Understanding the impacts of a natural disaster: Evidence from the 2004 Indian Ocean tsunami.

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March 2023

Abstract: Measuring impacts of extreme events on population well-being is complicated if data are not representative of the pre-event at-risk population or a representative sample of the population is not followed post-event. The sources and nature of some important biases are documented using data from the Study of the Tsunami Aftermath and Recovery (STAR) which documents the evolution of population well-being before and after a major natural disaster, the 2004 Indian Ocean tsunami. The baseline, collected 10 months before the tsunami, is representative of the at-risk population. Respondents have been followed and re-interviewed multiple times in the fifteen years since the tsunami achieving high follow-up rates. We empirically document the importance of construct samples that represent the pre-event at-risk population, rather than an opportunistic sample of those in the vicinity of the event. Pre-event characteristics condition where and in what circumstances people live post-event. Post-event well-being is associated with post-event living conditions in the short-term, and that over time, the link weakens between short-term living arrangements and post-event well-being. Failure to follow-up all respondents, especially those who move away from the location of the event, yields biased estimates of impacts of the event.

Acknowledgements: Support from the National Institute for Child Health and Human Development (R01HD052762, R01HD051970, R03HD071131, P2C HD050924), the National Institute on Aging (R01AG031266), the National Science Foundation (CMS-0527763), the Hewlett Foundation, the World Bank, and the MacArthur Foundation (05-85158-000) is gratefully acknowledged.

Across the globe, human and animal populations and the ecosystems in which they reside are experiencing pressures from climate change, both from slow-onset gradual changes and from rapid-onset events that are often large-scale and more intense. These pressures affect the health and resources of those exposed to them, but at present our knowledge of which outcomes are affected, the magnitude of the effects and their longevity is limited.

For scientists who study human and natural systems and the links between them, one key challenge to understanding the impacts of a changing climate is the lack of "pre-onset" information against which to compare the evolution of various phenomena over time and thereby quantify the effects of climate change on outcomes of interest. Samples constructed without regard to the populations in place before a change, that rely only on data from those still in place after a change, or that focus on residents displaced only to organized highly visible camps and shelters, risk mischaracterizing an event's impact on the entire population. From a methodological perspective, it is important to understand how estimates of the impacts of contextual change may be biased by samples that miss particular population sub-groups. On one hand, it may include people who are most able to adapt to the change and move away before or immediately after the event. On the other hand, those most deleteriously impacted by the event, including those who die, may be missed. The magnitude and direction of this bias is not obvious.

This paper investigates the nature and importance of these biases for understanding the impacts on well-being in both the short- and longer-term of a large-scale natural disaster, the 2004 Indian Ocean earthquake and tsunami. We use data from a large-scale household survey collected on the island of Sumatra, Indonesia. Importantly, the survey is longitudinal, spanning the period before and after the 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 the coastline of the Indonesian province of Aceh. The tsunami completely destroyed some communities but left other comparable, nearby coastal communities relatively untouched. Although the tsunami was not a consequence of climate change, the waves flooded coastal areas and pushed water up river basins, generating a surge of saltwater over land in the way that storm surges often accompany tropical cyclones.

The Study of the Tsunami Aftermath and Recovery (STAR) is ideally-suited for this research. In 2004, ten months before the tsunami, Statistics Indonesia conducted a large socioeconomic survey (SUSENAS) throughout Indonesia, as a part of an annual survey that is population-representative at the *kabupaten* (district) level. After the tsunami inundated the western coastline of the province of Aceh and, to a lesser extent, North Sumatra, we worked with Statistics Indonesia to field a longitudinal follow-up. The goal was to recontact every surviving SUSENAS respondent who was living in any of the 11 districts that had a potentially vulnerable coastline in the provinces of Aceh and North Sumatra.

Two features of STAR are unusual but critically important for this research investigating biases that arise from using non-representative samples to understand the effects of disasters. First, our pre-tsunami baseline is representative of the entire at-risk population and thus an ideal vehicle for a longitudinal study that tracks the lives of survivors in the aftermath of the tsunami. Second, we continue to follow survivors to this day. In each survey round, we track each target respondent to their location of residence, including those who were displaced or chose to move after the tsunami. Many have moved multiple times to places in Aceh, North Sumatra and other provinces across Indonesia. We attempt to interview every respondent in every follow-up. We are, therefore, able to provide scientific evidence on the value of this design for drawing conclusions about the short and longer-term impacts of exposure to a large-scale natural disaster.

CONTEXT

At 8 a.m. on Sunday, December 26, 2004, one of the most powerful earthquakes in recorded history occurred 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 coast of Sumatra about 15 minutes later, eventually reaching across the 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 Sumatra, was hardest hit. Along 800 kilometers of coastline 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 coastal communities that were otherwise similar and 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 Aceh's west coast, 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. 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-- a benefit for those who sell food or housing but not for net food purchasers or renters.

The tsunami was followed by an unprecedented outpouring of financial support from governments, aid agencies, international and domestic NGOs, and private citizens. Pledges to Indonesia totaled more than US$7 billion (Nicol, 2013). Of the total amount committed to Indonesia, US$ 1.5 billion were in excess of the estimated cost of the reconstruction, which allowed the Indonesian government to set the goal of "building back better."

The tsunami resulted in the destruction of livelihoods and tremendous economic stresses for many along with disruption to their social networks (Frankenberg et al, 2008; Gillespie et al, 2014). Many of the people living in the hardest hit areas moved away to temporary housing in barracks or camps, for example, or to private homes (Gray et al. 2014). Some of those people returned to their pre-tsunami communities, particularly after a massive housing reconstruction was launched (Laurito et al, 2022). Studies have also established some individuals and families displayed resilience and navigated the trauma of the disaster with modest impacts on well-being, others were able to recover much of the economic losses and others have fallen permanently behind (Lawton et al, 2022).

DATA

Working with Statistics Indonesia to select 11 districts in the province of Aceh and two in North Sumatra whose 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 were selected to form the STAR baseline study population.

The February/March 2004 SUSENAS, which was conducted 10 months before the tsunami, provides the population-representative baseline for STAR and covers communities in all coastal districts in Aceh and North Sumatra that would have been at-risk of being directly affected by the tsunami. We conducted the first follow-up between May 2005 and July 2006, at a time when the full impact of the tsunami and where it had hit was not well-known. The fieldwork was extremely challenging. We remained permanently in the field and completed four annual follow-ups and then completed additional follow-ups at roughly ten and fifteen years after the disaster.

In the communities that were hardest hit, 80% of the respondents died in the tsunami (Frankenberg et al, 2011). We triangulated across multiple sources of information to establish survival status. We are confident it is accurate for 99% of the pre-tsunami baseline 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 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.

In this paper we analyze 16,342 baseline respondents who survived the tsunami and were 15 or older at that time. Half are male. The average respondent was age 35y at the time of the tsunami and had completed 8 years of schooling (just shy of completing junior secondary school in Indonesia). Our first measure of well-being is completed schooling of each respondents.

STAR is designed to collect data at the household and individual levels. A key respondent in each household provides information about every household member along with household-level measures of social and economic well-being including expenditures. We draw on these data to trace the evolution of a key marker of economic status, household per capita expenditure (PCE), in the aftermath of the tsunami. We have information on PCE for between 91% and 94% of the baseline respondents in each of the follow-ups. This is a high rate of follow-up in any large-scale longitudinal survey. It is unprecedented in a follow-up after a large-scale natural disaster that caused enormous damage to the built and natural environment and resulted in large-scale displacement and migration.

Every member of a STAR household age 15y or older is eligible for an interview that collects more detailed information about their health, economic status and perceptions of well-being. We draw on these interviews to investigate the evolution of an indicator of overall measure of well-being in the aftermath of the tsunami. The indicator is measured for 80-85% of the respondents for whom PCE is measured in each follow-up.

METHODS AND MEASURES

Our primary question revolves around the ways in which members of our baseline sample redistribute themselves in the aftermath of a major disaster. We begin by analyzing how pre-tsunami characteristics are associated with location one year after the tsunami, then turn to how location one year after the tsunami is related to economic resources in that year and at two and five years after the tsunami. The question is important for the design of studies that aim to understand well-being associated with the environmental and contextual changes that will accompany global warming, where the goal is characterizing outcomes for a population as a whole, rather than solely those found in a particular location or type of housing in the aftermath of change.

To characterize location after the tsunami we create a variable that assumes four values. Those who are in the same location at the first follow up, roughly one year after the tsunami, as they were in the baseline survey are distinguished from those living in a different location but within the same neighborhood, those living in a different neighborhood but within the same village or township, and those living in a different village or township. For the analytical sample 53% remained in the same home at the first follow up interview, 13% had changed residences but were in the same neighborhood, 8% had changed neighborhoods but remained in the same village, and 14% had moved to a new village (11% were not interviewed).

For individuals who cannot or do not want to remain in their original location, another factor in relocation is the type of housing available to them. In the aftermath of a disaster, securing safe stable shelter is a core component of recovery, but it is challenging when significant property destruction has occurred. For those living somewhere other than their pre-tsunami location we classify individuals based on whether they were in emergency temporary housing (tents, camps, or barracks, 4.4%) or private housing (31%).

Where people live, the type of housing in which they live, and how they fare after a major event depends in part on the degree of damage to which they were exposed. We designed STAR to include communities along a continuum ranging from destruction of almost all buildings and vegetation to no direct damage from the tsunami waves (though some communities sustained damage from the earthquake).

For our analyses we classify communities into three groups with respect to level of damage in the community (heavy, moderate, and not directly damaged). The damage measure is based on remote sensing measures of damage, direct observations from our team supervisors, and reports from community leaders.[1] This measure is closely correlated with levels of tsunami mortality and other outcomes for individuals. About 20% of respondents analyzed here resided in communities heavily damaged by the tsunami, 58% were in moderately damaged communities, and 22% were in communities with light to no damage.

We use three measures to characterize human capital and well-being before and after the tsunami. The first measure is years of educational attainment, which for most study subjects was established before the tsunami. Education is widely regarded as a good indicator of long-run economic well-being and has the advantage, in this context, of being fixed over time.

The second measure is monthly household PCE which varies over time. PCE is calculated from questions about spending on 7 food and 12 non-food categories of goods. Examples of food categories are rice; meat and fish; fruits and vegetables; non-food examples are clothing; personal goods; and energy. For those who do not pay rent, housing expenditures are imputed based on the rental value of the home. In general, PCE is thought to be a good measure of resource availability and thus economic well-being (Deaton, 2016), particularly in settings of substantial temporal variation in income because of seasonality or the nature of work. This is important in the context of a disaster that destroyed livelihoods and income-earning capacity. During the 1998 financial crisis when incomes collapsed in Indonesia, households adjusted their spending patterns and drew on their savings, support from family and friends as well as public programs (Frankenberg, Smith and Thomas, 2003). Since household expenditures increase with household size, we standardize by household size which is a crude way to take this into account. PCE is measured in real terms taking into account local area price variation. The distribution of PCE is skewed to the right and so we use the natural logarithm of PCE, lnPCE, in the analyses. In the year after the tsunami, the average household spent Rp 1.4 million per month which is approximately $150 (or $40 per person).

[1] Our satellite-based damage measures come from three publicly-available damage products produced after the tsunami and a measure we constructed using data from NASA's MODIS sensor. Images from December 17, 2004 and December 29, 2004 were geographically linked using the MODIS reprojection tool.

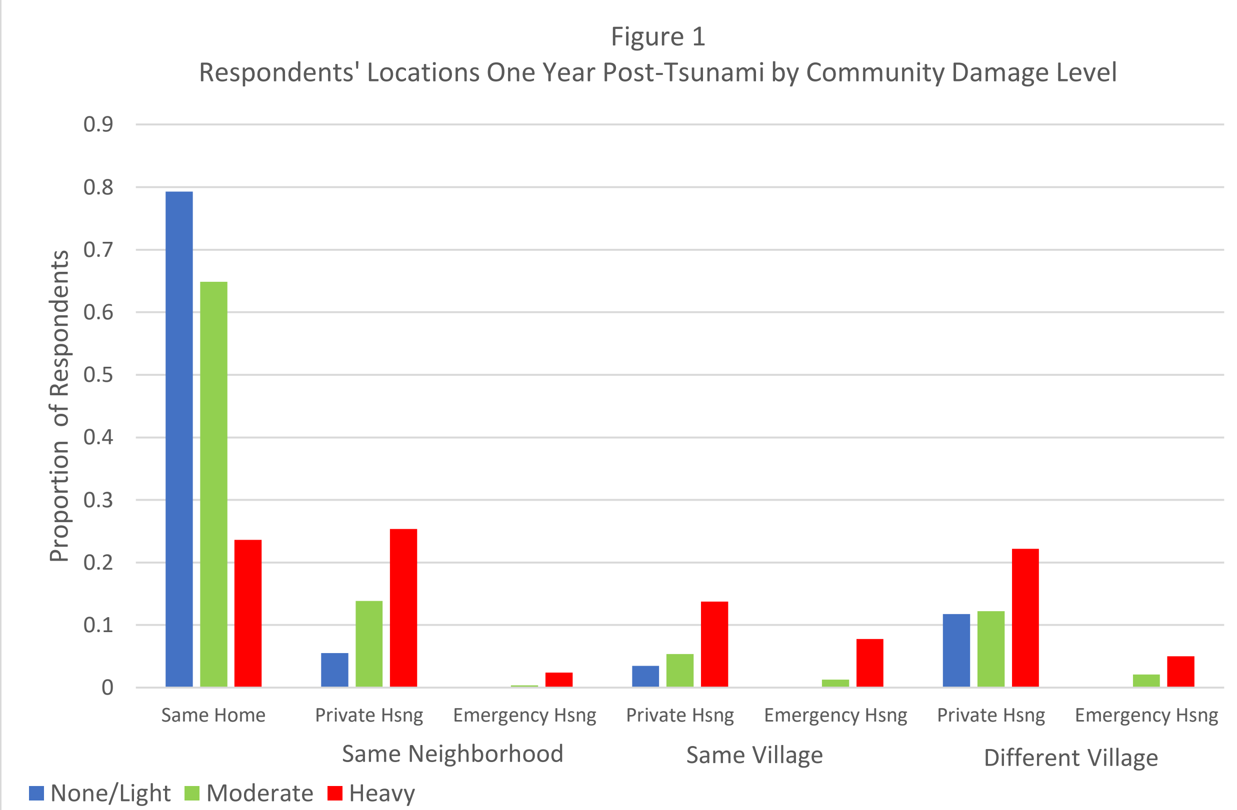
We complement lnPCE with a global indicator of well-being that is measured at the individual level using responses to a Cantril ladder-type question. Specifically, are asked to imagine a six-step ladder where on the bottom (the first step), stand the poorest people, and on the highest step (the sixth step), stand the richest people. They are then asked to locate where they feel they are at the time of the survey. The question has been used extensively as a source of information on perceptions of well-being around the world. At the first post-disaster interview, 51% of respondents reported themselves on the first or second step, and just under 8% reported themselves on the fourth, fifth, or sixth step.

This third measure of well-being has three advantages relative to lnPCE. First, PCE is measured at the household level and every household member is assigned the same level of PCE. This does not take into account potential within-household variation in access to resources which may be especially important after a disaster if some members tighten their belts more for the sake of others in the household. This pattern was documented in the context of the 1998 financial crisis in Indonesia where older women apparently reduced their own consumption in favor of grandchildren in the household (Frankenberg, Smith and Thomas 2003). Second, and related, when individuals split off from a household and form a new household or live alone, changes in PCE may not accurately reflect changes in well-being. This is also important in the context of a the tsunami as large numbers of people were displaced and many of the affected household split up. Third, it is complicated to deal with price heterogeneity in surveys and this concern is side-stepped by the ladder question.

The ladder question has two disadvantages. First, the definition of poorest and richest is likely to vary with socio-economic status which affects interpretation of the indicator. It is advantageous, therefore, to simultaneously investigate patterns in lnPCE and the ladder question to interpret the results with these caveats in mind. The second disadvantage is that since the question reflects each individual's perception of well-being, it imposes a higher burden on the survey as each respondent has to be individually interviewed. Completion rates of individual assessments are lower than household-level assessments.

RESULTS

To set the stage for descriptions of the evolution of well-being in the aftermath of the tsunami and how it varies with community-level damage and post-event location, Figure 1 displays the distribution of respondents across damage level and residential arrangement at the time of the first post-tsunami interview. Three points are important. First, across the three damage levels there is substantial variation with respect to the proportion of respondents who remain in the same location as before the tsunami, but even in undamaged locations 20% of respondents have relocated by the first follow up (in heavily damaged areas fully 76% of respondents are elsewhere). Second, substantial proportions of respondents relocate to private homes. Even among those from moderately and heavily damaged areas, post-disaster residence at one year is dominated by private residences rather than temporary shelter. Third, a lot of movers leave their communities to settle in new places. This is true regardless of level of damage to the community but is particularly dominated by movers from areas without damage.



Pre-tsunami characteristics and post-tsunami changes in location and living arrangements

Table 1 presents summary statistics for educational attainment (in years) and household PCE, both measured before the tsunami. Means are presented for individual respondents, stratified by where they were living at the time of the first post-tsunami follow up (on average one year after the tsunami), relative to their pre-tsunami location.

Education levels are lowest, at just under 8 years, for those who, one year after the tsunami, are still located at the site of their pre-tsunami residence. Individuals in different locations all have on average about a half a year more education. The sizes of the gaps, which range from 0.539 to 0.642, are presented in column 2. These differences are all statistically significant, indicating that movers in the aftermath of the disaster differ from stayers on educational attainment, a key component of human capital.

Means of lnPCE are reported in column 3 of Table 1. The gaps in column 4 can be interpreted as approximately percentage differences. Relative to individuals who remain in their pre-tsunami location, the PCE of those who are in a new location, but within the same neighborhood, is about 14% higher before the tsunami—a gap that is statistically significant. No substantively important or statistically significant differences exist between stayers and those who are found outside of their original neighborhood.

The results of this table provide initial evidence that individuals who move from their pre-event place of residence in the aftermath of a major change differ from those who do not move. These results illustrate the importance of tracking movers in the aftermath of an event, rather than simply interviewing those who remain in their original location.

In Table 2 we again consider years of education and economic resources measured before the tsunami, but we stratify by level of tsunami damage in the community. For each level of damage, evidence emerges that respondents' educational levels and household spending levels differ by individuals' post-tsunami locations relative to their pre-tsunami locations.

In areas without direct tsunami damage, for example, those who relocated within the same village but outside of their original neighborhood have about a year and a half more education than their counterparts who remain in the same location. These individuals also have higher levels of per capita spending. In areas of moderate damage there differences between those who remain in their pre-tsunami location and those who move, but for both measures the advantages appear for those who shift residences within the same neighborhood.

The results differ for those from areas that were heavily damaged by the tsunami. In these areas levels of education and per capita spending are significantly lower for those who relocate within their village than for those who stay in the same place.

These results confirm that not only do movers differ from stayers on important dimensions of human capital and economic resources, but the direction of the differences varies by extent of damage from the disaster.

The bottom panel examines patterns by both location of post-tsunami residence and type of housing that individuals were living in at the first follow up interview. These results are presented only for individuals who originated in areas that sustained moderate or heavy tsunami damage because the small number of individuals from areas without direct damage precludes analysis.

In this panel we see that individuals interviewed in emergency housing are systematically less educated and from households with fewer resources before the tsunami. This is true for those from moderately damaged and for those from heavily damaged areas. In other words, one year after the tsunami, the individuals who are in emergency shelters were poorer and are more poorly educated than individuals who were not displaced. In areas of heavy damage the educational disparity is over one year for those in emergency housing relative to those who remained in their origin location. With respect to education, for those from moderately damaged areas, movers who are living in private homes are significantly better educated than those who remain in the same location. In areas of both moderate and heavy damage, the pattern of relative disadvantage (pre-tsunami) for those in emergency housing is present with respect to per capita spending levels but the differences are less consistently statistically significant.

These results further enrich the narrative. It is not just where one moves that varies by important pre-tsunami characteristics. In addition the type of housing that movers find themselves living within varies as well. To capture a full picture of how individuals fare after a disaster, tracking movers across the myriad types of locations and living arrangements is important, because pre-event characteristics are associated with what happens after the event.

Post-tsunami locations and the evolution of economic resources

We turn now to the ladder question to investigate how one's individual perception of economic circumstances evolves after a disaster, and how this varies by living situation in the first year after the event (Table 3).

In areas without tsunami damage relocating out of one's original neighborhood in the year after the tsunami is associated with significantly higher per capita spending than remaining in place. This same relationship holds for individuals from moderately and heavily damaged areas, where relocation to a private home (but not to emergency housing) is associated with higher per capita spending. Two years after the tsunami, those who have relocated beyond their original neighborhood (but not those who relocated within it) have significantly higher spending than those who remained in place. By five years after the tsunami this relationship has weakened, regardless of damage zone.

Although residence in emergency housing one year after the tsunami was significantly more likely for those from households with fewer resources before the tsunami, living in emergency housing is not associated with lower spending levels relative to those of non-movers, in any of the post-tsunami waves.

As mentioned above, our per capita spending measure reflects household-level economic resources, the allocation of which may vary across households. The question on perception of socioeconomic status, as represented by steps on a ladder, is a measure of economic resources that is specific to individuals rather than to households. In Table 4 we present results from assessing the relationship of this ladder measure with location of residence one year after the tsunami.

In the year after the tsunami, those from heavily damaged areas who are living in emergency housing position themselves on a substantially and significantly lower step than do individuals who remain in the same residence. Regardless of location relative to their pre-tsunami home, those in emergency housing report being half a step lower on the ladder. Also the relationship is strong in year 1, it is not detectable in year 2 or in year 5.

For those from moderately damaged areas residence in emergency housing does not have the same dramatic relationship with perception of ladder step. In these areas, there are no statistically significant differences between those in emergency housing and those who did not move in either in the first year or second year after the disaster. By year five, those who were in emergency housing in a different village report an improvement in status of about third of a step, whereas those in emergency housing within the same community at year 1 report about a quarter of a step drop in status—a strong difference in outcomes.

For those who moved but to private homes, differences in step relative to those in the same location tend to be positive, but small and not statistically significant. One exception to this pattern is that those from heavily damaged areas who moved to private homes in the same village report a significantly lower ladder position than those who remained in the same location.

Among those from undamaged areas some movers report a higher step position than stayers, whereas some report a lower step position. No clear pattern emerges for those from areas that were undamaged in the tsunami.

Although the focus of this paper is on the methodological importance of harnessing baseline data and following up respondent who move, we note in passing that although first post-tsunami locations vary widely, these locations do not dictate degree of recovery in the subsequent period. We have documented considerable resilience even after such a devastating disaster but, for some population subgroups the effects are long-lasting, particularly for economic and health-related indicators of well-being (Frankenberg et al, 2016; Frankenberg et al, 2017; Frankenberg et al, 2019; Lawton et al, 2021, Lawton et al , 2021; Thomas et al, 2018)

DISCUSSION AND CONCLUSION

As extreme events increase in frequency and severity, there is a need for data on how people fare during and recover from these threats, based on representative samples of the population at risk. Because constructing such a sample can be a complicated endeavor, much of the work on the impacts of disasters relies on convenience samples of one form or another, such as people remaining in their pre-event residence rather than moving, or people who have relocated to official shelters or camps for the displaced.

Our results provide scientific evidence of the importance of samples that represent the population before the event, rather than studying only individuals present after an event. We have shown that pre-event characteristics condition where and in what circumstances people live after an event, that post-event well-being is associated with post-event living conditions in the short-term, and that over time, the link weakens between short-term living arrangements and post-event well-being. Were one to interpret the results for a subset of those we interview as the outcomes for the entire population, one would misrepresent population outcomes both at points in time as well as with respect to the evolution of outcomes over time.

The STAR project uses a pre-tsunami survey as a baseline, which was possible both because Statistics Indonesia regularly conducts large high quality cross-sectional surveys and because of their collaboration in the aftermath of the devastation of the tsunami. Other studies have repurposed survey or census data in order to construct a baseline (see for example the RISK project in New Orleans), relied on records from databases of mailing addresses or phone numbers, or used pre-event satellite imagery to build a frame of structures from which a sample can be drawn.

As environmental pressures mount, designs for data collection that produce unbiased estimates of the impact and evolution of population well-being are imperative. These designs may draw on tools social scientists have used for decades, supplemented with novel methods harnessing new technologies or new administrative data streams. Investments in establishing observatories where data collection can occur regularly and at relatively high frequency may have important pay-offs with respect to developing a better understanding of the impacts of climate change.

References

Borrero, J. (2005). Field data and satellite imagery of tsunami effects in Banda Aceh., *Science*, vol. 308, pp. 1596.

Deaton, A. (2016). Measuring and Understanding Behavior, Welfare, and Poverty. *American Economic Review*, 106 (6): 1221-43.

Frankenberg, E., Smith, J.P., & Thomas, D. Economic shocks, wealth, and welfare: evidence from the Indonesia Family Life Survey. 2003. *The Journal of Human Resources*. 38(2): 280-321

Frankenberg, E, Sumantri, C. & Thomas, D. (2016). "The evolution of well-being in the aftermath of a disaster: Evidence from Aceh and North Sumatra." in Helen James and Douglas Paton, (eds.), *The Consequences of Disasters: Demographic, planning and policy implications*, C. C. Thomas, Illinois.

Frankenberg, E., Lawton, R., Seeman, T., Sumantri, C. & Thomas, D. (2019). The causal impact of stress on inflammation over the long-term. Manuscript.

Frankenberg, E., Friedman, J., Ingwersen, N., & Thomas, D. (2017). Linear child growth after a natural disaster: a longitudinal study of the effects of the 2014 Indian Ocean tsunami, *The Lancet*, 389: S21: April 2017. //doi.org/10.1016/S0140-6736(17)31133-9

Frankenberg, E., Friedman, J., Gillespie, T., Ingwersen, N., Pynoos, R., Rifai, I.U., Sikoki, B., Sumantri, C., Suriastini, W. & Thomas, D.. 2008. Mental Health in Sumatra after the Tsunami. *American Journal of Public Health.* 98(9): 1671-1677.

Frankenberg, E., Gillespie, T., Preston, S., Sikoki, B. and Thomas, D. 2011. Mortality, the Family, and the Indian Ocean Tsunami. *The Economic Journal*. 121: F162-182.

Gillespie, T, Frankenberg, E., Chum, K.F. & Thomas., D. 2014. Nighttime lights time series of tsunami damage, recovery, and economic metrics in Sumatra, Indonesia. *Remote Sensing Letters.*

Gray, C., Frankenberg, E., Sumantri, C. & Thomas, D. 2014. Studying Displacement after a Disaster Using Large Scale Survey Methods: Sumatra after the 2004 Tsunami. *Annals of the Association of American Geographers*. 104(3): 594-612.

Kohl, P., O'Rouke, A., Schmidman, D., Dopkin, W. & Birnbaum, M. (2005). The Sumatra-Andaman earthquake and tsunami of 2004: The hazards, events, and damage, *Prehospital and Disaster Medicine*, 20(6), 355-363.

Laurito, M., Frankenberg, E. & Thomas, D. 2022. Effects of Housing Aid on Psychosocial Health after a Disaster. *Int. J. Environ. Res. Public Health* **2022**, *19*(12), 7302.

Lawton, R., Frankenberg, E., Friedman, J. & Thomas, D. (2022). Long-term economic well-being after the 2004 Indian Ocean tsunami. Manuscript.

Lawton, R., Frankenberg, E., Sumantri, C., Seeman, T., Crimmins, E. & Thomas, D. (2021). Cortisol levels 15 years after a natural disaster. Manuscript.

Monecke, K., Finger, W., Klarer, D., Kongko, W., McAdoo, B., Moore, A., & Sudrajat, S..(2008). A 1,000-year sediment record of tsunami recurrence in northern Sumatra, *Nature*. 453: 1232-1234.

Nicol, W. 2013. *The Tsunami Chronicles: Adventures in Disaster Management*. CreateSpace Independent Publishing Platform; 1st edition (June 13, 2013)

Ramakrishnan, D., Ghosh, S., Raja, V., Chandran, R., & Jeyram, A. (2005). Trails of the killer tsunami: A preliminary assessment using satellite remote sensing technique, *Current Science*. 88(5): 709-711.

Thomas, D., Frankenberg, E., Seeman, T., & Sumantri, C. (2018). "Effect of stress on cardiometabolic health 12 years after the Indian Ocean tsunami: a quasi-experimental longitudinal study", *The Lancet Planetary Health*, 2.S8.

Umitsu, M., Tanavud, C. & Patanakanog, B. (2007) Effects of landforms on tsunami flow in the Plains of Banda Aceh, Indonesia, and Nam Khem, Thailand, *Marine Geology*. 242, 141-153.

Table 1.
Pre-tsunami characteristics and subsequent residential mobility
Years of education and ln(per capita expenditure) measured pre-tsunami
Location measured in year after tsunami relative to location pre-tsunami

	Years of education		lnPCE	
	Means	Gaps	Means	Gaps
	[1]	[2]	[3]	[4]
Pre-tsunami location	7.97		2.82	
	[0.12]		[0.02]	
Same neighborhood	8.59	0.62	2.95	0.14
	[0.23]	[0.22]	[0.04]	[0.04]
Same desa	8.51	0.54	2.84	0.03
	[0.19]	[0.20]	[0.03]	[0.03]
Different desa	8.61	0.64	2.83	0.01
	[0.20]	[0.20]	[0.03]	[0.03]
No. respondents	16,342		16,342	
R^2	0.825	0.006	0.964	0.007
p: F(all locations)	0.000	0.001	0.000	0.013

Notes: Standard errors in parentheses below means and gaps take into clustering at level of baseline enumeration area. p: F(…) is p-value of F test for joint significance of all locations in year after tsunami.

Table 2.
Tsunami exposure, pre-tsunami education and lnPCE, and residence in year after tsunami

	Years of education			lnPCE		
Extent of damage:	No direct	Moderate	Heavy	No direct	Moderate	Heavy
	[1]	[2]	[3]	[1]	[2]	[3]
A. Location of residence in year after tsunami						
Pre-tsunami location	8.03	7.71	9.36	2.77	2.79	3.08
	[0.19]	[0.15]	[0.36]	[0.04]	[0.03]	[0.07]
Relative to pre-tsunami location						
Same neighborhood	-0.55	0.65	-0.11	0.05	0.13	-0.05
	[0.52]	[0.30]	[0.41]	[0.07]	[0.06]	[0.08]
Same desa	1.53	0.54	-0.80	0.18	-0.01	-0.20
	[0.41]	[0.30]	[0.40]	[0.08]	[0.05]	[0.07]
Different desa	0.48	0.40	0.14	-0.08	-0.07	0.00
	[0.42]	[0.25]	[0.41]	[0.04]	[0.04]	[0.07]
B. Location and type of residence in year after tsunami						
Relative to pre-tsunami location						
Same neighborhood - emergency		-0.35	-1.34		-0.18	-0.47
		[1.02]	[0.59]		[0.21]	[0.15]
Same neighborhood - private		0.67	0.01		0.14	-0.01
		[0.29]	[0.41]		[0.05]	[0.08]
Same desa – emergency		-0.80	-1.20		-0.10	-0.22
		[0.69]	[0.53]		[0.11]	[0.08]
Same desa - private		0.85	-0.58		0.02	-0.20
		[0.28]	[0.39]		[0.05]	[0.08]
Diffferent desa - emergency		-0.51	-1.73		-0.22	-0.17
		[0.42]	[0.72]		[0.09]	[0.09]
Different desa – private		0.56	0.56		-0.05	0.04
		[0.25]	[0.40]		[0.03]	[0.08]
No. respondents	3,660	9,508	3,174	3,660	9,508	3,174
p: F(location)	0.002	0.066	0.071	0.017	0.010	0.003
p: F(location+type res)		0.001	0.002		0.00705	0.000415

Notes: Standard errors in parentheses below coefficient estimates take into clustering at level of baseline enumeration area. p: F(…) is p-value of F test for joint significance of covariates in (…).

Table 3.
Tsunami exposure, lnPCE and location and type of housing 1, 2 and 5 years after tsunami

	1 year after			2 years after			5 years after		
Extent of damage:	No direct	Moderate	Heavy	No direct	Moderate	Heavy	No direct	Moderate	Heavy
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Same neighborhood - emergency		-0.20	0.15		-0.08	-0.03		-0.22	-0.05
		[0.29]	[0.12]		[0.23]	[0.13]		[0.28]	[0.16]
Same neighborhood - private	0.06	0.18	0.24	-0.16	0.09	0.18	-0.05	0.04	0.06
	[0.08]	[0.07]	[0.09]	[0.08]	[0.07]	[0.10]	[0.04]	[0.06]	[0.08]
Same desa - emergency		-0.07	0.10		-0.09	0.06		0.04	0.06
		[0.11]	[0.11]		[0.07]	[0.12]		[0.10]	[0.09]
Same desa - private	0.24	0.11	0.17	0.24	0.11	0.20	0.16	0.03	0.08
	[0.10]	[0.07]	[0.09]	[0.09]	[0.05]	[0.09]	[0.09]	[0.07]	[0.08]
Diffferent desa - emergency		0.13	0.23		0.07	0.16		0.05	0.03
		[0.09]	[0.14]		[0.08]	[0.12]		[0.06]	[0.09]
Different desa - private	0.28	0.42	0.59	0.20	0.24	0.47	0.08	0.12	0.19
	[0.13]	[0.05]	[0.09]	[0.11]	[0.05]	[0.10]	[0.07]	[0.04]	[0.08]
Reference (pre-tsunami	3.28	3.22	3.50	3.47	3.48	3.80	3.93	3.94	4.14
location)	[0.04]	[0.03]	[0.08]	[0.04]	[0.03]	[0.09]	[0.03]	[0.02]	[0.08]
No. respondents	3,487	8,995	2,879	3,464	8,652	2,824	3,537	8,964	2,933
p: F(All location/residence)	0.024	0.000	0.000	0.003	0.000	0.000	0.025	0.036	0.078

Notes: Standard errors in parentheses below coefficient estimates take into clustering at level of baseline enumeration area. p: F(…) is p-value of F test for joint significance of all locations and residence types relative to pre-tsunami location.

Table 4.
Tsunami exposure, step on well-being ladder and location and type of housing 1, 2 and 5 years after tsunami

	1 year after			2 years after			5 years after		
Extent of damage:	No direct	Moderate	Heavy	No direct	Moderate	Heavy	No direct	Moderate	Heavy
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Same neighborhood – emergency		0.01	-0.45		-0.08	-0.11		-0.23	-0.10
		[0.20]	[0.17]		[0.11]	[0.11]		[0.17]	[0.10]
Same neighborhood - private	0.07	0.15	0.14	-0.24	0.06	0.17	-0.08	0.14	0.13
	[0.08]	[0.06]	[0.08]	[0.12]	[0.05]	[0.06]	[0.09]	[0.05]	[0.07]
Same desa - emergency		-0.09	-0.39		-0.14	0.05		0.05	-0.01
		[0.12]	[0.11]		[0.08]	[0.09]		[0.08]	[0.10]
Same desa – private	0.09	-0.01	-0.22	-0.09	0.01	0.07	0.16	0.03	-0.03
	[0.09]	[0.06]	[0.10]	[0.12]	[0.05]	[0.07]	[0.08]	[0.05]	[0.08]
Diffferent desa - emergency		-0.13	-0.50		-0.01	0.01		0.32	-0.02
		[0.08]	[0.11]		[0.05]	[0.09]		[0.07]	[0.09]
Different desa - private	-0.09	0.07	-0.05	0.10	0.08	0.10	-0.04	0.12	0.08
	[0.08]	[0.04]	[0.10]	[0.07]	[0.03]	[0.08]	[0.09]	[0.04]	[0.07]
Reference (pre-tsunami	2.54	2.43	2.62	2.67	2.66	2.74	2.94	2.86	2.99
location)	[0.04]	[0.03]	[0.08]	[0.04]	[0.02]	[0.06]	[0.03]	[0.02]	[0.06]
No. respondents	3,001	7,521	2,461	2,733	6,898	2,212	3,033	7,665	2,492
p: F(All location/residence)	0.386	0.014	0.000	0.078	0.051	0.024	0.204	0.000	0.136

Notes: Standard errors in parentheses below coefficient estimates take into clustering at level of baseline enumeration area. p: F(…) is p-value of F test for joint significance of all locations and residence types relative to pre-tsunami location.