the effects of individual-level exposures, drawing contrasts between individuals who, at the time of the tsunami were living in the same community so that the estimates are not contaminated by differences across communities in vulnerability, socio-economic status and the availability of resources.

We focus on mortality and psycho-social health in the fifteen years after the tsunami among 5,927 individuals, from 334 baseline communities, who were age 35 and older at the time of the tsunami and who survived to the first post-tsunami interview. Face to face interviews were completed with 97.8% of this group in the 15 years after the disaster (0.5% refused, 1.7% were not found). This re-interview rate is unprecedented for a large-scale population-representative follow-up 15 years after baseline and stands out given the extent of displacement and the complexity of conducting fieldwork in the aftermath of the tsunami. It reflects the combination of well-designed and extensively tested tracking protocols, high quality fieldwork, and the commitment of respondents, enumerators and team supervisors to the scientific goals of the project.

METHODS

We examine the correlates of mortality and levels of PTSR after the tsunami by estimating a sequence of models that allow us to consider different measures of exposure and take into account unobserved factors specific to the community by drawing comparisons among survivors who were living in the same community at the time of the tsunami. For the mortality model we analyze a binary dependent variable, θ_{ic}, which takes the value 1 if the tsunami survivor, i, who was living in community, c, at baseline died during the fifteen years after the tsunami and 0 if the individual survived for fifteen years:

$$\theta_{ic} = \alpha + \beta T_c + \gamma X_{ic} + \varepsilon_{ic} \qquad [1]$$

where T_c indicates community-level tsunami exposure, specifically either (1) whether the respondent's pre-tsunami community was affected by the tsunami (our geographically-based measure of exposure described above which parallels exposure measures in most other empirical work on this topic), or (2) the percentage of baseline respondents from the respondent's pre-tsunami community who were killed in the tsunami (which we know from updating the baseline data with survival status at the first follow-up). The vector X_{ic} includes individual background characteristics measured at the pre-tsunami baseline: age (in single years), education, whether the respondent was married, and household expenditures per capita (a well-established measure of economic resources; Deaton, 1997). We also include a measure of height (measured in the follow up surveys) as a control for health endowment. Unobserved heterogeneity is captured by ε_{ic}.

The baseline model is extended to examine how individual exposures to the disaster's direct impacts are related to death over the next fifteen years:

$$\theta_{ic} = \alpha + \beta T_c + \lambda E_{ic} + \gamma X_{ic} + \varepsilon_{ic} \qquad [2]$$

where E_{ic} is a vector of measures of exposure based on individual reports of experiences and losses at the time of the tsunami, whether the respondent experienced high levels of post-traumatic stress reactivity, and whether the respondent lived in temporary housing in the two years after the tsunami.

To address the possibility that the community-level measures of tsunami exposure reflect factors such as vulnerability, and to highlight the role of individual exposures, the model is extended to draw comparisons in variation in exposure between individuals within the same community:

$$\theta_{ic} = \alpha + \lambda E_{ic} + \gamma X_{ic} + \mu_c + \varepsilon_{ic} \qquad [3]$$

where μ_c are enumeration area (EA) indicators that absorb the influence of all community-level variation that does not change over time and affects mortality in a linear and additive way. This includes levels of vulnerability that are shared by community members, the extent of damage in the community because of the earthquake and tsunami, post-tsunami reconstruction, and pre-tsunami levels of infrastructure and economic activity, as well as other unobserved community-level factors that might be correlated with both choice of pre-tsunami location and mortality.

When we shift to post-traumatic stress reactivity, our dependent variable varies from 0 to 21, with higher scores corresponding to a combination of higher incidence and greater intensity of symptoms. For PTSR, we estimate models 2 and 3 to examine how the exposure measures at the time of the tsunami and in the two years after the disaster relate to psychosocial health at five, ten, and fifteen years post-disaster.

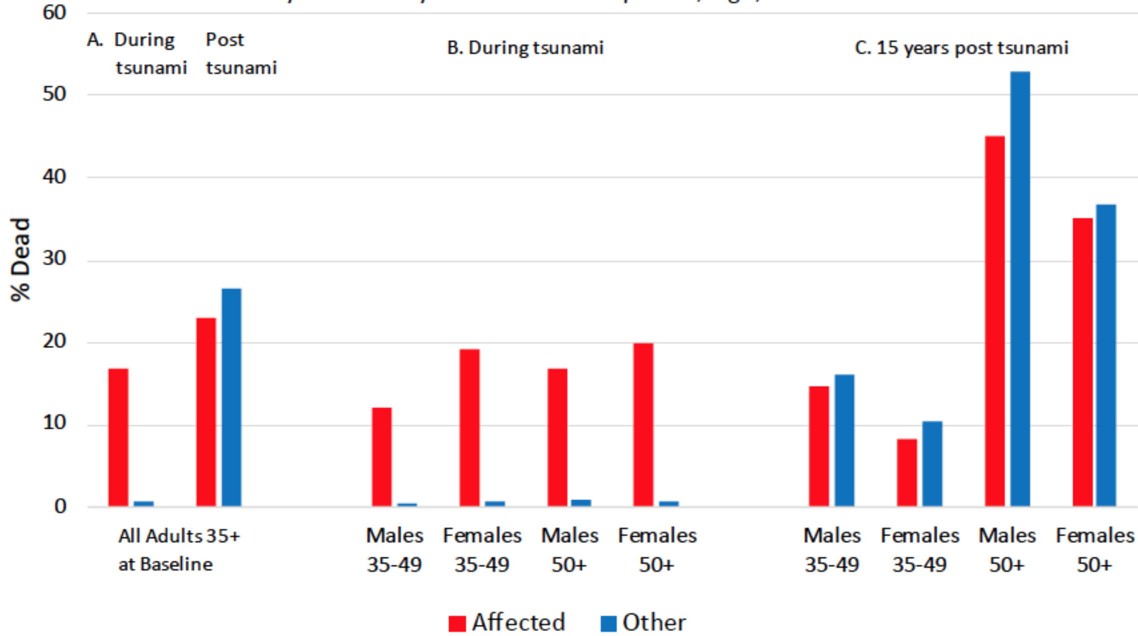
RESULTS

We begin by presenting descriptive statistics for key variables (Table 1). Our respondents were living in 334 communities in 2004, before the tsunami, of which 191 were directly affected by the tsunami, as indicated by our geographically-based measure of exposure at the community level (Panel A). This dichotomy captures tsunami-related exposures well and separates areas where there was tsunami-related mortality (among household members at baseline, an average of 14.3% were killed) from areas where death due to the tsunami was negligible (less than 1%, on average, were killed).

We use this dichotomous measure to contrast the percentage of baseline respondents who died during the tsunami and the percentage, among those who survived the disaster, who died in the next fifteen years (Figure 1).

The first series of four bars presents the results for the full sample of 6,687 individuals in the baseline (to estimate mortality between baseline and the first follow-up) and the 5,927 baseline individuals who survived to the first follow-up (to estimate mortality between the first follow-up and the fifteen-year follow-up). All were 35 years of age or older at the time of the baseline survey in 2004. Not surprisingly, among those from tsunami-affected communities (in red), mortality was markedly higher (17%) than for those from other communities (in blue, 0.6%). However, in the fifteen years after the disaster the direction of this differential reverses: 27% of those from “other” communities are dead by the 2020 survey, whereas only 23% of those from tsunami-affected communities have died.

Figure 1
% Dead at and in the 15 Years after the Tsunami
by Community-level Tsunami Exposure, Age, and Sex



Community of Residence at the Time of the Tsunami

This reversal is consistent with the idea that the tsunami exerted a force of positive selection—causing the deaths of more frail members of communities in which the waves came ashore and left behind a group of survivors who were, on average, more robust than individuals in the communities where waves did not strike. Evidence for positive mortality selection emerged in the first five and ten years after the tsunami (Ho et al., 2017; Frankenberg et al., 2020).

Age and sex were important determinants of survival during the tsunami (Frankenberg et al., 2011) and therefore may shape survival patterns in its aftermath. Accordingly we also present mortality patterns for four groups differentiated by sex and by age (respondents aged 35-49 at the tsunami are distinguished from individuals 50 and older). The evidence for positive selection is replicated for each of these four groups, although it is particularly strong for older males.

In the aggregate, and without controls for other factors, mortality selection appears to be positive. We explore this result in several ways: examining mortality after the tsunami as a function of the community-level mortality rate during the disaster (to better distinguish the magnitude of the tsunami's impact), by controlling for baseline demographic and socioeconomic characteristics, and by including measures of individual-level exposures. Descriptive statistics for these variables are presented in panels B and C of Table 1.

With respect to the individual measures of tsunami exposure, for all but PTSR the percentage exposed is at least twice as high for respondents originally from directly affected communities as for respondents from other communities. With respect to demographic and socioeconomic characteristics at baseline, survivors in the directly affected and other communities are very similar. Individuals from directly affected communities are a little more likely to be male, about a year younger, have an additional year of education, and are more likely to be widowed. These differences largely reflect differential tsunami survival. In contrast, there is no difference between the directly affected and other communities in the level of household resources at the time of the tsunami, as indicated by the logarithm of household per capita expenditure measured in the pre-tsunami baseline, which is widely considered to be the best indicator of resource availability in low income settings and is a good time-varying marker of socio-economic status (SES).

Mortality in the Fifteen Years after the Tsunami

In Table 2 we present the results from Model 1 (columns 1 and 2), to explore the relationship between community-level measures of exposure and mortality in the fifteen years after the tsunami. The dependent variable is multiplied by 100 so that the coefficients are interpreted as changes in percentage points. The coefficients associated with both the dichotomous and the continuous measures of community-level tsunami impact are negative and statistically significant. Both measures are associated with a reduction in mortality risk over the long-term: given surviving the tsunami itself, those from exposed communities are more likely to survive the fifteen years after the 2004 tsunami than those from communities in which impacts were minor. Age is controlled in the models (using indicators for single years) so these results do not reflect differences in age composition across communities. Nor do they reflect differences in gender, widowhood, education, or pre-tsunami resources, all of which are taken into account in the models.

Because the continuous measure of community mortality provides a more fine-grained measure of exposure relative to the dichotomous indicator, subsequent regressions control for the community tsunami mortality rate.

Moving to column 3, we add controls for individual exposures. This addition only strengthens the negative effect of the community mortality rate, which increases in magnitude by roughly 40%, from -0.17 to -0.23. Two of the individual exposure measures exhibit relatively strong positive effects on mortality: death of a spouse (3.71, albeit not statistically significant) and having lived in temporary housing (5.11, statistically significant). These results suggest that although positive mortality selection operates in the aggregate, individuals with certain experiences carry scars that affect their long-term survival prospects. The coefficients on the other exposure measures are much smaller in magnitude and none is statistically significant.

Column 4 presents the results based on Model 3, which includes community fixed effects and thus draw comparisons between individuals who were living in the same community at the time of the tsunami. The size of the coefficient associated with living in poor housing is reduced and less precisely estimated (p=0.14). This reflects the fact that there is little variation in the extent of physical damage to property within a community, relative to the variation across communities. As a result, the need for temporary housing is highly correlated across individuals who were living in the same community at the time of the tsunami.

With respect to the baseline characteristics, males have markedly higher mortality than females—by ten to eleven percentage points. Additionally, as baseline level of economic resources rises, mortality risk falls, suggesting that pre-disaster SES exerts a protective effect on health long after the event. Neither educational level nor baseline marital status is related to post-tsunami survival.

As shown in Figure 1, mortality risks in the tsunami vary by age and sex. Accordingly we estimate Models 1 and 3 separately for each of the four age-sex groups distinguished in Figure 1. These results are presented in Table 3.

Perhaps the most important overall result from the stratified models is the substantial difference in our ability to predict post-tsunami mortality for older versus younger respondents. For younger respondents, neither the community-level mortality rate nor the measures of individual exposures are statistically significant predictors of mortality after the disaster. Nor for the most part are the measures of demographic and socioeconomic background (the one exception is per capita expenditure levels for younger males in the fixed effect specification). Post-tsunami mortality risks do rise with age for both males and females (results not shown).

For older individuals the story is markedly different. The force of positive mortality selection is very powerful for both males and females. For each 1% increase in the percentage of residents killed in the tsunami, the risk of mortality in the next fifteen years falls by 0.36 percentage points for males and by 0.38 percentage points for females.

In addition, a number of the individual exposure measures elevate mortality risks of older adults. For older males three exposure measures are large in size and marginally significant. Mortality risks are 11.6 percentage points higher for men who lived in temporary housing (p=0.054) and 9 percentage points higher (p=.07) for men who experienced high levels of post-traumatic stress in the first two years after the tsunami. On the other hand, the mortality risks of men who lost a spouse are reduced by 13.4 percentage points (p=.065).

Turning to older women, the loss of a spouse has exactly the opposite relationship with mortality risks. For women, losing a spouse increases the risk of subsequent mortality by almost 18 percentage points. The difference between the effect for males and females is large and statistically significant (results not shown). One possible reason for this difference is the difference in opportunities available to older males and females who are widowed. In particular they face very different marriage markets. For the younger respondents death of a spouse is not statistically related to mortality for either males or females, but we note that the coefficients are relatively large and the signs are the same as for older adults: negative for men but positive for women.

For older women the other exposure measures are not statistically significant, although the impact of living in poor housing is large and positive (and marginally significant in the model without the community-level fixed effect, which is not shown).

Among older respondents background variables matter little for males, although 7-11 years of schooling reduces mortality risks relative to men with 0 to 4 years of education (the omitted group). For females, higher levels of economic resources before the tsunami are associated with lower levels of mortality post-tsunami, but being widowed or divorced at baseline increases mortality risks.

Post-traumatic Stress

Over and above survival, it is important to examine other dimensions of health which are likely to be indicative of quality of life and subsequent mortality. We turn, therefore, to an indicator of psychosocial well-being that is particularly salient in this context. Our earlier work documented the strong role that exposure played with respect to levels of post-traumatic stress in the first few years after the tsunami (Frankenberg et al., 2008). Here we examine the degree to which exposure continues to play a role in post-traumatic stress reactivity at five, ten, and fifteen years after the disaster.

Table 4 presents results from Model 2 (where the outcome variable is the index of PTSR that varies from 0 to 21) for the three time periods, estimated separately for the four age-sex groups. For each group some aspects of exposures matter, although what is important varies by time period and by group. Moreover, the exposure measures are more closely correlated with PTSR for the younger age groups than they are for the older ones (the reverse of what we see for mortality). Among males aged 35-49 years, losing a spouse increases the PTSR level at the five years post-tsunami mark. At ten years both direct exposure to the waves and being from a community with a higher mortality rate are associated with higher levels of PTSR. At fifteen years only the community mortality rate emerges as important, with a higher mortality rate associated with more symptoms.

Among women age 35-49 years, the community mortality rate is not associated with PTSR levels at any point, but each of the other exposure measures affects PTSR levels in at least one period. In fact the individual exposure measures are more closely associated with PTSR for women age 35-49 years than for any other group. In terms of magnitude, the largest effects are for losing a spouse, which elevates the PTSR level at both five and ten years after the disaster. Losing another close family member also elevates PTSR at five and at ten years. Living in temporary housing is associated with higher levels of PTSR at years five and fifteen. Finally direct exposure to the waves elevates PTSR at fifteen years post-disaster. Although exposure does not translate into reduced longevity for the younger women, each of the individual-specific indicators of tsunami-related trauma continues to take a toll on this indicator of psychosocial health more than a decade later.

Among older respondents some exposures are linked to PTSR levels, but the effects are far more muted. For older men losing a spouse reduces PTSR symptoms five years after the tsunami (which matches the negative relationship that losing of a spouse exhibits with mortality), but there is no relationship between spousal loss and PTSR at other points. At ten years direct exposure to the waves and loss of a parent, child, or sibling increases PTSR levels. For older men, none of the exposure measures are relevant at fifteen years post tsunami. For older women there are few correlations between exposure and PTSR. For this group, the community mortality rate is positively related to PTSR levels ten and fifteen years after the tsunami, but this is the only measure of exposure that is correlated with post-traumatic stress.

Background characteristics appear to have little impact on PTSR for any group, although for males in both age groups, higher levels of education are associated with lower levels of PTSR at five and ten years after the disaster.

Table 5 presents the results for PTSR with the addition of a community fixed effect (Model 3). The result is a reduction in the importance of the exposure measures for all groups, particularly 10 and 15 years after the tsunami. For younger males having lived in temporary housing affects PTSR at 5 years, but no other exposure measures are related to PTSR. Among younger females loss of a spouse or other close kin affects PTSR at years five and ten, but none of the exposure measures matter at year 15. For older males direct exposure elevates PTSR at year 10. while for older females it elevates PTSR at year 15. Thus it appears that within communities variation in levels of PTSR many years after the tsunami is not primarily explained by exposures at the time of the event.

DISCUSSION AND CONCLUSIONS

Taken together the results for mortality and PTSR establish that a large-scale natural disaster exerts enduring impacts on health and well-being. In communities that were directly affected by the tsunami, survivors are positively selected with respect to characteristics associated with longevity. Nonetheless the effect of their experiences at the time of the tsunami and in the first years after the tsunami are evident over the long-term, both in terms of their survival rates and their psycho-social health. Several findings suggest important questions for future research.

First, the differences between older males and females in the impact of losing a spouse are striking and warrant additional research on differences by sex in how lives unfold after a disaster. It is not clear how much of these differences can be attributed to differences in remarriage after loss of a spouse in the tsunami, relationships with children and other family members, evolution of economic circumstances, or the availability of assistance from family, the community, or the government. An important policy issue that has received little attention in the literature on disaster relief revolves around the design of assistance and support programs that mitigate the large negative consequences of premature spousal death for women.

Second, exposure to poor housing conditions is indicated as a risk factor for mortality and poor psycho-social health for males and females across the entire adult age spectrum. This points to the potential of well-designed housing assistance programs that are deployed soon after a destructive natural disaster to substantially reduce the negative health consequences of the disaster.

Third, there are long-lasting impacts of exposure to disaster-related trauma on psycho-social health. Even fifteen years after the tsunami event, PTSR is shaped by what happened during and after the disaster. The continued role these exposures play is strongest for younger women, for whom loss of either a spouse or another close family member negatively affects psychosocial health, but it is present to varying degrees for all demographic groups. Access to mental health services was extremely limited after the tsunami. The literature suggests that deploying services on a broader scale soon after the disaster limits some of the long-term repercussions of the experience.

We close with two observations. First our data and methods provide unusual and important evidence on the causal impact of exposure. It is, however, of substantial interest—and of great importance—to investigate the mechanisms underlying heterogeneity in these outcomes and isolate the factors that seem to be associated with greater resilience and recovery in the aftermath of the tsunami.

Second, although high mortality disasters are relatively rare in high income countries, extreme events are on the rise world-wide. The U.S. has seen numerous hurricanes and wildfires in recent years—events that generate the kinds of exposures we consider, even if mortality associated with them is low. Events that cost lives, damage property, and expose people to potentially traumatic experiences will punctuate life for the foreseeable future, and it is important to study their short and long-term implications for health and well-being.

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Table 1
Descriptive Statistics

		Communities Directly Affected by the Tsunami	Other Communities
A. Community Exposures	Number of communities	191	143
	Percent died at time of tsunami	14.3	0.4
B. Individual Tsunami Exposures (%)	Direct experience with waves	20.4	4.3
	Death of spouse	5.5	2.3
	Death of parent, child and/or sibling	22.1	9.4
	In temporary housing after tsunami	20.8	6.4
	High post-traumatic stress reactivity	21.2	14.1
C. Baseline Characteristics	Male (%)	50.7	48.3
	Age at time of tsunami (mean in years)	49.7	50.9
	Years of education (mean)	7.7	6.7
	Widowed or divorced (%)	15.4	14.1
	Ln of per capita expenditure pre-tsunami	12.8	12.8
N		3185	2742

Individual exposures and baseline characteristics are computed for tsunami survivors age 35 and older at time of tsunami. All estimates weighted to represent population of survivors at time of tsunami.

Table 2

Community Exposure, Individual Exposure, and Risk of Mortality 2005-2020

		(1)	(2)	(3)	(4)
Tsunami	Community affected	-2.91			
Exposures		[1.02]**			
	% of Community Killed		-0.17	-0.23	
			[0.04]**	[0.05]**	
	Direct exposure to waves			0.01	-0.32
				[1.68]	[2.04]
	Spouse killed			3.71	3.73
				[2.94]	[3.20]
	Parent, child, or sibling killed			-1.53	-1.22
				[1.31]	[1.40]
	Lived in temporary housing			5.11	3.17
				[1.45]**	[2.14]
	High Level of Post-traumatic Stress			-0.61	-0.86
				[1.34]	[1.50]
Baseline	Male	10.87	11.17	11.01	11.38
Characteristics		[1.42]**	[1.43]**	[1.42]**	[1.45]**
	Widowed or Divorced	-0.53	-0.43	-0.03	-0.32
		[1.67]	[1.66]	[1.67]	[1.74]
	Education: 4-6 years	-0.56	-0.53	-0.59	-0.89
		[1.39]	[1.39]	[1.39]	[1.50]
	7-11 years	-2.12	-1.87	-2.03	-2.94
		[1.78]	[1.77]	[1.77]	[1.96]
	12+ years	-1.70	-1.88	-1.59	-2.88
		[1.63]	[1.63]	[1.62]	[1.98]
	Monthly per capita expenditure	-2.35	-2.33	-2.22	-3.14
		[0.90]**	[0.92]*	[0.91]*	[1.24]*
Constant		55.46	53.86	50.88	64.22
		[18.97]**	[19.18]**	[19.12]**	[21.98]**
Observations		5927	5927	5927	5927
R-squared		0.22	0.23	0.23	0.23
EA Fixed Effect		No	No	No	Yes
Number of Eas					333

Robust standard errors in brackets. Controls for age (in single years).

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 3

Community Exposure, Individual Exposure, and Risk of Mortality 2005-2020, by Age and Sex

		Males 35-49		Females 35-49		Males 50+		Females 50+	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tsunami	% of Comm. Killed	-0.08		0.01		-0.36		-0.38	
Exposures		[0.05]		[0.07]		[0.11]**		[0.16]*	
	Direct exposure to waves		-0.50		-1.25		-2.50		-6.91
			[3.16]		[3.13]		[6.13]		[6.66]
	Spouse killed		-5.12		6.06		-13.39		17.82
			[5.98]		[5.65]		[7.23]+		[7.92]*
	Parent, child, or sibling killed		0.86		-2.87		-4.27		5.12
			[2.82]		[2.00]		[4.29]		[4.11]
	Lived in temporary housing		0.05		2.57		11.58		7.33
			[3.53]		[4.02]		[6.02]+		[6.96]
	High Level of Post-traumatic Stress		-2.00		-3.37		8.86		-2.23
			[2.59]		[2.13]		[4.90]+		[4.44]
Baseline	Widowed or Divorced	-7.12	-12.92	0.91	3.69	-2.28	4.72	4.36	6.10
Characteristics		[6.98]	[9.23]	[2.26]	[2.38]	[6.18]	[6.54]	[2.88]	[3.45]+
	Education: 4-6 years	0.69	0.61	2.64	2.64	-2.79	-4.57	-3.68	-4.27
		[2.92]	[3.24]	[2.03]	[2.34]	[3.58]	[4.19]	[2.95]	[3.65]
	7-11 years	-1.77	-2.35	1.31	1.70	-7.72	-7.44	1.48	3.40
		[3.28]	[3.88]	[2.38]	[2.83]	[4.65]+	[6.14]	[4.77]	[6.20]
	12+ years	-1.42	-2.06	1.64	2.17	-5.31	-4.98	-7.33	-13.65
		[3.00]	[3.89]	[2.19]	[2.90]	[4.72]	[5.73]	[4.83]	[6.45]*
	Monthly per capita expenditure	-2.64	-5.60	0.10	-2.57	-1.06	-1.50	-6.38	-5.54
		[1.68]	[2.48]*	[1.21]	[1.87]	[2.45]	[3.73]	[2.29]**	[3.95]
Constant		40.64	68.84	40.37	70.81	101.26	70.48	133.18	131.41
		[30.03]	[42.33]	[25.46]	[35.02]*	[52.42]+	[69.27]	[51.07]**	[71.29]+
Observations		1799	1799	1686	1686	1242	1242	1200	1200
R-squared		0.05	0.06	0.04	0.04	0.16	0.18	0.21	0.22
EA Fixed Effect		No	Yes	No	Yes	No	Yes	No	Yes
Number of Eas			330		316		319		302

Robust standard errors in brackets. Controls for age (in single years).

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 4

Community Exposure, Individual Exposure, and Levels of Post-Traumatic Stress 5, 10 and 15 years after the Tsunami

	Males age 35-49			Females age 35-49			Males age 50+			Females age 50+		
# of years post-tsunami	+5	+10	+15	+5	+10	+15	+5	+10	+15	+5	+10	+15
Tsunami Exposures												
% of Comm. Killed	0.00	0.02	0.02	0.01	0.01	0.00	0.02	0.00	-0.01	0.03	0.05	0.05
	[0.01]	[0.01]**	[0.01]*	[0.01]	[0.01]	[0.01]	[0.01]	[0.02]	[0.01]	[0.02]	[0.02]*	[0.03]+
Direct exposure to waves	-0.14	0.63	0.15	0.09	0.14	0.61	0.45	1.39	0.56	0.38	0.86	1.39
	[0.27]	[0.24]**	[0.23]	[0.40]	[0.31]	[0.32]+	[0.48]	[0.54]*	[0.42]	[0.50]	[0.63]	[0.85]
Spouse killed	1.22	0.48	-0.59	1.28	1.86	0.44	-1.61	0.69	-0.53	-0.66	-0.12	1.23
	[0.66]+	[0.42]	[0.48]	[0.64]*	[0.72]*	[0.54]	[0.68]*	[1.02]	[0.49]	[0.65]	[0.70]	[1.02]
Parent, child, sibling killed	0.09	-0.28	-0.03	0.73	0.54	0.12	-0.38	0.73	0.32	-0.54	0.35	-0.14
	[0.28]	[0.21]	[0.20]	[0.31]*	[0.28]+	[0.20]	[0.40]	[0.37]*	[0.34]	[0.40]	[0.45]	[0.39]
Lived in temporary housing	0.39	-0.42	0.23	0.80	-0.45	0.49	-0.25	-0.18	-0.10	0.26	-0.55	0.26
	[0.27]	[0.19]*	[0.20]	[0.31]**	[0.26]+	[0.26]+	[0.40]	[0.38]	[0.39]	[0.49]	[0.45]	[0.54]
Baseline Characteristics												
Widowed or Divorced	-0.89	0.15	-0.04	0.12	0.14	-0.14	-1.17	0.45	-0.83	-0.28	0.12	0.00
	[0.74]	[0.96]	[0.53]	[0.31]	[0.29]	[0.21]	[0.59]*	[1.00]	[0.59]	[0.33]	[0.31]	[0.28]
Education: 4-6 years	-0.40	0.20	-0.48	0.78	-0.28	-0.03	-0.52	0.34	0.05	0.06	-0.26	0.08
	[0.31]	[0.22]	[0.22]*	[0.28]**	[0.24]	[0.20]	[0.36]	[0.32]	[0.37]	[0.35]	[0.37]	[0.34]
7-11 years	-0.95	0.38	-0.29	0.56	-0.30	-0.33	-1.95	0.20	-0.14	0.13	0.56	-0.39
	[0.35]**	[0.27]	[0.24]	[0.35]	[0.29]	[0.23]	[0.44]**	[0.43]	[0.37]	[0.59]	[0.60]	[0.45]
12+ years	-1.13	0.08	-0.32	-0.13	-0.26	-0.19	-1.68	0.08	-0.25	-0.20	-0.81	-0.85
	[0.32]**	[0.22]	[0.23]	[0.30]	[0.31]	[0.25]	[0.46]**	[0.40]	[0.39]	[0.66]	[0.55]	[0.56]
Monthly per capita spending	0.46	-0.05	0.04	0.15	0.01	0.43	-0.06	0.00	0.31	0.47	-0.33	0.35
	[0.19]*	[0.16]	[0.14]	[0.19]	[0.17]	[0.14]**	[0.24]	[0.20]	[0.24]	[0.30]	[0.26]	[0.24]
Constant	1.61	5.09	2.54	6.16	5.54	-4.93	14.86	3.91	-4.27	0.16	7.42	1.82
	[3.62]	[2.74]+	[2.87]	[3.54]+	[3.10]+	[2.50]*	[5.51]**	[4.45]	[6.16]	[5.86]	[5.06]	[4.50]
Observations	1333	1407	1292	1421	1438	1382	554	541	471	652	623	569
R-squared	0.03	0.05	0.03	0.06	0.03	0.04	0.15	0.12	0.09	0.07	0.07	0.11

OLS regressions, robust standard errors in brackets. Restricted to survivors to the most recent STAR follow up, controls for age (single years).

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 5

Individual Exposure and Levels of Post-Traumatic Stress after the Tsunami

Enumeration Area Fixed Effects

	Males age 35-49			Females age 35-49			Males age 50+			Females age 50+		
# of years post-tsumami	+5	+10	+15	+5	+10	+15	+5	+10	+15	+5	+10	+15
Tsunami Exposures												
Direct exposure to waves	-0.28	0.41	-0.11	0.49	-0.07	0.60	-0.09	1.58	0.70	0.64	-0.05	2.37
	[0.31]	[0.25]	[0.26]	[0.44]	[0.36]	[0.42]	[0.61]	[0.79]*	[0.93]	[0.66]	[0.84]	[1.03]*
Spouse killed	1.32	0.70	-0.06	0.47	2.28	0.68	-1.15	-0.10	-0.64	-0.78	0.02	-0.85
	[0.81]	[0.46]	[0.60]	[0.72]	[0.78]**	[0.70]	[0.87]	[1.24]	[0.73]	[0.86]	[0.97]	[0.91]
Parent, child, or sibling killed	0.26	-0.37	-0.07	0.63	0.53	0.00	0.48	0.82	0.09	-0.26	0.71	-0.1
	[0.33]	[0.25]	[0.20]	[0.31]*	[0.29]+	[0.23]	[0.51]	[0.51]	[0.46]	[0.54]	[0.56]	[0.55]
Lived in temporary housing	0.93	-0.08	0.00	0.48	-0.14	-0.28	0.91	0.67	0.58	0.11	-0.09	1.83
	[0.44]*	[0.37]	[0.29]	[0.53]	[0.42]	[0.40]	[0.79]	[0.96]	[0.60]	[0.87]	[0.75]	[1.53]
Baseline Characteristics												
Widowed or Divorced	-1.02	0.37	0.04	0.28	0.23	-0.09	-0.32	1.21	0.01	0.04	0.16	-0.13
	[0.87]	[1.08]	[0.61]	[0.30]	[0.29]	[0.24]	[0.82]	[1.44]	[0.58]	[0.36]	[0.42]	[0.35]
Education: 4-6 years	-0.49	0.09	-0.20	0.75	-0.40	0.04	-1.08	0.14	0.49	0.09	-0.24	0.32
	[0.33]	[0.23]	[0.21]	[0.29]*	[0.26]	[0.22]	[0.42]*	[0.48]	[0.39]	[0.38]	[0.42]	[0.43]
7-11 years	-0.58	0.37	-0.15	1.14	-0.55	-0.28	-2.25	0.20	0.06	0.22	1.14	-0.52
	[0.39]	[0.28]	[0.25]	[0.35]**	[0.32]+	[0.24]	[0.51]**	[0.66]	[0.50]	[0.67]	[0.70]	[0.68]
12+ years	-0.63	-0.12	-0.24	0.85	-0.53	-0.01	-1.01	-0.22	-0.38	0.48	-0.47	-0.36
	[0.37]+	[0.25]	[0.24]	[0.36]*	[0.33]	[0.27]	[0.65]	[0.70]	[0.64]	[0.82]	[0.66]	[0.82]
Monthly per capita expenditure	0.36	-0.06	-0.15	-0.23	0.13	0.05	0.75	0.29	-0.46	0.78	0.12	0.57
	[0.25]	[0.20]	[0.16]	[0.28]	[0.25]	[0.19]	[0.43]+	[0.32]	[0.41]	[0.43]+	[0.40]	[0.39]
Constant	0.09	4.29	2.85	3.45	2.58	-0.34	-1.44	1.27	2.11	-1.81	6.85	-9.11
	[4.32]	[3.35]	[2.97]	[4.65]	[4.38]	[2.94]	[7.31]	[7.13]	[6.68]	[7.51]	[7.23]	[7.52]
Observations	1333	1407	1292	1421	1438	1382	554	541	471	652	623	569
R-squared	0.03	0.03	0.01	0.03	0.04	0.02	0.16	0.18	0.15	0.15	0.11	0.14

EA-level fixed effects. Robust standard errors in brackets, Restricted to survivors to the most recent STAR follow up. Controls for age (single years).

+ significant at 10%; * significant at 5%; ** significant at 1%