

Research Article

How Social Infrastructure Saves Lives: A Quantitative Analysis of Japan's 3/11 Disasters

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Observers have long debated how societies should invest resources to safeguard citizens and property, especially in the face of increasing shocks and crises. This article explores how social infrastructure - the spaces and places that help build and maintain social ties and trust, allowing societies to coordinate behavior - plays an important role in our communities, especially in mitigating and recovering from shocks. An analysis of quantitative data on more than 550 neighborhoods across the three Japanese prefectures most affected by the tsunami of 11 March 2011 shows that, controlling for relevant factors, community centers, libraries, parks, and other social infrastructure measurably and cheaply reduced mortality rates among the most vulnerable population. Investing in social infrastructure projects would, based on this data, save more lives during a natural hazard than putting the same money into standard, gray infrastructure such as seawalls. Decision makers at national, regional, and local levels should expand spending on facilities such as libraries, community centers, social businesses, and public parks to increase resilience to multiple types of shocks and to further enhance the quality of life for residents.

Introduction

Even though most physical infrastructure projects bring hefty price tags, we nonetheless overinvest in them while underinvesting in more cost-effective alternatives, especially *social infrastructure*.¹ Social infrastructure's definition varies widely (see Joshi and Aldrich 2022 for an overview of the uses of the term), with some using the term indiscriminately, labeling any kind of facility that supports social services - including those in the fields of education, healthcare, housing, and transport - as social infrastructure (MOFA 2005; Ishizuka, Hara, Nama, and Hirota 2019). Others have conflated social

capital – the ties that bind us to each other (Aldrich 2019) – and social infrastructure – the places that build those connections. This article uses the term social infrastructure more selectively, referring only to the spaces and places that create and maintain the connection. Hence free and publicly funded spaces like libraries, parks, *kōminkan*, and community centers along with private social businesses such as cafés and restaurants fit in this approach (see Fraser et al 2022 for details on mapping this infrastructure). This definition excludes gray infrastructure, that is, roads, ports, dams, and other spaces built for transportation infrastructure, along with homes and office buildings, regardless of occasional uses of those spaces for social reasons.

Societies regularly mitigate risks – such as natural hazards, terror attacks, and crime – through physical infrastructure. To fight risks like tsunamis and floods, governments construct concrete seawalls, elevate homes, and reinforce beaches with sand. To fight terrorism, they build military bases abroad (Calder 2007; Cooley 2008), set up hardened shelters (Elran 2017), and build and send out drones to eliminate extremists. To fight crime, law enforcement relies on often aging and overcrowded prisons (Harding, Morenoff, Nguyen, Bushway, and Binswanger 2020). We certainly need much of the investment in physical infrastructure given the regularly failing grades assigned to it by engineers in North America (ASCE 2021). Studies have shown that investments in physical infrastructure to mitigate water damage can reduce flood consequences (Ishiwatari and Sasaki 2021). And much of that gray infrastructure – roads, ports, bridges – helps our society and our economy run smoothly.

While impressionistic evidence suggests that social infrastructure can alter the trajectories of shocks for residents (Klinenberg 2018; Aldrich 2021), few studies have sought to investigate this question using quantitative data, especially in direct comparison with the impact of mitigating physical infrastructure. This article pushes the discussion forward, using quantitative data from Miyagi, Iwate, and Fukushima prefectures in Japan to illuminate how higher levels of social infrastructure – controlling for other important factors – correlated with lower mortality rates among the most vulnerable population, that is, the elderly, during the 3/11 triple disasters. I first define three core categories of infrastructure, analyze the outcomes of a vulnerable population during Japan's 11 March 2011 events using data from more than 550 neighborhoods, and then suggest other policy arenas of challenging problems (cf. Kolko 2012) in which social infrastructure can serve an important, low-cost role.

Defining Infrastructure

The United States government defined 16 sectors as *critical infrastructure*, including chemical plants, commercial facilities, critical manufacturing plants, dams, the defense industrial base, emergency services, energy facilities, financial services companies, food and agriculture sector firms, government facilities, healthcare, the information technology sector, nuclear reactors, materials, and waste, transportation, and water and wastewater systems (White House 2013). I recategorize infrastructure into three types: gray, green, and social, as laid out in Table 1 below.

A current push in North America for *physical or gray infrastructure* investment has focused attention on the quality of the nation's bridges, roads, ports, and dams. The American Society of Civil Engineers (ASCE) regularly issues a report card for this type of public investment in the United States, and bridges, dams, and other built environment facilities regularly receive failing to poor grades (ASCE 2021). At the same time, research has shown that *green infrastructure* – such as biophilic urban parks, urban forestry, rainwater harvesting and gardens, water capturing plazas, roof and community gardens, and other ways of water management – improves the quality of life, air quality, and reduce heat (Currie 2021). These newer investments have become more popular for crowded, hot, urban environments (Grabowski and McPhearson 2021) and include projects such as biomimicry-based flood protection (Currie 2021).

A third often overlooked type of infrastructure – *social infrastructure* – may prove more critical still. Social infrastructure provides the foundation on which civic engagement, trust, information sharing, and social ties grow. Spaces and places where people can meet, play, and build trust – including community centers, libraries, walking trails, and faith-based spaces – provide the structures on which social capital can be built and maintained. In turn, our horizontal (bonding and bridging ties) and our vertical ties (linking social capital) influence our behavior, provide information, and help overcome collective action problems. In this way, social infrastructure – the architecture, space, and shade around us – influences the ways we interact with others and therefore the direction we take as communities and societies (Jacobs 1961; Klinenberg 2018).

| Type of Infrastructure | Examples | Influenced by | Benefits |
|---------------------------------|---|--|--|
| Gray | Roads, bridges, ports, dams, electrical, gas, water and waste management systems | Government regulation, construction industry demand and lobbying, zoning laws, building ordinances | Standard form of critical infrastructure necessary for transportation, supply chain management, flood control, heating and cooling, etc. |
| Green (also labeled blue/green) | Floodable parks, roof gardens, rainwater harvesting, biomimicry in streets | Progressive urban planners, engaged local citizens, urban threats | Less expensive and environmentally damaging form of managing flood risks, cooling down heat islands |
| Social | Community centers, libraries, walking trails, parks, cafes, dog walks, basketball courts, museums, public spaces, synagogues, mosques, churches | Citizen demand, civil society pressure, philanthropic giving | Enhances residents' capacity to interact, coordinate, develop relationships horizontally and vertically |

Table 1. Relevant Infrastructure Types

What sort of potential do social infrastructure sites have in serving as mitigating facilities against shocks?

Empirical Investigation: Social Infrastructure during 3/11

I now investigate how social infrastructure can measurably alter the trajectory of vulnerable groups facing natural hazards using a hard case, namely Japan's 11 March 2011 disasters. With more than 18,400 deaths caused mostly by the 20+ meter waves, this triple disaster of earthquake, tsunami, and nuclear meltdown provides an opportunity to compare, side by side, the impact of physical vs. social infrastructure on a highly vulnerable population. The Japanese government has long pushed for the use of traditional, gray infrastructure like seawalls and berms for mitigating the impact of tsunamis and flooding (Aldrich 2019). Here I compare the empirical consequences of seawalls of different

heights on varying concentrations of social infrastructure. Using observational data from Ye and Aldrich (2019), I look at how *kōminkan*, community centers, and other social infrastructure facilities across more than 550 *machi ōaza* (neighborhoods) in the three prefectures affected most strongly by the tsunami – Fukushima, Iwate, and Miyagi – correlate with mortality rates for those over 65.

Determinants of Mortality

Several communal, hazard-related, and geographic factors may influence how residents – especially elderly residents – encounter a shock like a tsunami. First, **geographic conditions** may influence mortality rates among those 65 years of age (Frankenberg et al, 2011). Neighborhood size – especially its area – could have one of two impacts. Larger neighborhoods may provide more space for residents to find higher ground (such as higher buildings and mountaintop shrines), or they may force them to move further to get to such high ground and therefore spend more time exposed to the threat. Another geographic condition is the presence (or absence) of a seawall, and its height. Japanese engineers regularly argue that higher seawalls provide more protection from tsunamis (Author interviews, August 2022).

A second type of factor that could influence the outcome involves the **hazard** itself and exposure to that hazard. A higher tsunami can more easily come further ashore, so neighborhoods hit by higher waves are likely to see higher rates of mortality. Communities that are more inland, though, may have some mitigation from the tsunami, as its strength may wane several kilometers from the beach. A third set of factors revolves around the **economic conditions** in the neighborhoods affected by the shock. While we lack direct measures of residents' wages and income, we can make some inferences based on broader conditions of housing and education. Here, we capture both the proportion of residents owning (versus renting) homes along with the percentage of those that are educated. Better educated, home-owning residents may live in higher quality structures that can better survive a tsunami and may have better knowledge of forthcoming events, making them more likely to evacuate.

A fourth set of factors that may impact mortality among the elderly is **social capital**, which is the connections that bind residents to each other. Some studies have found that stronger social ties in communities reduced overall mortality through collective action and mutual aid (Aldrich and Sawada 2014; Aldrich 2019), but others have argued that providing aid to those in vulnerable sites may increase overall mortality (by placing the lives of friends and family in danger). Here I capture social ties through the normed density of nonprofit organizations and through the percentage of citizens

still in their homes after a five-year period (2005 through 2010). The final set of factors of interest revolves around **social infrastructure** – the places and spaces that help maintain and build social capital – defined here as the number of community centers, libraries, kōminkan, and parks divided by the neighborhood population.

Controlling for several relevant factors, including geography, characteristics of the hazard, social ties, and economic factors, an ordinary least squares (OLS) regression demonstrates that social infrastructure measurably and negatively correlates with reduced mortality rates. To better isolate potential causal mechanisms, I move to nearest neighbor matching (NNM) and average treatment effect (ATE) frameworks to show how communities with higher than average, normed numbers of such facilities have lower mortality rates than similar but less equipped communities.

Table 2 below lays out the data collected by Aldrich and Ye (2019) in their study of the interaction between social ties, age, and mortality rates. The outcome of interest is the proportion of elderly residents (those over the age of 65) who perished in the 3/11 tsunami. Please see Appendix Table 1 for details on the measurement and sources of these variables.

| Variable | N | Mean | Std. Dev. | Min | Max |
|--|-----|---------|-----------|---------|-----------|
| <i>Outcome of Interest</i> | | | | | |
| Elder Mortality (Proportion) | 562 | 4.69 | 7.92 | 0.00 | 80.00 |
| <i>Geography</i> | | | | | |
| Area of the Neighborhood (meters sq) | 562 | 7236215 | 46000000. | 3069.82 | 992000000 |
| Height of the seawall (m) | 562 | 6.90 | 2.81 | 0.00 | 15.50 |
| <i>Hazard</i> | | | | | |
| Height of the tsunami (m) | 562 | 6.45 | 5.10 | 0.08 | 22.77 |
| Distance to the sea (m) | 562 | 875.77 | 1397.66 | 0.00 | 10970.00 |
| <i>Economic Conditions</i> | | | | | |
| Proportion of residents owning homes | 562 | 0.79 | 0.19 | 0.12 | 1.00 |
| University educated (percent) | 562 | 0.07 | 0.05 | 0.00 | 0.29 |
| <i>Social infrastructure</i> | | | | | |
| Social infrastructure density (normed) | 562 | 0.001 | 0.00 | 0.00 | 0.05 |
| <i>Social capital</i> | | | | | |
| Non-Profit Organizations (normed) | 562 | 0.00 | 0.00 | 0.00 | 0.03 |
| Residential stability (percent) | 562 | 0.84 | 0.11 | 0.10 | 1.00 |

Table 2. Descriptive Statistics

Here, I focus on the density of social infrastructure, which is captured through the number of *kōminkan* (citizens' public halls), community centers, libraries, and parks in each neighborhood divided by the population (i.e. normed for population). Table 3 below shows the estimated coefficients for the OLS regression of mortality rates among the 65+ residents on a variety of geographic, economic, social capital, and social infrastructure variables. Validation through other models – including generalized linear models (GLMs) and left censored tobit models – showed little to no

difference in estimated coefficients. As expected, and across models, higher tsunamis had a positive correlation with mortality, while greater distances to the sea and higher seawalls had a lower one. Most important for this analysis is the fact that, controlling for these factors, social infrastructure was statistically significant and negatively correlated with our outcome of interest. Higher density of libraries, parks, and *kōminkan* measurably connect with lower mortality rates among the elderly.

| Regression | Estimated Coefficient | Standard Error | P Value |
|--|-----------------------|----------------|---------|
| Area of the Neighborhood (meters sq) | -1.20E-08 | 7.03E-09 | 0.089 |
| Height of the seawall (m) | -0.2331501 | 0.1144487 | 0.042 |
| Height of the tsunami (m) | 0.355137 | 0.0778792 | 0 |
| Distance to the sea (m) | -0.0008725 | 0.0002571 | 0.001 |
| Proportion of residents owning homes | -1.448593 | 2.7733 | 0.602 |
| University educated (percent) | -20.87056 | 9.36441 | 0.026 |
| Social infrastructure density (normed) | -152.3586 | 77.45105 | 0.05 |
| Non-Profit Organizations (normed) | 680.7388 | 198.5966 | 0.001 |
| Residential stability (percent) | -1.289772 | 4.901967 | 0.793 |
| Constant | 8.654676 | 3.789289 | 0.023 |

Table 3. Regression Coefficient Estimates

As these data are observational and not experimental, I move from regression to an average treatment effect (ATE) approach using nearest neighbor matching to better estimate potential causality. Matching on the other covariates in the OLS regression (area, height of the seawall, height of the tsunami, distance to the sea, home ownership, etc.), the estimated ATE of a neighborhood having more than the average number of normed social infrastructure facilities on over 65 mortality rates during the 3/11 tsunami is -1.1 (standard error .77, p-value of .1, 138 treated observations, 424 control observations. For more details on the balance of matched and unmatched observations please see Appendix 2). These data provide reasonable evidence that social infrastructure – controlling for potential confounding factors and existing levels of social ties through NPOs and other organizations

– mitigates shocks for the most vulnerable. I next go beyond hard-to-interpret statistical tables to visually illustrate the relationship between the quantities of interest using simulation and confidence intervals (King, Tomz, and Wittenberg 2000). Figure 1 below shows the statistically significant and measurable relationship in the unmatched, original sample between social infrastructure facilities and elderly mortality rates.

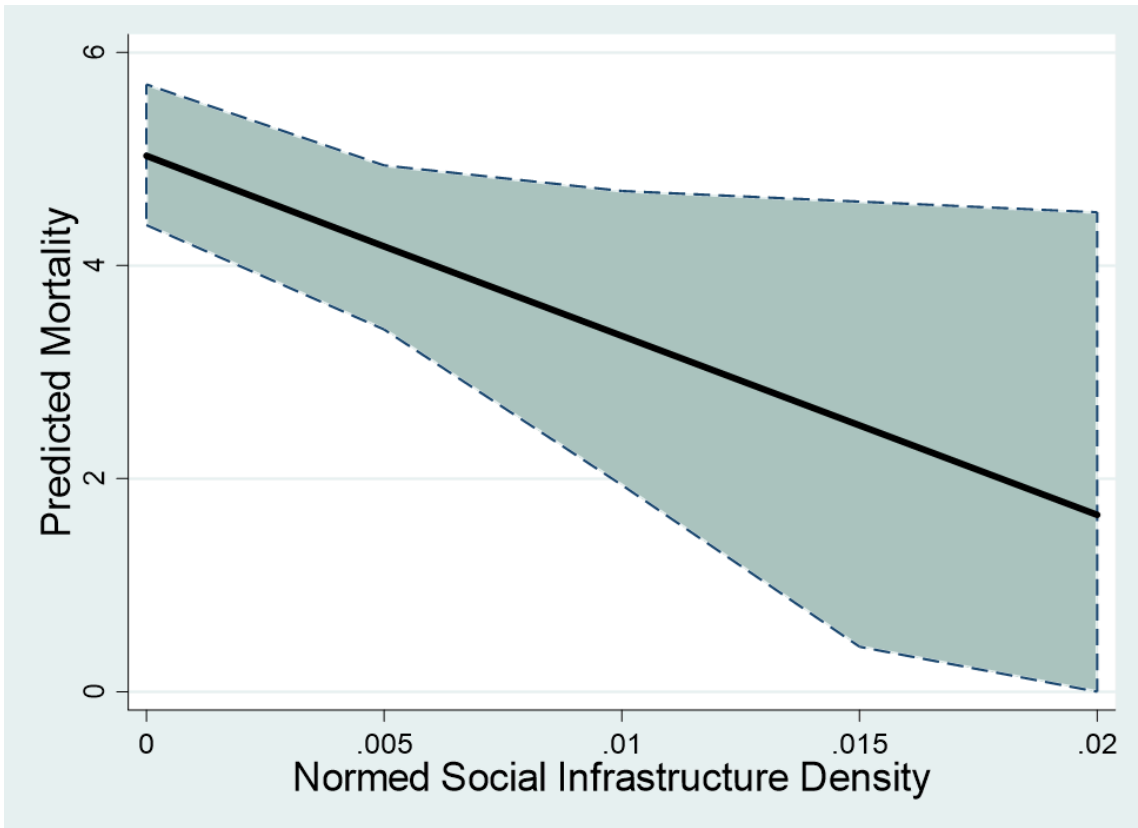


Figure 1. Predicted relationship between social infrastructure and elderly mortality rates

Note: N = 562, number of simulations = 1000, OLS model. All variables (residential stability, area, height of the seawall, height of the tsunami, distance to the sea, proportion of residents owning homes, NPOs, etc) held at their means except for the social infrastructure value, which varied between 0 and .02 (the interquartile range of the sample). The shaded area indicates the 95% confidence interval around the predicted value.

Given this clear relationship, and with a few transparent assumptions about costs, it is possible to compare the life-saving benefits during shocks from investing in physical as opposed to social

infrastructure (see Appendix 3 for details on these assumptions). A one-meter increase in seawall height results in a -.23 change in elderly mortality rates, while investment in one extra site of social infrastructure per 1000 residents is predicted to result in a -0.15 change in that same outcome. In other words, increasing a seawall by 1 meter might translate into 40 fewer elderly residents dying in a tsunami. In contrast, investment in one site of social infrastructure (e.g., library, community center, park, etc.) could save 26 elderly people. At a smaller financial cost (\$1 million USD vs \$5 million USD), a neighborhood adding locally appropriate social infrastructure would potentially mitigate some of the potentially fatal consequences of this kind of disaster.

Discussion: Social Infrastructure's Application to Challenging Policy Issues

This article has quantitatively demonstrated how *kōminkan*, libraries, community centers, and other social infrastructure facilities correlated with improved survival rates for a vulnerable population during a large-scale natural hazard in Japan. Social infrastructure may serve as an efficacious and cost-effective solution when directed towards challenges that have no, simple technical solution, as seen below in Table 4. Importantly, many of these facilities have multiple uses in their neighborhoods. Community centers, such as the *Ibasho* project in *Massaki-chō*², for example, not only help the elderly survive shocks (as this article has shown), but they also provide places where people can build ties to other demographics and age groups, learn new skills, and continue traditional practices such as *matsuri* (festivals) (Lee, Aldrich, Kiyota, Yasuhiro and Sawada 2022). So too libraries are not just repositories for books – they can provide English language skills to new immigrants, social ties to the lonely, a cooling shelter for those without air conditioning, and a place for events such as voter registration and tax filing (Klinenberg 2018).

In this way, social infrastructure builds resilience not only to natural hazards like tsunamis but also to chronic stressors like loneliness and a lack of critical social interaction. In North America, for example, high-quality social infrastructure – such as in-demand social businesses like restaurants and cafes (which I did not test directly in this article) – may help not only boost revenue for local entrepreneurs and grow foot traffic, but can also mitigate the impact of polarization, providing spaces where people of different political parties could meet for social interaction (Fraser et al 2022). It is important to note that, like other policies, social infrastructure requires bottom-up activation to be

successful; simply building a low-quality, unwanted, and therefore unlikely-to-be-used park, library, or public swimming pool will not help build resilience or mitigate shocks.

Fortunately, societies around the world have begun to experiment with community-driven investments in locally appropriate social infrastructure. Trinidad and Tobago, for example, have begun creating community policing zones, school programs, and NGO sites where residents can seek to deter crime and reduce violent extremism (Anever 2015; Aldrich and Mahabir 2022). The US State Department continues to push for nontraditional approaches to human security revolving around schools and religious institutions in the Sahel (Aldrich 2012b; Aldrich 2014) and even local police departments in North America claim that changes to the structure of neighborhood parks and other social infrastructure have decreased crime (Riddle 2022). Whether these infrastructure programs can scale and whether they are as or more effective than traditional gray infrastructure approaches remain open questions.

| Problem Area | Standard Gray Infrastructure Example | Social Infrastructure: Prevention | Social Infrastructure: Response |
|---------------------------------|--|--|---|
| Natural hazards (e.g. flooding) | Seawalls, berms, dikes, tetrapods, raising coastal structures, flood-proofing electrical systems | Community centers as educational, trust-building, and evacuation sites | Community centers as sites for temporary housing, rebuilding planning |
| Crime | Jails, militarization of police equipment and vehicles, surveillance | Drug treatment centers, community policing zones, neighborhood watch sites | Job training centers |
| Terrorism | Drone strikes, targeted assassinations, military conflict | Schools and mosques providing vocational training and activities | Faith-based place-based deradicalization programs |

Table 4. Application of Social Infrastructure in Three Problem Areas

Conclusions

The United States, Japan, and other advanced industrial democracies have long underinvested in the obvious, tangible, and mundane built environment that sustains our economy: roads, bridges, ports, and dams. The American Society of Civil Engineers has yet to rate the facilities in any state or localities in the U.S. with a grade above a C, and many pieces of our gray infrastructure have received failing grades (ASCE 2021). But even the current North American administration's push for a large-scale overhaul of physical infrastructure may be missing more critical elements of our society: the invisible, often overlooked social infrastructure which helps solidify and strengthen our civic infrastructure.

Other challenges come with gray infrastructure: standard physical infrastructure projects, designed to mitigate the impact of climate change and other shocks, may increase damage to local communities (Hummel, Griffin, Arkema, and Guerry 2021). Shore hardening and armoring projects - using concrete breakwaters, seawalls, tetrapods, and ripraps to reduce flood impact - regularly destroy local ecosystems and reduce biodiversity (Gittman et al 2016). While we certainly need much of our gray infrastructure, we also have the tendency to underestimate its negative externalities on society.

Given its cost-effectiveness, social infrastructure has the potential to help solve major challenges across policy realms. In the field of counter-terrorism, for example, facility-based vocational training and mosque-based reconciliation can decrease the likelihood of recruitment and draw away support for terror groups (Aldrich 2012b, 2014). Without the ability to divert would-be terrorists from joining violent extremist groups or provide medical treatment to addicts, we continue to invest in law enforcement systems that provide punishment but not justice or equity. In fighting crime, programs that support mental health through halfway homes, drug treatment centers, and library-based skills improvement can reduce recidivism and crime (Steadman et al 2000; Compton et al 2008). In mitigating and responding to natural hazards like tsunamis, floods, and earthquakes, investments in school-based citizen science and community centers have reduced harm and accelerated recovery (Aldrich 2012, 2019). Japan's 3/11 disasters demonstrated how \$250 billion USD invested in 40+ foot tall concrete seawalls disrupted local ecosystems, angered residents, and did little to save lives, while the intangible bonds in coastal Tohoku communities helped people survive and thrive (Matanle, Littler and Slay 2019; Yarina 2022).

Many questions remain, and future research should pursue four related avenues of inquiry. First, given available data on physical and social infrastructure, scholars should seek to understand why we

overinvest in seawalls, berms, and other projects, and underinvest in *kōminkan*, community centers, libraries, and other social infrastructure. This question is sharpened by a growing body of evidence that higher investments in physical infrastructure may, in fact, slow or reverse population recovery after disasters (cf. Nagamatsu 2018; Fraser, Aldrich and Small 2021). It is likely that our overinvestment in physical infrastructure stems at least in part from the traditional use of cost-benefit analyses, which collect data on built structures and the costs of rebuilding but cannot capture issues of equity and social consequences (Junod, Martin, Marx, and Rogin 2021). Further, public sector spending on large-scale gray infrastructure projects crowds out organic, bottom-up, community-led growth (Kameda, Miwa, and Nagamine 2021). By harming the natural environment, disproportionately incarcerating people of color, and creating collateral damage among civilians, physical infrastructure responses often exacerbate racial inequality and further climate injustice (Sunter, Castellanos, and Kammen 2019).

Some answers are likely to be found in the political economy of physical infrastructure - namely that politicians and decision-makers benefit from physical infrastructure spending through lobbying and political donations from firms in the industry. Further, social infrastructure investments may be less attractive to decision-makers who prefer the larger-scale, more expensive investments connected with physical infrastructure due to their visibility and rapidly visible outcomes. Because of these challenges and the path dependence around traditional investments, government agencies around the world planning new facilities and spaces to manage climate change are starting to recognize that older school, cost-benefit analysis (CBA) approaches miss the nuances that more sophisticated approaches like the triple-dividend approach can uncover (Hegelson and Li 2022).

Second, this paper has looked primarily at the role of a limited set of social infrastructure facilities - namely *kōminkan* (citizens' public halls), community centers, libraries, and parks - and did not look at the role of other free-to-enter, publicly support sites such as schools and shrines or private, closed sites such as social businesses (e.g. cafes, pubs, food trucks parked outdoors, barbershops, etc.). While data availability precludes analyzing the impact of these types of facilities in this article, qualitative research has indicated that one type of social infrastructure - shrines in Tohoku, Japan - may have saved the lives of coastal residents through their deliberate location on high ground (Takase, Yoshida, and Kumagai 2012). Future research should expand the types of social infrastructure facilities under investigation.

Third, we need to begin illuminating the degree to which social infrastructure can measurably impact the resilience of communities to other global challenges, such as terrorism and crime (Compton et al 2008; Anever 2015; Aldrich 2012b, Aldrich 2014). Too often decision-makers continue to fall back on standard, kinetic approaches to terrorism, violent extremism, and crime rather than considering alternatives that may simultaneously be less expensive and more efficacious. A fourth and final area of investigation is the degree to which quality – and not just density or quantity – of social infrastructure facilities builds resilience to shocks and stressors in neighborhoods. Little systematic data exist on whether a highly utilized, top-quality park, library, or café builds collective action potential and increases intergroup connections more effectively than poorly constructed, rarely utilized sites.

We need to begin taking the architecture of our cities and towns seriously, recognizing that without common spaces, parks, pools, and defensible space we will see more and more ruptures in our social fabric (Newman 1972). Without unity, collaboration, and communication, residents may lack trust in pronouncements from government officials, as we have seen during the ongoing COVID-19 pandemic (Fraser, Aldrich, Page-Tan 2021). Our social infrastructure – and the NGOs and civil society organizations that flourish because of them – should not be overlooked (Ananthanathan 2021). Without confidence in our leaders and ties to our neighbors, finding the good life will continue to be only a dream for many (Pharr and Putnam 2000).

Appendix 1

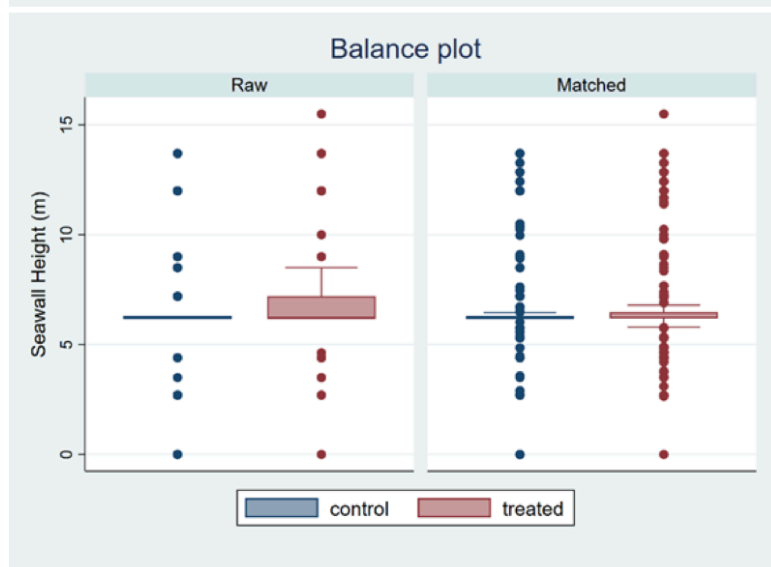
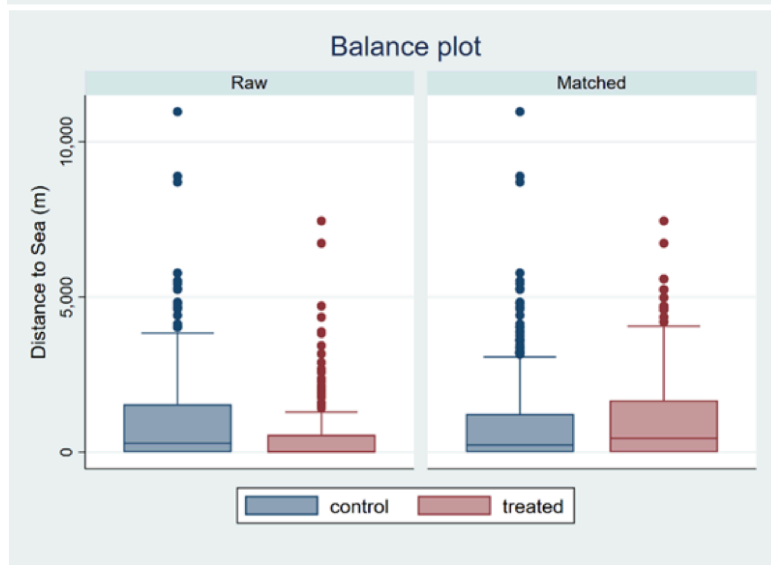
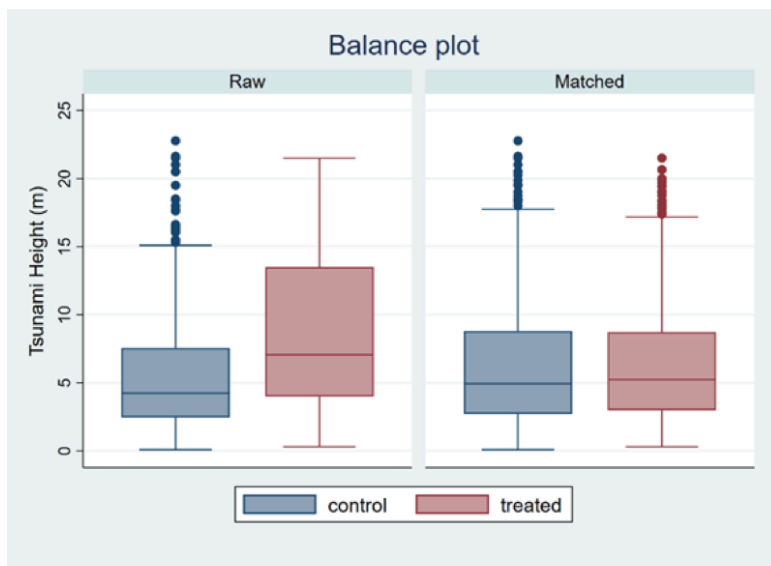
| Variable | Measured through | Data source |
|---|---|---|
| Elder Mortality (Proportion) | Number of deaths of those over 65 divided by the population in the neighborhood | 2012, Kenji TANI, Distribution of the number of deaths and the death rate on the Great East Japan Earthquake http://ktgis.net/tohoku_data/small_area_map/ |
| <i>Geography</i> | | |
| Area of the Neighborhood (meters sq) | Area of the neighborhood in square meters | Statistics Bureau, Ministry of Internal Affairs and Communications (https://www.e-stat.go.jp/gis) |
| Height of the seawall (m) | Height of the nearest seawall to the neighborhood in meters | Ministry of Land, Infrastructure, Transport and Tourism (http://www.thr.mlit.go.jp/) |
| <i>Hazard</i> | | |
| Height of the tsunami (m) | Height of the tsunami in meters | 2011 Tohoku Earthquake Tsunami Joint Survey (TTJS) Group (http://www.coastal.jp/ttjt/index.php) |
| Distance to the sea (m) | Distance from the neighborhood to the Pacific Ocean | Geospatial Information Authority of Japan (GSI) (http://www.gsi.go.jp/ENGLISH/) |
| <i>Economic Conditions</i> | | |
| Proportion of residents owning homes | Proportion of the neighborhood residents owning (as opposed to renting) their homes | Statistics Bureau, Ministry of Internal Affairs and Communications |

| Variable | Measured through | Data source |
|--|---|--|
| University educated (proportion) | Proportion of the community with a college or university education | Statistics Bureau, Ministry of Internal Affairs and Communications (https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00200521) |
| <i>Social infrastructure</i> | | |
| Social infrastructure density (proportional) | Number of kominkan, cultural centers, and parks in the neighborhood divided by the population | National Land Numerical Information, Japan (http://nlftp.mlit.go.jp/ksj/index.html) |
| <i>Social capital</i> | | |
| Non Profit Organizations (proportional) | Number of NPOs in the neighborhood divided by the population | Cabinet Office, Government of Japan (https://www.npo-homepage.go.jp/npoportal/) |
| Residential stability (percent) | Percentage of the population living in the same community as five years ago | Statistics Bureau, Ministry of Internal Affairs and Communications (https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00200521) |

Table A1. Variables, their measurements, and sources

Appendix 2: Balance plots of raw and matched data for selected

variables



Appendix 3: Cost and Mortality Reduction Calculations

Researchers estimated the per-meter cost of seawall construction in Tohoku at 482,877 JPY (roughly \$3500 USD) per meter (Burnett et al 2016) while others argued that a 4 m high, 420 m length wall runs \$10 million USD with a 20m height wall of the same length reaching some \$50 million (Kanda 2015). Following this approach, which found a linear relationship between elevating existing walls and cost, I assume that increasing the height of a 420 m tsunami wall (sufficient to ward a neighborhood) by a meter runs roughly \$5 million USD. For the cost of \$5 million USD, a 1-meter increase in average neighborhood seawall height is projected to decrease elderly mortality rates by 0.233.

The cost of building a single community center – a prime example of social infrastructure – runs at roughly \$1 million USD (including maintenance and energy costs) (based on Aldrich and Kiyota 2017); each neighborhood in our sample hosts an average of fewer than 2 social infrastructure sites with an average population of 1500, that is, 0.0013 sites per capita. For every million dollars spent on more social infrastructure (i.e. one more community center or park), elder mortality rates decrease further, by -0.228 given the original 2 sites, -0.342 given 3 for \$1 million more, then -0.456 (4), -0.57 (5), -0.685 (6), totaling a decrease of -0.799 (7) for a hypothetical \$5 million investment.

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