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ABSTRACT

We investigate the short- and long-run impacts of unexpected mortality on psychosocial health in the context of a large-scale high-mortality natural disaster, the 2004 Indian Ocean earthquake and tsunami. The effects of the tsunami-related mortality measured at the community level are contrasted with the effects of individual-specific loss of close kin using population-representative longitudinal survey data from the Study of the Tsunami Aftermath and Recovery. In the short-run, two years post-tsunami, both community and individual-level mortality exposures are significant predictors of elevated depression and post-traumatic stress symtoms. In the longer-run, ten years post-tsunami, individual-level exposures are slightly attenuated but remain significant predictors of both psychosocial health measures; in contrast, community-level mortality predicts post-traumatic stress but not depression symptoms. Mortality is linked to smaller household sizes in the short- and long-run and to less social support in the long-run, although the latter effect differs substantially for males and females. The estimates adjust for other tsunami exposure measures and, in the individual-level analyses, we compare people living in the same community at the time of the tsunami who were exposed to the same community-level mortality rate.

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Across the globe, unexpected deaths of family and friends from wars, political and gang violence, natural disasters and novel infectious diseases upend the lives of millons of people every year. Demographers have a long history of estimating mortality rates, analyzing variations in those rates over time and across groups, and examining links between mortality and fertility (Smith-Greenaway et al., 2025). However, the field has contributed relatively little evidence on the causal impact of unexpected death on the health and well-being of family members. This is important as conflicts erupt across the globe, the frequency and severity of natural disasters increases and the threat of emerging infectious disease epidemics is omnipresent.

We contribute to the literature by analyzing how sudden and unexpected mortality from a natural disaster, the 2004 Indian Ocean Tsunami, affects psychosocial health, social support, and household size. We draw on unusual data collected as part of the Study of the Tsunami Aftermath and Recovery (STAR), a long-running panel survey in Indonesia. For the analyses presented here, we analyze 14,380 adults interviewed before and twice after the 2004 Indian Ocean tsunami.

The study design, in combination with the nature of the disaster, supports analysis of how unexpected mortality impacts the health and well-being of survivors over the short- and longer term. We contrast estimates of impacts of a community-level measure of exposure to mortality and an individual-level specific measure. The tsunami was a high-mortality disaster: it killed roughly five percent of the population of Aceh, the Indonesian province that sustained the greatest damage. However, mortality varied enormously across and within communities. In the hardest-hit communities, more than 50% of the population died in the tsunami. Within the same villages, some families lost multiple family members

while others lost none. We relate measures of individual well-being both to community-level mortality and to individuals' own losses of close kin. To identify the effects of exposure to mortality we control for other impacts of the disaster, at both the community and the individual-level, and for demographic and socio-economic background variables. Our results speak directly to questions about how individuals are affected by sudden and unexpected mortality in the short-run and about the extent to which those effects endure over ten years.

Mortality from Disasters and other Events

Year after year, disasters and conflicts result in deaths that are, in many cases, unexpected. Total mortality from these sources fluctuates unpredictably. For example, in 2025, it is estimated that natural disasters caused about 16,000 deaths, although since the 1980s the average annual number of deaths from natural disasters, computed based on total deaths in the decade, ranges from 40,000 to 80,000 per year (Ritchie et al., n.d.). Warning systems and other adaptive approaches have helped improve disaster survival at a given level of threat, but climate change and population redistribution is increasing the frequency and intensity of exposures to disasters and extreme weather, as well as to chronic conditions of flooding and heat. Most estimates of disaster-related mortality do not include deaths from indirect causes, but recent evidence suggests these are important (Young & Hsiang, 2024).

Beyond disasters COVID-19 is estimated to have caused some 16 million excess deaths between 2020 and 2022, reducing global life expectancy by between 1.6 and 1.8 years (Schumacher et al., 2024). Recent and ongoing conflicts, political upheavals and gang violence have resulted in high mortality levels. For example, life expectancy in Gaza is

estimated to have fallen from about 75.5 years to 40.5 years over the 12 months beginning in late 2023 (Guillot et al., 2025). Global estimates of conflict-related deaths vary across agencies, but the Armed Conflict Location and Event Dataset (ACLED) estimates approximately 240,000 conflict-related deaths in 2025. Exposure to conflict is also associated with elevated levels of mental disorders (Charlson et al., 2019).

Impacts of Unexpected Loss

Estimates of deaths from specific events and general classes of events serve as one measure of impact. Underlying these counts, deaths affect victims' families and the broader community through the grief they cause, and families are also affected by disruption to living arrangements and economic activties, patterns of resource sharing and time allocation, and activities of daily life (Easterlin & O'Connor, 2023; van den Berg et al., 2017). In the aftermath of sudden upticks in mortality, or the emergence of significant mortality disparities, researchers have increasingly calculated impacts in terms of the numbers of individuals affected by deaths of kin. In the United States, for every COVID-19 death, an estimated 9 individuals experienced the loss of a close family member (Verdery et al., 2020). Extending this multiplier approach to a wider range of countries suggests that for some contexts the risk of a kin loss doubled at points during the epidemic (Snyder et al., 2022).

Other work addresses questions of how death affects the psychological health of those most directly touched by a loss. Psychologists in particular have focused on these impacts, developing the umbrella construct of "complicated grief" to describe patterns of prolonged grief and symptoms of depression, anxiety, and post-traumatic stress (Hilberdink et al., 2023). Of particular relevance for our context, some studies focus on

"unnatural" deaths that are sudden and violent. Theoretically these may pose more difficulties psychologically if they challenge feelings of safety or are accompanied by more negative memories (Boelen et al., 2006, 2016). A meta-analysis of 25 studies unnatural losses revealed that nearly half of the bereaved adults experienced prolonged grief disorder, which is considerably higher than the 10% reported in an analysis of bereavement from non-violent causes of death (Djelantik et al., 2020). Two smaller scale studies consider families of tsunami victims. Fourteen months after the tsunami, almost 40% of bereaved relatives of Swedish victims reported symptoms of complicated grief (Johannesson et al., 2009). A study of 262 displaced tsunami survivors in Aceh documents higher risks of great distress as the number of household members killed rises (Souza et al., 2007).

Sociologists have also begun to examine bereavement and associated processes, emphasizing structural features of society that contribute to differential exposure and dimensions of variation in the effects of loss of kin and emphasizing the relevance of life course theory (Smith-Greenaway et al., 2025). A small literature considers links between family deaths from any cause and outcomes such as indicators of cardiometabolic health and social isolation (Donnelly et al., 2023; Garcia et al., 2025). With respect to "unnatural" deaths, Alburez-Gutierrez and colleagues have focused on conflicts, using demographic modelling to quantify the persistence of exposure to bereavements over the long-term (Acosta et al., 2026; Alburez-Gutierrez, 2022; Alburez-Gutierrez et al., 2024). This literature build on older strands of demographic and economic research that focused on the multidimensional implications of the HIV/AIDS epidemic in Africa (Ainsworth & Over, 1994).

Trauma Exposures associated with Disasters

In addition to mortality exposures, disasters frequently expose survivors to other traumatic experiences such as fearing for one's life or sensory experiences of destruction, with implications for well-being. Two recent papers conduct systematic reviews and meta-analyses of disasters and mental health (Dückers et al., 2026; Keya et al., 2023). Both find positive and statistically significant relationships between disaster exposure and poor psychosocial health. Dückers et al describe a pattern of exposure effects that diminish over time, but peak again about ten years after an event. However, few high quality studies provide data beyond four years. Both studies document substantial variation across studies in the estimated effect sizes. An earlier extensive review of 225 studies documents several consistencies across a wide range of contexts. In particular adverse effects of disaster exposures are stronger for women, for those of lower socioeconomic status, and for those with pre-disaster psychiatric histories (Norris et al., 2002).

Context, Data, and Methods

The disaster we study began when, at 7:58 am on December 26, 2004, an earthquake measuring an estimated 9.3 on the Richter scale occurred off the coast of Indonesia (Lavigne et al., 2013). One of the largest recorded earthquakes, it generated a 1,200 km rupture along the Sunda Trench, which created a series of giant waves that slammed into the island of Sumatra within 15 minutes of the earthquake, as well as into other countries bordering the Indian Ocean. In Aceh, the Indonesian province closest to the rupture, the tsunami engulfed communities along 800 kilometers of coastline and spread further inland as well. Although earthquakes are common in Indonesia, at the time, tsunamis were not thought to be a risk in the Indian Ocean where no early warning systems were in place

(Satake, 2014; Syamsidik et al., 2021). The disaster was both sudden and unexpected. The last major tsunami on the coast of mainland Aceh took place over 600 years ago (Monecke et al., 2008). Retreating water, a signature of an impending tsunami, was not interpreted as a sign of danger by the vast majority of the population and many ran towards rather than away from the shore.

In Indonesia, the country hardest hit, the 2004 tsunami killed some 160,000 people and displaced another 700,000. Property damage was estimated at $4.5 billion (BAPPENAS, 2005). The aggregate numbers mask enormous spatial variation. Some communities were largely destroyed while others were untouched, and some fell in between these two extremes. The variation was idiosnyncratic, even within relatively small geographic areas, because the force and height of the tsunami waves depended on a complex set of features including topography of the ocean floor and coastline (Degueldre et al., 2016; Lavigne et al., 2013; MCADOO et al., 2007). These features create variation in the tsunami's impacts that is plausibly exogenous to behaviors and structural features that typically pattern mortality.

The STAR study covers individuals who were living, before the tsunami, in districts with vulnerable coastlines in the Indonesian provinces of Aceh and North Sumatra. The baseline survey participants were part of a socio-economic survey, SUSENAS, conducted by Statistics Indonesia in February 2004, ten months before the Sumatran-Andaman earthquake. SUSENAS, which is designed to represent the population at the district (*kabupaten)* level, is extensively used in the scientific and policy communities and widely regarded as high quality.

The baseline for STAR includes all households interviewed in the February/March 2004 wave of SUSENAS (conducted 9-10 months before the tsunami) that were located in 13 districts

along the coast of Aceh and North Sumatra. We selected these districts for STAR because they were geographically positioned so that, ex ante, their coastlines were at risk of inundation from the tsunami waves. Within these districts all SUSENAS enumeration areas (EAs) were included in STAR so that the STAR sample is population-representative. There are 486 enumeration areas and 429 villages or neighborhoods in the STAR baseline.

We targeted 26,919 individuals of all ageswho were assessed in the pre-tsunami baseline, in the first follow up survey which we started in May 2005 in collaboration with Statistics Indonesia and with the assistance of their field supervisors. That follow-up took slightly more than 12 months to complete. Subsequent follow-ups were collected annually over the next four years, and then at 10 and 15 years after the tsunami. We collected individual and household-level data, drawing on and augmenting the baseline questionnaire. In each follow-up, every adult member of every household was eligible to be interviewed and information about every child was collected from a parent or the primary caretaker. Every member of the baseline household survey who survived the tsunami was eligible to be tracked and interviewed in their new location. Of the baseline respondents, 93% survived the tsunami and we have interviewed over 98% of those survivors in at least one post-tsunami follow-up.

For this paper we draw on interviews conducted in STAR2, roughly two years after the event, and interviews with the same people conducted in STAR6, roughly 10 years after the event. We restrict attention to baseline respondents who were aged 15 to 59 years at the time of the tsunami. We have data on 91% of those respodents in the 2-year follow-up and 89% in the 10-year follow-up. The analytical sample covers 85% of all age-eligible respondents.

We investigate the relationships between exposure to mortality and psychosocial health over the short and long-run. In addition, to place this evidence in context, we examine indicators of social support. We begin with two dimensions of psychosocial health: depression and measures of post-traumatic stress reactivity, both of which are well-documented sources of psychological distress after disaster exposures (Keya et al., 2023).

Depressive symptoms are measured with the Center for Epidemiologic Studies-Depression (CESD) instrument, a 20-item screener designed to measure depressive symptomatology (Radloff, 1977). The absence of a particular symptom is scored as 0 and while a symptom frequently felt is scored as 3. The maximum depression score is 60.

The stress measures are constructed from information on post-traumatic stress reactions (PTSR), which were assessed using seven items from the 17-item PTSD Checklist Civilian Version (PCL) (Weathers et al., 1993)

Adult respondents in the post-tsunami surveys were asked about specific symptom items that in combination covered three distinctive psychological domains of post-traumatic stress: re-experiencing the event, avoidance and numbing, and hyper-arousal. The PTSR scale ranges from 0 (absence of any reactions) to 21 (all reactions experienced frequently) (Frankenberg et al., 2008). Higher values reflect higher post-traumatic stress reactivity, and thus poorer psycho-social health. [1]

We turn next to two indicators related to social support measured after the tsunami. The first is household size. Although household size does not reflect well-being, it is a

[1] For those respondents who did not complete the PTSR or CESD battery in STAR2, we use their reports from the preceding waves for PTSR and the following wave (for CESD since CESD was first asked in STAR2). Restricting the sample to those respondents who were assessed in STAR2 has no impact on the substantive results or any of the conclusions.

potential intermediary factor in a context where the tsunami resulted in both deaths and destruction of housing, the built and natural environment. The combination of deaths and reduced housing stock affected living arrangements. Ten years after the tsunami, the housing stock and much of the infrastructure was almost entirely rebuilt as a part of a major reconstruction effort which, along with migration, resulted in a further reorganization of living arrangements (Laurito et al., 2022). The impacts of mortality on household size two years and then ten years post-tsunami provide a window into the evolution of these dynamics in combination with individual and family choices.

Second, in the ten year post-tsunami follow-up we included a set of questions to assess respondents' perceptions of social support. These questions are drawn from the RAND Social Support Inventory (Sherbourne & Stewart, 1991). We draw on 10 items from the inventory that cover emotional and tangible support and positive social interaction. Questions ask about whether others are available for such activities as cooking meals, talking about problems, and just relaxing. Responses were collected using a 5-point Likkert-based scale ranging from " no support available" (assigned a score of zero) to "support always available" (assigned a score of 4). The resulting index varies from 0 to 40.

Measures of tsunami-related exposures, are constructed at the community and individual level. At the community level, our mortality measure is the percentage of baseline respondents who died as a result of the tsunami in the respondent's community of residence at the time of the tsunami. Mortality rates are correlated with the extent of damage wrought by the tsunami which we take into account with a trichotomous classification of damage we constructed using satellite imagery in conjunction with reports of damage by survey supervisors and village leaders in the first post-tsunami follow-up

(Frankenberg et al., 2011; Gray et al., 2014). We distinguish communities that sustained heavy damage and some damage from those that had little or no damage. The models include sub-district (*kecamatan*) fixed effects as well as distance to the coast and elevation of the community of residence so that pre-tsunami differences between communities do not contaminate the estimates.[2]

A contribution of this work is the investigation of the impacts of mortality measured at both the community- and individual-level. The number of close kin lost in the tsunami is our individual-level measure. Close kin consists of a spouse, mother, father, daughter or son. In earlier work we estimated that among children under 15 who survived, 10% lost a parent, and that among married adults who survived, 10% lost a spouse (Frankenberg et al., 2011). Our measure understates exposure to mortality to the extent that people also lost siblings, more distant family, and friends and neighbors. We operationalize the measure with two indicator variables, loss of one close family member and loss of two or more close family members, as we hypothesize that losing multiple family members simultaneously may increase distress. In other work we have considered the impact of loss of parents for children and loss of a spouse for adults (Cas et al., 2014; Frankenberg et al., 2020). In this study, we investigate the impacts of mortality within one's family, more generally. In order to isolate individual-specific from community-level exposures, we include community fixed effects in the models so that the impacts of loss of close family members can be interpreted as conditional on death, damage and destruction at the community level.

[2] We have documented that there are no differences in pre-tsunami characteristics of those who were exposed relative to those not exposed within kecamatan after controlling elevation and distance to the coast. See, for example, (Ingwersen et al., 2023).

To further isolate the impact of loss of close family members, we include indicators for whether a respondent saw or heard the waves come ashore and whether their home was damaged or destroyed by the disaster. As control variables, we include measures of sex, age and years of education of the respondent as well as a measure of pre-tsunami resource availability, the logarithm of monthly per capita household expenditure recorded in the baseline survey.

We first present summary statistics for the analytical sample and examine how the exposure measures vary across communities classified by the degree of tsunami damage. We then report estimates from multivariable regression models that relate our outcome variables (depression, PTSR, household size and social support), to our community-level indicators of mortality and destruction, and to our individual-level measures of loss of close kin, whether they saw or heard the tsunami water, and damage or destruction of housing. Heteroskedasticity consistent standard errors are clustered at the level of the enumeration area in all models.

Results

Summary statistics are provided in Table 1 for the entire sample and stratified by the three damage zones. Symptoms of depression are about the same in 2006 and 2014 overall, and in each of the damage zones (around 14 out of a maximum score of 60). Symptoms of PTSR are almost three times higher in 2006 relative to 2014 overall. The symptoms are highest, particularly in 2006, among those who were, at the time of the tsunami, living in areas that were heavily damaged (which accounts for about 20% of the sample). Household size is 4.8 in 2006 but falls to 3.8 in 2014, with household size being slighty smaller in both waves in communities that were heavily damaged. The index of

social support, which was only measured in 2014, averages 33.7 out of 40 and it is also about the same across damage zones. For all the indicators, including those that do not vary across damage zones, there is considerable variation in the sample, as shown by the standard deviations in column 2.

Turning to exposures measured at the community level, overall 6.13% of the population died, with the deaths largely confined to the heavily damaged areas in which 28% of the population died. There were very few tsunami-related deaths in the other areas. At the individual level, for the average respondent, 0.12 close kin who were lost. Over 90% did not lose close kin, while 5.5 % lost one close family member and 3% lost two or more family members. Loss of kin is also largely confined to those who were living in heavily damaged areas: over a quarter lost at least one family member and the average person who was living in those communities lost 0.5 members. Similarly, over 8% saw or heard the waves, but in in heavily damaged areas this rises to almost 30%.

Damage and destruction of housing was far more widespread: overall 41% reported housing damage, rising to 81% of those in heavily damaged areas. This reflects the effects of both the tsunami waves and the earthquake that spawned the tsunami.

In terms of individual background characteristics, about 46% of the sample is male, the average respondent is about 33.4 years old and has 8.4 years of schooling. The fraction of the sample that is male is slightly higher among those who were living in heavily damaged areas because females were more likely to die in the tsunami. This also contributes to the higher education levels among those people: taller adults (who also tend to be better educated) are more likely to have survived the tsunami (Frankenberg et al., 2011). Part of the education differences reflects higher levels of resources before the

tsunami in the heavily damaged areas as indicated by the logarithm of per capita household expenditure. This is primarily driven by the fact that Banda Aceh, the capital of Aceh, sustained substantial damage. It is also a reason why we draw comparisons within kecamatan and enumeration areas in the regression models.

Depressive symptoms and PTSR

In Table 2 we present the results from multivariable regressions in which depressive symptoms and PTSR are regressed on the community-level exposure measures, with controls included for sex, age, pre-tsunami resources, and years of education along with kecamatan fixed effects. We convert the depression and PTSR scores to z-scores so that coefficient estimates can be interpreted in terms of standard deviation impacts which facilitates comparisons across the measures. For both measures, higher scores indicate poorer mental health, and thus negative coefficients imply better outcomes. Models are estimated separately for 2006 and 2014.

Beginning with the damage level of the community, being from communities that were damaged in the disaster is not associated with higher levels of depression, but is associated with higher levels of PTSR in both years particularly among those who were living in communities that sustained heavy damage. Conditional on the extent of damage, the fraction of the population that died is strongly related to higher levels of depression in 2006 and to PTSR in both years. Whereas the differences in PTSR across the damage zones decline over time, the impact of the fraction that died increases over time (although that difference is not statistically significant). In contrast, the impact of community-level mortality on depression is not long-lasting: it has completely faded by 2014.

We also present results of the models that examine mortality and tsunami exposure measured at the individual level, drawing comparisons between those who were exposed and those who were not exposed among those living in the same community at the time of the tsunami and, therefore, experienced the same community-level mortality and destruction. We interpret the estimates of individual exposures as conditional on community-level exposures.

As noted above, we contrast those who did not lose a close family member with those who lost one family member and with those who lost two or more family members. (The test for the joint significance of losing any kin is reported at the foot of the table.) Each indicator of loss of kin is a strong predictor of elevated depression and PTSR scores in 2006 and they are jointly significant. The coefficients are larger for the measure of loss of two or more family members. These effects persist in 2014 and are jointly significant, although the coefficient on loss of two or more family members shrinks in size. Our other markers of exposure (seeing or hearing the water and damage and home damage) are also positive predictors of depression and PTSR in 2006. By 2014 neither of these is predictive of depression and although both predict PTSR, the coefficients are much smaller and significance is only at 10% for house being damaged or destroyed.

The comparison of the results using community-level mortality and individual-level loss of kin highlights a strength of the STAR study design. The effect of community-level mortality has faded out by 10 years post-tsunami for the depression score but remains significant for PTSR. However, the impact of individual-level loss of family remains large and statistically significant through the entire study period for depression and PTSR. Few studies measure individual-specific exposures and rely on community-level measures: they

are likely to understate the long-term impacts of exposure to unanticipated mortality on psychosocial health.

Estimates for the individual characteristics included in the model are reported in the lower part of Table 2. Consistent with evidence in the literature, males' reports of symptoms of depression and PTSR are substantially lower than females' reports in each year. Variation in symptom levels by age differs between 2006 and 2014, and across the the symptom types. In 2006, the youngest respondents in the sample (aged 15-24 years at the time of the tsunami) have higher levels of depression but lower levels of PTSR than the oldest respondents (those aged 50-59 years, who serve as the reference group). PTSR levels (but not depression) are also lower for those aged 25-34 years. No differences in symptom levels emerge for those aged 35 to 49 years, relative to their older counterparts. By 2014, however, symptoms of depression and PTSR are lower for all three age groups relative to the oldest group, and there is a clear positive age gradient in depression and PTSR symptoms, suggesting older respondents lag their younger peers in recovering from the imacts of the tsunami. Levels of economic resources at the time of the tsunami, measured by ln(per capita household expenditure) are positively related to depression but negatively related to PTSR in 2006, but not significantly related to either marker by 2014. Education effects are small in magnitude and not significant at a 5% size of test.

Household size and social support

Table 3 displays results for household size and levels of social support reported by each respondent. Social support is also converted to a z-score. At the community level, greater physical damage is associated with significantly larger household sizes in 2006 and 2014, although the differences are not significant in 2006. However higher community-

level mortality is associated with significantly and substantially smaller household sizes in 2006 which declines in magnitude but persists through 2014. Similar patterns are apparent within communities with those who lost close kin in the tsunami having smaller household sizes in both 2006 and 2014, although the long-term effect is significant only for those who lost 2 or more close kin. The fact that these mortality effects at the community and individual level persist over 10 years indicates the long-lasting impacts of the tsunami on families and their living arrangements. In contrast, non-mortality exposure (seeing the tsunami waves) only has a short-term impact (which may be correlated with loss of non-kin). There is no evidence that household size varied with whether the home was damaged or destroyed.

For social support (columns 5 and 6) the fraction in the community that died is negatively associated with levels of support (at a 10% size of test), and the level of community damage is not. At the individual level loss of one family member is correlated with reports of more social support, but losing two or more is correlated with lower reports of social support indicating a complex pattern of support that is not linear in mortality exposure. As with the measures of psychosocial health, mortality is persistently associated with these outcomes.

Demographic and socioeconomic characteristics are related to household size in both years. Males live in larger households in 2014 but there are no differences in 2006. The signs on the coefficients for different age groups (relative to those age 50-59) are mixed in 2006, but by 2014 household sizes are larger for each of the younger age groups than they are for those 50-59. Although resource levels were not strongly associated with

psychosocial health, those who are better educated and those who had more resources pre-tsunami live in smaller households.

For social support patterns are somewhat different. Males report higher levels of social support and the coefficients are large relative the coefficients for other indicators. Those in the middle age groups (covering ages 25 to 49) report higher levels of support than older respondents. Rising levels of education are positively related to social support but levels of pre-tsunami per capita expenditure are not.

Stratifications by sex

Given the associations of respondents' sex to the outcomes we consider, Table 4 reports the results for the individual exposures stratified by sex for depression and PTSR.

In 2006 women's levels of depression are much more strongly related to loss of one, family member than are men's levels of depression. For PTSR the differences by sex are not statistically significant. This is also the case for seeing or hearing the waves and for experiencing destruction or damage of a house (both of which affect depression and PTSR for both sexes).

By 2014, there are no differences by gender in the association between loss of close kin and depression. However, loss of one kin is a strong predictor of PTSR for females but not for males. Neither seeing/hearing the water or damage/destruction of housing is predictive of depression or PTSR for males or females.

Table 5 relates individual exposure measures, stratified by sex, to household size and social support. Loss of family members is strongly correlated with household size in 2006 for both males and females and the sizes of the coefficients are similar. In 2014 losing

two or more family members is associated with smaller household sizes for males but not for females. Loss of one family member is not significant for males or females.

An intriguing difference by sex relates to social support in 2014. Both males and females who have lost one family member report higher levels of social support than those whose without a family loss, although the effect is not significiant for males. Social support is significantly lower among males who lost two or more family members, but there is no impact of two or more family deaths for females.

The relationships between age and household size and family support also operate differently for males and females. In 2006, younger males (both those 15-24 and 25-34 years) are in smaller households than other males but by 2014, this is true only for the youngest males and those in the middle age groups live in significantly larger households. For females, in 2006 and 2014 those in the youngest and middle age groups live in significantly larger households than the oldest women (aged 50-64 years). For the youngest men, the pattern extends to social support in 2014, while women aged 15-34 years report more social support than the oldest women. These differences in age effects suggest that patterns around rebuilding family and living arrangements differ considerably by sex.

Higher levels of pre-tsunami resources are associated with smaller household sizes, especially in 2006, but there are no differences by sex. Social support levels are positively affected by education and levels of resources, slightly more so for men.

Discussion

Over a lifetime deaths of family members and friends are inevitable, but many factors shape how individuals experience grief (Hilberdink et al 2023). Understanding the

consequences of deaths for health and well-being, their duration, and how they manifest differently across individuals is important, especially in the aftermath of the COVID-19 pandemic and recurring high-mortality disasters and conflicts (Smith-Greenaway et al., 2025).

Drawing on longitudinal data collected before and at multiple points after a sudden and unexpected natural disaster, we examine the impacts of mortality at the community level and deaths of close family members. Four dimensions of this work are distinctive. First, because the disaster was unexpected and its impacts were locally idiosyncratic, the deaths were also unexpected, providing greater confidence that the estimates can be interpreted as causal. Second, because individuals and households were first interviewed before the disaster, we are able to measure exposure to mortality precisely at both the community and the individual level while controlling for other potentially relevant exposures, reinforcing the causal interpretation. Third, we relate mortality exposures to two measures of psychosocial well-being, depressive and post-traumatic stress symptoms, along with perceptions of social support, and household size. Fourth, we draw on interviews conducted two and ten years after the disaster, which provides insights into the short-term impacts of deaths and a longer-term perspective than is typically possible.

Our most important result is that the impacts of exposure to mortality are strong and persistent over a decade. At two and at ten years post-disaster, symptoms of depression and post-traumatic stress are significantly higher for individuals who lost close kin in the tsunami. The community-level mortality rate is also strongly related to both symptoms two years after the disaster, but only to post-traumatic stress after ten years. Population psychosocial well-being is affected both by family-level losses and by mortality

in the broader community. Exposure to mortality also affects household size in the short and long-term and social support measured in 2014. At a methodological level, the results underscore the value-added of measuring mortality at both the individual and community levels and tracing these impacts over many years.

In contrast to mortality, most of our other measures of exposure—damage to property, seeing or hearing the tsunami waves—are predictive of psychosocial well-being in 2006, but the effects are muted and often not statistically significant by 2014. The longer-run impacts on household size and perceptions of social support are also muted.

In addition to exposures, sex and age are related to all four outcomes we consider. Males report fewer symptoms of poor psychosocial health than females. For the most part, the symptom levels of younger individuals are lower relative to older individuals (an exception to this age pattern is depression in 2006). By 2014, a strong pattern of poorer psychosocial health and lower perceptions of social support has emerged among older individuals.

To further explore the role of sex we estimated the regressions separately for males and females. In these models mortality exposures are more strongly related to women's symptoms of depression than to men's. This is not true for PTSR or household size, where the mortality exposure coefficients are similar for males and females. Nor is it true for social support, where men's perceptions are significantly lower when they have lost two or more kin, whereas women's perceptions are not.

Consistent with the results we report, other research documents important and lasting psychological consequences of exposure to disasters, although in some cases loss of kin is particularly important (Raker et al., 2019) while in other cases economic disruption

stands out (Kino et al., 2021). The role of household size as both an outcome after a disaster and a mechanism through which disasters may affect psychosocial well-being has been described in the context of the 2011 earthquake and tsunami in Japan (Sun & Yan, 2020). Studies differ across many dimensions and there are relatively few long-term follow-ups of disaster-exposed population-representative samples, making explicit comparisons difficult. That several studies do document long-lasting effects of exposures points to the relevance of mental health services as part of recovery programs, although constraints of money and manpower complicate fully embedding effective culturally-relevant services in the aftermath of a devastating disaster.

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Table 1. Summary statistics: Outcomes, Exposures and Controls

	All sample		Means by community damage level		
	Mean	Std dev	Heavy	Moderate	None
	[1]	[2]	[3]	[4]	[5]
A. Outcomes					
1. Depression index (range: 0-60)					
2006	13.7	7.1	14.1	13.6	13.6
2014	14.2	6.0	14.0	14.1	14.5
2. PTSR index (range: 0-21)					
2006	4.4	3.8	5.5	4.4	4.0
2014	1.6	2.8	1.8	1.5	1.6
3. HH size					
2006	4.8	2.1	4.3	4.9	4.9
2014	3.8	1.7	3.5	3.9	3.8
4. Social support index (range: 0-40)					
2014	33.7	7.5	33.5	33.2	34.7
B. Exposures					
1. Community of residence at time of tsunami					
1. Extent of damage (%age)			19.8	52.1	28.2
2. Died because of tsunami (%age)	6.13	17.27	27.59	0.93	0.69
2. Individual					
1. Number of close kin lost	0.12	0.47	0.49	0.06	0.05
2. Lost close kin (%age)					
None	91.6		71.4	94.8	95.9
Lost 1 family member	5.5		14.4	4.2	3.4
Lost 2 or more close kin	3.0		14.2	1.1	0.7
3. Saw or heard the waves (%age)	8.2		29.7	5.6	2.2
4. House damaged or destroyed (%age)	40.7		81.3	41.9	19.0
C. Individual/HH characteristics					
Male (%age)	46.1		48.3	46.1	44.9
Age (years)	33.4	11.7	33.1	33.6	33.1
Education (completed years)	8.4	3.9	9.4	8.1	8.5
ln(per capita HH expenditure pre-tsunami)	12.6	0.6	12.8	12.6	12.5
Sample size	14,380		2,840	7,486	4,054

Table 2. Mortality, tsunami exposures, depression and post-traumatic stress: 2 & 10 years post-tsunami

Measured in	2006				2014			
	Depression		PTSR		Depression		PTSR	
Covariates	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
1. Community-level exposures								
Indicator variables								
Heavy damage	-0.04		0.23**		0.03		0.14*	
	[0.05]		[0.05]		[0.07]		[0.06]	
Some damage	-0.01		0.08**		0.04		0.07*	
(Reference: No damage)	[0.03]		[0.03]		[0.05]		[0.03]	
Fraction popn died	0.80**		0.64**		0.07		0.86**	
	[0.13]		[0.13]		[0.12]		[0.14]	
2. Individual-level exposures								
Indicator variables								
Lost 1 close kin		0.10**		0.15**		0.15**		0.16**
		[0.04]		[0.04]		[0.04]		[0.05]
Lost 2 or more close kin		0.19**		0.23**		0.14*		0.15*
(Reference: Lost none)		[0.06]		[0.07]		[0.06]		[0.06]
Heard/saw tsunami waves		0.15**		0.25**		0.00		0.09*
		[0.04]		[0.04]		[0.03]		[0.04]
House damaged/destroyed		0.22**		0.24**		0.02		0.05+
		[0.03]		[0.03]		[0.03]		[0.03]
3. Individual and HH characteristics								
(1) if male	-0.17**	-0.17**	-0.14**	-0.15**	-0.20**	-0.20**	-0.17**	-0.18**
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]
(1) If aged 15-24y	0.14**	0.14**	-0.16**	-0.17**	-0.27**	-0.25**	-0.26**	-0.26**
	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]
(1) if aged 24-34y	0.01	0.02	-0.09**	-0.09**	-0.21**	-0.19**	-0.15**	-0.15**
	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]
(1) if aged 35-49y	0.00	0.00	-0.02	-0.03	-0.14**	-0.12**	-0.12**	-0.10**
(Ref: Aged 50-64y)	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]
Education (completed years)	0.00	0.00	0.00	0.00	0.00	0.00	-0.00+	0.00
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ln(per capita expenditure)	0.04+	0.05*	-0.05**	-0.05*	-0.03	0.03	-0.03	-0.01
	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.02]	[0.03]
Constant	-0.38	-0.74*	0.75**	0.63*	0.67*	-0.14	0.69*	0.34
	[0.28]	[0.30]	[0.26]	[0.28]	[0.30]	[0.28]	[0.27]	[0.33]
F(damage/kin died)	13.14	27.48	20.36	40.54	0.35	3.98	17.60	5.86
p-value	0.00	0.00	0.00	0.00	0.72	0.00	0.03	0.00
F(all exposures)	21.20	28.66	16.02	28.28	16.48	20.52	22.16	19.27
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R^2	0.17	0.02	0.11	0.03	0.10	0.02	0.10	0.02
Sample size	14,380	14,380	14,380	14,380	14,380	14,380	14,380	14,380

Note: Dependent variables specified as z scores. Robust standard errors in brackets take into account clustering at community level. ** p<0.01, * p<0.05, + p<0.1

Table 3. Mortality, tsunami exposures, household size and social support after the tsunami

Measured in	2006 HH size		2014 HH size		2014 Social support	
Covariates	[1]	[2]	[3]	[4]	[5]	[6]
1. Community-level exposures						
Indicator variables						
Heavy damage	0.30		0.36**		-0.01	
	[0.20]		[0.10]		[0.05]	
Some damage	0.07		0.15*		-0.04	
(Reference: No damage)	[0.09]		[0.06]		[0.03]	
Fraction popn died	-2.52**		-0.96**		-0.23+	
	[0.33]		[0.20]		[0.12]	
2. Individual-level exposures						
Indicator variables						
Lost 1 close kin		-0.43**		-0.09		0.09*
		[0.08]		[0.07]		[0.04]
Lost 2 or more close kin		-0.78**		-0.27**		-0.11*
(Reference: Lost none)		[0.12]		[0.09]		[0.06]
Heard/saw tsunami waves		-0.18*		-0.03		-0.07+
		[0.07]		[0.05]		[0.03]
House damaged/destroyed		-0.05		-0.05		0.00
		[0.07]		[0.04]		[0.02]
3. Individual and HH characteristics						
(1) if male	0.01	0.00	0.06*	0.04+	0.22**	0.22**
	[0.03]	[0.03]	[0.02]	[0.02]	[0.02]	[0.02]
(1) If aged 15-24y	0.06	-0.08	0.34**	0.26**	-0.03	-0.02
	[0.07]	[0.06]	[0.05]	[0.05]	[0.03]	[0.03]
(1) if aged 24-34y	-0.11+	-0.18**	1.24**	1.16**	0.07*	0.07*
	[0.06]	[0.06]	[0.05]	[0.05]	[0.03]	[0.03]
(1) if aged 35-49y	0.44**	0.38**	0.90**	0.85**	0.07*	0.06*
(Ref: Aged 50-64y)	[0.06]	[0.06]	[0.05]	[0.05]	[0.03]	[0.03]
Education (completed years)	-0.02**	-0.01	-0.01*	0.01	0.03**	0.03**
	[0.01]	[0.01]	[0.00]	[0.00]	[0.00]	[0.00]
ln(per capita expenditure)	-0.86**	-1.20**	-0.31**	-0.47**	-0.01	0.03
	[0.07]	[0.08]	[0.04]	[0.05]	[0.02]	[0.02]
Constant	15.74**	20.05**	6.93**	8.96**	-0.29	-0.71*
	[0.88]	[1.04]	[0.55]	[0.65]	[0.25]	[0.30]
F(damage/kin died)	19.56	15.13	10.49	2.849	2.026	4.318
p-value	0.30	0.00	0.00	0.00	0.30	0.00
F(all exposures)	42.17	52.11	84.95	86.22	36.26	37.02
p-value	0.00	0.00	0.00	0.01	0.00	0.00
R^2	0.143	0.072	0.146	0.082	0.121	0.028
Sample size	14,380	14,380	14,380	14,380	14,380	14,380

Note: Dependent variables specified as z scores. Robust standard errors in brackets take into account clustering at community level. ** p<0.01, * p<0.05, + p<0.1

Table 4. Mortality, tsunami exposures, depression and post-traumatic stress by sex

Measured in	2006				2014			
	Depression		PTSR		Depression		PTSR	
	Male	Female	Male	Female	Male	Female	Male	Female
Covariates	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
1. Individual-level exposures								
Indicator variables								
Lost 1 close kin	0.00	0.16**	0.13*	0.17**	0.15**	0.16*	0.05	0.24**
	[0.06]	[0.05]	[0.06]	[0.05]	[0.06]	[0.06]	[0.06]	[0.07]
Lost 2 or more close kin	0.19*	0.17*	0.30**	0.18+	0.11	0.16+	0.11	0.16
(Reference: Lost none)	[0.09]	[0.08]	[0.09]	[0.09]	[0.09]	[0.08]	[0.09]	[0.10]
Heard/saw tsunami waves	0.14**	0.18**	0.22**	0.32**	0.03	-0.05	0.05	0.12+
	[0.05]	[0.06]	[0.05]	[0.06]	[0.05]	[0.05]	[0.05]	[0.06]
House damaged/destroyed	0.15**	0.28**	0.24**	0.25**	0.02	0.03	0.05	0.04
	[0.04]	[0.04]	[0.04]	[0.03]	[0.04]	[0.04]	[0.03]	[0.03]
2. Individual and HH characteristics								
(1) If aged 15-24y	0.17**	0.12**	-0.16**	-0.18**	-0.16**	-0.34**	-0.23**	-0.26**
	[0.04]	[0.04]	[0.04]	[0.05]	[0.04]	[0.05]	[0.04]	[0.05]
(1) if aged 24-34y	0.06	-0.02	-0.05	-0.12**	-0.12**	-0.28**	-0.12**	-0.17**
	[0.04]	[0.04]	[0.04]	[0.05]	[0.04]	[0.05]	[0.04]	[0.05]
(1) if aged 35-49y	0.04	-0.03	0.02	-0.06	-0.03	-0.23**	-0.07+	-0.12**
(Ref: Aged 50-64y)	[0.04]	[0.04]	[0.04]	[0.04]	[0.04]	[0.04]	[0.04]	[0.05]
Education (completed years)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01*
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ln(per capita expenditure)	0.09**	0.03	-0.03	-0.07*	0.05+	0.01	-0.01	-0.01
	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.03]	[0.04]
Constant	-1.44**	-0.49	0.17	0.96*	-0.74+	0.21	0.07	0.45
	[0.42]	[0.40]	[0.39]	[0.38]	[0.40]	[0.36]	[0.40]	[0.46]
F(exposures)	8.59	23.32	22.51	23.70	2.33	2.30	1.41	4.64
p-value	0.00	0.00	0.00	0.00	0.06	0.06	0.23	0.00
R^2	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01
Sample size	6,624	7,756	6,624	7,756	6,624	7,756	6,624	7,756

Note: Dependent variables specified as z scores. Robust standard errors in brackets take into account clustering at community level. ** p<0.01, * p<0.05, + p<0.1

Table 5. Mortality, tsunami exposures, household size and social support after the tsunami by sex

Measured in	2006 HH size		2014 HH size		2014 Social support	
	Male	Female	Male	Female	Male	Female
Covariates	[10]	[11]	[12]	[13]	[14]	[15]
1. Individual-level exposures						
Indicator variables						
Lost 1 close kin	-0.43**	-0.40**	-0.03	-0.06	0.09	0.11*
	[0.12]	[0.09]	[0.10]	[0.08]	[0.06]	[0.05]
Lost 2 or more close kin	-0.82**	-0.72**	-0.32**	-0.20	-0.20*	-0.01
(Reference: Lost none)	[0.18]	[0.14]	[0.11]	[0.13]	[0.08]	[0.07]
Heard/saw tsunami waves	-0.20*	-0.08	-0.09	0.06	0.00	-0.12*
	[0.09]	[0.11]	[0.07]	[0.07]	[0.05]	[0.05]
House damaged/destroyed	-0.09	-0.02	-0.08	0.01	-0.01	0.01
	[0.09]	[0.08]	[0.06]	[0.05]	[0.04]	[0.03]
2. Individual and HH characteristics						
(1) If aged 15-24y	-0.33**	0.17*	-0.35**	0.87**	-0.18**	0.12**
	[0.09]	[0.09]	[0.07]	[0.07]	[0.04]	[0.04]
(1) if aged 24-34y	-0.64**	0.24**	0.74**	1.61**	0.05	0.12**
	[0.08]	[0.08]	[0.07]	[0.07]	[0.04]	[0.04]
(1) if aged 35-49y	0.04	0.75**	0.86**	0.92**	0.07+	0.06
(Ref: Aged 50-64y)	[0.08]	[0.08]	[0.06]	[0.07]	[0.04]	[0.04]
Education (completed years)	-0.03**	0.01	-0.01	0.01	0.03**	0.02**
	[0.01]	[0.01]	[0.01]	[0.01]	[0.00]	[0.00]
ln(per capita expenditure)	-1.22**	-1.21**	-0.49**	-0.43**	0.07+	0.00
	[0.10]	[0.09]	[0.06]	[0.06]	[0.03]	[0.03]
Constant	20.76**	19.70**	9.70**	8.11**	-0.94*	-0.33
	[1.25]	[1.07]	[0.76]	[0.72]	[0.44]	[0.37]
F(exposures)	7.67	9.54	3.62	0.80	2.53	2.91
p-value	0.00	0.00	0.01	0.53	0.04	0.02
R^2	0.08	0.08	0.12	0.10	0.02	0.01
Sample size	6,624	7,756	6,624	7,756	6,624	7,756

Note: Dependent variables specified as z scores. Robust standard errors in brackets take into account clustering at community level. ** p<0.01, * p<0.05, + p<0.1