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Socio-economic consequences of post-disaster reconstruction in hazard-exposed areas

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Supplementary Note 1: Hazard exposure and socio-economic segregation

One exception to the general pattern of lower-income households living in hazard-exposed areas occurs where a wealthy class that is able to self-insure remains in or moves into coastal areas for reasons such as coastal amenities^{1,2}.

Supplementary Note 2: Rapid-onset coastal hazards

Although tsunamis and storm surges differ in their generating mechanisms, warning lead times, speed of onset, and other physical characteristics, in both cases the hazard they pose is greatest closest to the coast. Consequently, the tradeoffs made in resettlement decisions will have many similarities across both types of coastal hazard. Given the rarity of extreme events of either type, it can be helpful to draw lessons from resettlement following both types of hazard event in order to help coastal communities manage their overall coastal risk, whether they are exposed more to storm surges, or more to tsunamis, or to both.

Aceh remains exposed to coastal hazards. Aside from coastal hazards associated with sea-level rise and storm surges, the proximity of Aceh to a subduction zone exposes Aceh to recurring large tsunamis. Geological and archaeological evidence indicate that indeed Aceh has been affected by many large tsunamis in the past, with recurrence intervals ranging from ~56 years to more than 2000 years^{3,4}.

Supplementary Note 3: Local tsunami knowledge before the 2004 tsunami

There is no clear historical or geological evidence of a major tsunami having affected the coastline of Banda Aceh since perhaps the late 14th century^{3,4}, while anecdotal evidence indicates that before the 26-Dec-2004 tsunami, no-one in Banda Aceh knew that a tsunami could occur there. To investigate this further, we asked focus groups of 6-10 residents in each of 7 villages in the tsunami-affected area of Banda Aceh whether they knew that a tsunami was possible in their area. In 6 of these villages, residents said that no-one knew about tsunamis. In one village that lies directly on an exposed part of the coastline, one resident reported that her grandparents had told her that the area had been flooded in the past, but did not report stories of something as destructive as the 2004 tsunami. This evidence is consistent

with anecdotal accounts that tsunami risk was essentially unknown to the population of Banda Aceh prior to the 2004 tsunami.

The situation in Banda Aceh contrasts sharply with the case of the island of Simeulue, located to the southwest offshore the mainland part of Aceh. Simeulue (but not Banda Aceh) was affected by a locally large tsunami in 1907; knowledge of this was passed down through oral traditions and led the population of Simeulue to self-evacuate after the 26-Dec-2004 earthquake and prior to the arrival of the tsunami. As a result there were only 7 casualties reported from a population of 78,128 ⁵.

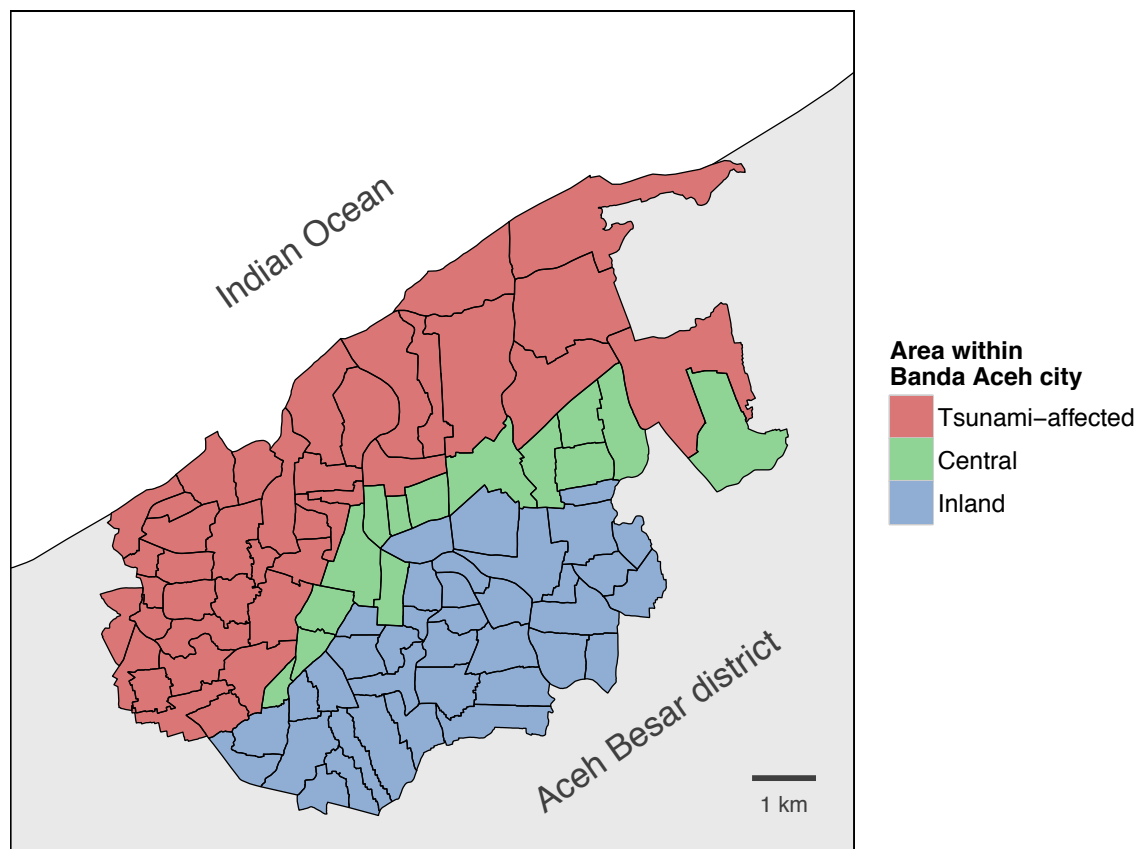
Supplementary Note 4: Housing aid

To examine the context of the decision by aid providers to rebuild predominantly in-place, we interviewed 14 officials who work or worked in higher levels of the local government, Indonesian Agency for Reconstruction (BRR), or NGOs. Their accounts suggest that a lack of funding to acquire land was a major obstacle to providing a relocation option in the early stages of reconstruction. Some accounts suggest that in the first few months after the tsunami, most survivors did not want to return because of the trauma from the disaster and fear that it could recur. This is consistent with a study conducted a few months after the tsunami, which found that roughly half of a sample of internally displaced people wanted to resettle outside the tsunami-affected area, rather than return to their original villages⁶. However, by the time Indonesian Agency for Rehabilitation and Reconstruction (BRR) officially formed four months after the disaster, they faced pressure from donors and affected persons to rebuild housing quickly. The BRR approved housing and infrastructure reconstruction projects within the tsunami-affected area.

Our surveys and interviews with residents and village leaders show that very few housing aid beneficiaries were given a choice to return or relocate: tsunami survivors who owned land before the tsunami were typically offered housing aid only to rebuild on that same land, whereas those who did not own land before the tsunami were typically offered housing aid only in a relocation complex outside their original community. Most of these relocation complexes are located on the far eastern edge of the urban periphery in Aceh Besar district. Though it was not the intention, this reconstruction approach effectively split pre-tsunami communities by socio-economic status, not by where people wished to live. In our

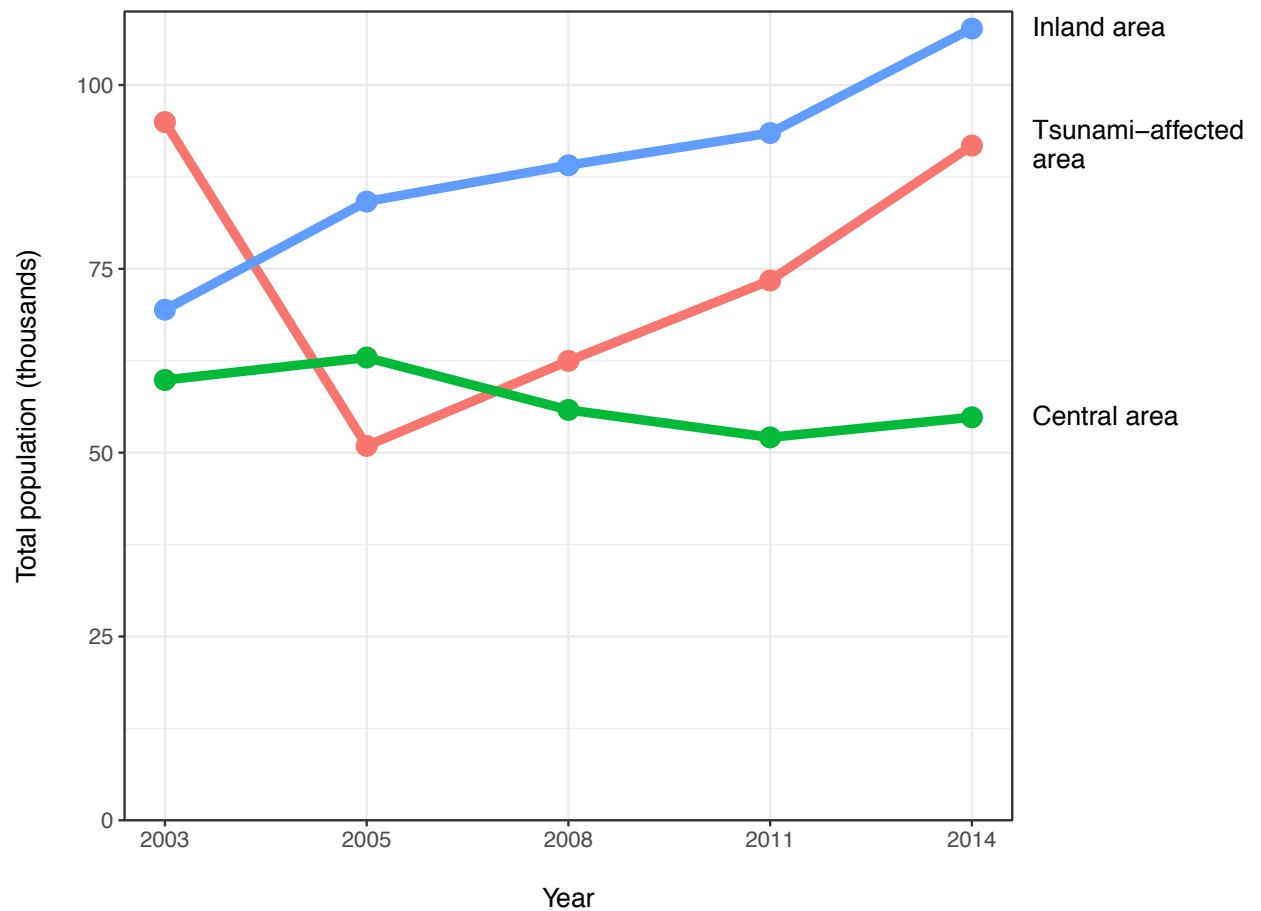
survey samples, only 2% of households in relocation complexes were given the option to return to their former village, while only 9% of households in tsunami-affected villages in Banda Aceh were given the option to relocate outside the tsunami-affected area. The few relocation options that were offered were generally offered to a village as a whole.

Housing aid was typically provided to surviving members of a household, with two exceptions that we cannot quantify. First, in cases where no members of the household survived, housing aid could have been provided to relatives who successfully claimed the land title. Second, some accounts suggest that some aid beneficiaries may have been newcomers who posed as tsunami survivors in order to receive aid houses. We cannot confirm this, nor are we aware of evidence that this could account for a large number of cases.



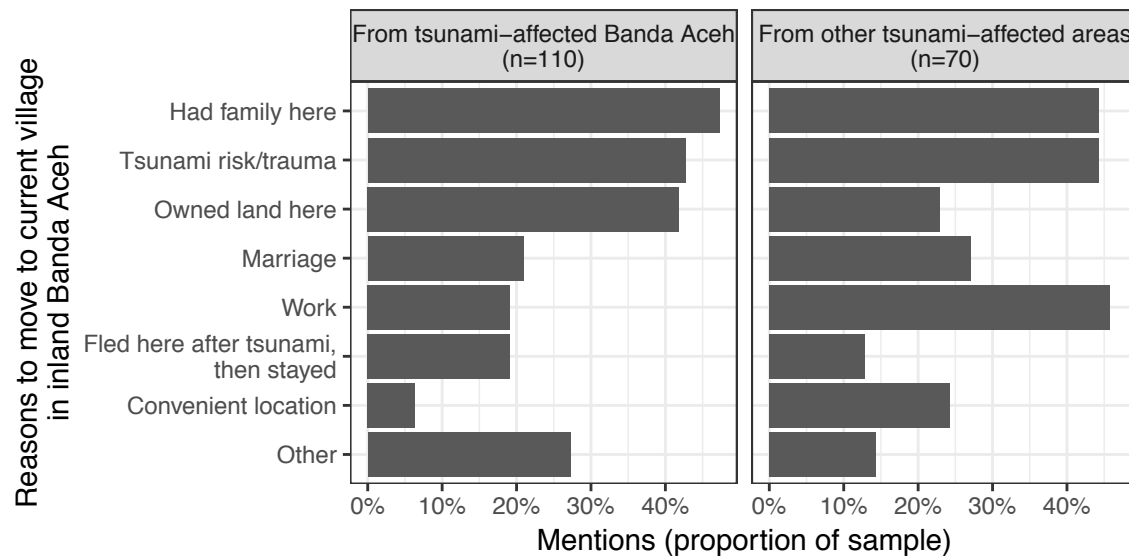
Supplementary Figure 1

Our classification of villages in the city of Banda Aceh, based upon damage caused by the 2004 tsunami^{7,8}: the 'tsunami-affected' area experienced moderate to total destruction; the 'central' area experienced minor to moderate damage; the 'inland' area was not affected. Village borders drawn within the city of Banda Aceh.



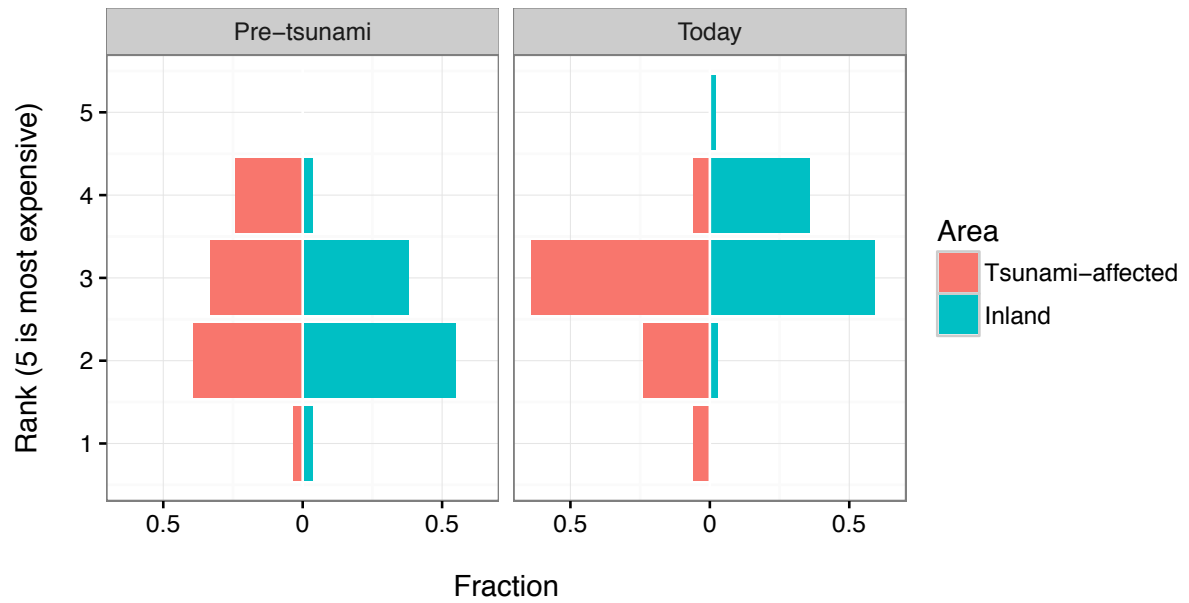
Supplementary Figure 2

Population of Banda Aceh by the areas identified in Supplementary Figure S1. Data from the Statistics Agency of Indonesia and Population Agency for Banda Aceh, as described in the Methods.



Supplementary Figure 3

Reasons mentioned for moving (open-response, unprompted) by those who moved from a tsunami-affected area to the inland part of Banda Aceh. Left: those whose original village is located within the city limits of Banda Aceh. Right: those whose original village is located elsewhere in the province of Aceh, including periurban and rural areas. Unsurprisingly work is mentioned more frequently by this group, as moves to the city enable access to new job opportunities. Nonetheless it is notable that tsunami risk was mentioned as frequently as a reason that they moved to their current village.



Supplementary Figure 4

Rankings by village leaders of property prices in their villages relative to other villages in Banda Aceh at the time (pre-tsunami, 2000-2003; today, 2010-2015). Data shown as fraction of all estimates by area and time period.

Supplementary Table 1

Comparison of main source of household income for the three groups discussed in the main text: tsunami survivors who moved on their own (without aid) to the inland part of Banda Aceh, tsunami survivors who still live in their aid houses in the tsunami-affected area, and newcomers to the tsunami-affected area. Data shown as percentages within each group.

Main source of household income	Tsunami survivors who moved inland	Tsunami survivors in tsunami area	Newcomers in tsunami area
Farming	1.8%	1.0%	4.2%
Fishing	2.7%	5.8%	1.9%
Civil service	35.4%	13.2%	15.3%
Business (including market sellers and cottage industry)	43.6%	52.6%	65.1%
Unskilled labor	9.1%	15.5%	8.4%
Unemployed	2.7%	1.6%	4.2%
Other (including retirees)	4.5%	10.3%	0.9%

Supplementary Table 2

Contrasts for proportions reported in Figure 2b. Using the post-hoc Marascuilo procedure, contrasts are significant at α where the difference between proportions is greater than the critical range value r , where $r_{i,j} = \sqrt{\chi^2_{1-\alpha, k-1}} \sqrt{p_i(1-p_i)/n_i + p_j(1-p_j)/n_j}$. SI = tsunami survivors living in the inland area, ST = tsunami survivors living in the tsunami-affected area, NT = newcomers to the tsunami-affected area.

Contrast	Value	Critical range $\alpha = .05$	Critical range $\alpha = .01$	Critical range $\alpha = .001$	Significant?
<i>Proportion with university/vocational degree</i>					
SI-ST	0.243	0.127	0.158	0.193	Yes ($\alpha = .001$)
SI-NT	0.145	0.137	0.170	0.208	Yes ($\alpha = .05$)
ST-NT	0.098	0.091	0.113	0.139	Yes ($\alpha = .05$)
<i>Proportion with income as civil servants</i>					
SI-ST	0.222	0.121	0.150	0.184	Yes ($\alpha = .001$)
SI-NT	0.201	0.127	0.157	0.193	Yes ($\alpha = .001$)
ST-NT	0.021	0.076	0.095	0.116	No

Supplementary Table 3

Statistics for inflation-adjusted estimates of property prices (in million IDR), for the pre-tsunami period (2000-2003) and today (2010-2015). Land price per m²; house price for 2-3 bedroom house; rental price for 2-3 bedroom house per year. Welch's *t*-test (two-tailed); effect size as $r = \sqrt{t^2/(t^2 + df)}$; differences in today's prices significant even applying the conservative Bonferroni correction for the three types of price estimate.

Time	Price type	Tsunami-affected			Inland area			<i>t</i>	df	<i>p</i>	<i>r</i>
		n	Mean	SE	n	Mean	SE				
Pre-tsunami	Land	26	0.71	(0.07)	18	0.76	(0.10)	−0.41	31.0	.68	.07
	House	20	291	(39.7)	14	366	(36.0)	−1.40	31.7	.17	.24
	House rent	24	6.65	(0.77)	18	7.21	(0.69)	−0.55	39.9	.59	.09
Today	Land	26	0.54	(0.06)	18	1.15	(0.11)	−4.90	25.1	<.001	.70
	House	26	178	(13.5)	18	436	(22.9)	−9.74	28.5	<.001	.88
	House rent	26	5.66	(0.33)	18	9.97	(0.58)	−6.51	27.7	<.001	.78

Supplementary Table 4

Raw data from the Statistics Agency of Indonesia and Population Agency for Banda Aceh and our calculation method for poverty rate estimates presented in Figure 3. As detailed in the Methods section, data that is reported consistently for all examined time periods (2003, 2011, and 2014) includes the number of households granted poverty status and the total population. To calculate estimated poverty rates as percentages, we multiply the number of households by the average household size of 4.99 persons per household for the 2003 data and by 3.89 persons per household for the 2011 and 2014 data. We then divide this by total population (further details provided in Methods).

	Tsunami-affected area	Central area	Inland area
2003 number of households granted poverty status	1829	1463	2110
2003 total population	94,971	59,881	70,141
2003 estimated poverty rate (using 4.99 people per household)	9.6%	12.2%	15.0%
2011 number of households granted poverty status	4467	1275	2340
2011 total population	73,422	55,127	97,728
2011 estimated poverty rate (using 3.89 people per household)	23.7%	9.0%	9.3%
2014 number of households granted poverty status	6395	1522	4427
2014 total population	91,771	58,182	112,271
2014 estimated poverty rate (using 3.89 people per household)	27.1%	10.2%	15.3%

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