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Rehabilitating coastal agriculture and aquaculture after inundation events: Spatial analysis of livelihood recovery in post-tsunami Aceh, Indonesia

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ABSTRACT

This paper presents GIS time-series land-use analysis of satellite images to quantify the recovery of rice cultivation and aquaculture following the 2004 Indian Ocean tsunami in coastal communities in Aceh, Indonesia. We supplement this with qualitative data to illustrate the post-disaster challenges faced by residents, and the extent to which coastal communities have adapted to post-tsunami realities. Our analysis shows that the rehabilitation of rice cultivation and aquaculture in areas inundated by the tsunami has been limited by extensive degradation of land, diversion of labor by tsunami mortality and transition to alternative livelihoods, and re-purposing of rice fields for residential use during the reconstruction phase. This is especially prominent in areas where subsistence activities are not the primary source of livelihood. The Aceh case study shows that social, economic, and environmental factors can be stronger determinants of how coastal livelihoods rebound and change following destructive inundation events than livelihood rehabilitation aid. Additionally, our case study suggests the human impact of coastal hazards can be felt outside the physical extent of inundation.

1. Introduction

The impact of disasters upon livelihoods has become an increasing concern (IFRC, 2010; Pomeroy et al., 2006; UNDP, 2013). It is widely accepted that disasters can negatively impact economic productivity through destruction of productive assets, disruption of markets and supply chains, and loss of labour (Noy, 2009; Raddatz, 2009). In coastal regions, the mechanical damage and ecological changes caused by inundation events such as floods, storm surges and tsunami result in extensive damage to agriculture and aquaculture (FAO, 2008; Griffin et al., 2013; Marohn et al., 2012). Examples from storm and tsunami prone areas, such as the Caribbean, South Asia and Southeast Asia, demonstrate that economic impacts of coastal hazards are felt at the household level, and can be difficult to recover from (Cutter et al., 2003; Fuentes-Nieva and Seck, 2010).

It has become increasingly common, especially in the developing world, for governments and humanitarian actors to emphasize the importance of increasing the resilience of coastal livelihoods, and to make sustainable subsistence livelihoods a core part of post-disaster reconstruction (IFRC, 2010; UNDP, 2013). Evidence from areas that experience regular and repeated inundation events suggests local economic systems may develop adaptive measures (Simmie and Martin, 2010; Vale and Campanella, 2005). However, it is not clear from the literature how systems respond following extraordinary or unanticipated events, such as major storm surges or tsunami (Ingram et al., 2006; Lettieri et al., 2009). This paper uses data from post-tsunami Aceh, Indonesia to discuss coastal livelihood recovery following high intensity and infrequent hazards that are not factored into, or greatly exceed, local adaptive measures.

The 2004 Indian Ocean tsunami caused massive loss of life,

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extensive damage to the built and natural environments, and reduction of livelihood opportunities for residents in Indonesia, Thailand, Malaysia, India, Sri Lanka, and the Maldives (World Bank, 2005; Jayasuriya et al., 2006; Suwat and Crookall, 2011; Thorburn, 2009; etc.). In Indonesia, the tsunami devastated local economies reliant upon subsistence livelihood strategies such as fishing, aquaculture (fish ponds), rice cultivation, and gardening (Thorburn, 2009). The physical impact of the earthquake and tsunami resulted in erosion, subsidence, coastal deformation, soil/water contamination, and widespread debris – all of which contributed to the degradation of rice fields and fish pond boundaries, water management systems, and seed stock necessary for both rice cultivation and aquaculture (Griffin et al., 2013; Marohn et al., 2012; Phillips and Budhiman, 2005; Subagyono et al., 2005; Tinning, 2011; etc.). The Food and Agricultural Organization of the UN (FAO) estimated the economic cost of the loss of rice cultivation in Aceh was approximately 270 million USD (FAO, 2006), whereas almost half the fish ponds used for aquaculture in Aceh were 'severely damaged or lost' (Phillips and Budhiman, 2005, p. 4); damage estimated at approximately 50 million USD (World Bank, 2005).

Significant resources were mobilized by governments, citizens, the private sector, and the international humanitarian system to rebuild tsunami-affected areas in Aceh (Daly, 2015; Daly et al., 2012; Daly and Brassard, 2011; Telford et al., 2006; etc.). Almost 400 million USD was allocated for rehabilitating agriculture and aquaculture in the Aceh province between 2005 and 2009, coordinated initially by the Indonesian Ministry of Agriculture, and then by the *Badan Rehabilitasi dan Rekonstruksi*[1] (FAO, 2006). A wide range of donor and government funded programs supported the physical rehabilitation of rice fields and fish ponds (which included clearing debris, rebuilding field/pond barriers and water management features, reconnecting roads and paths); provision of technical assistance (assessing levels of salinization, soil and water chemistry, introducing new approaches that combine mangrove planting and aquaculture, etc.); provision of productive assets (tools, seeds, fertilizer, fencing, new fish and crab species); grants and micro-credit programs; and small business skills training (FAO, 2006; Thorburn, 2009; Subagyono et al., 2005).

Initial assessments predicted that the damage to rice cultivation would be severe and long lasting – with some areas possibly never regaining pre-tsunami levels of productivity (World Bank, 2005; Marohn et al., 2012). However, a World Bank report in 2008 stated that by 2007 the agricultural sector had surpassed "pre-tsunami production by 5%" (World Bank, 2008). The same report concluded that by 2006 "the rehabilitation process has had a major impact in returning the agricultural sector to its previous level of productivity … Whilst there are no data that can be used to make comparisons between pre- and post-tsunami rice yields, the yields obtained post-tsunami are reasonable and clearly indicate a return to normality (World Bank, 2008, p. 3)."

Other studies have indicated that a combination of post-disaster assistance, including the introduction of new species, aquaculture techniques, and fisher cooperatives, helped replace aquaculture productivity lost during the tsunami (Mills et al., 2011; Padiyar et al., 2012; Rimmer et al., 2012). However, one study on the impact of the tsunami on coastal resources showed that 92 per cent of fishponds in selected areas in Aceh were not rehabilitated as of 2011 (Griffin et al., 2013). With the exception of Griffin et al. (2013), livelihood assessments in Aceh lack data on the extent rice cultivation and aquaculture changed after the tsunami, and thus cannot comment fully on the success of rehabilitation efforts, and how coastal communities have adapted.

In this paper we use GIS analysis of high resolution satellite images, coupled with qualitative data, to examine the macro-level changes to rice cultivation and aquaculture (consisting of fishponds) for three zones within the Aceh province of Indonesia that were affected by the tsunami. We conduct a time-series analysis to show changes in the number of hectares used for rice cultivation and aquaculture from the pre-tsunami period through 2013. We complement this with qualitative data obtained from local stakeholders to better understand the impact of the tsunami and the processes of rehabilitation. A more detailed understanding of the outcome of aid, and how local communities have adapted to altered environments, is important for formulating effective policies for managing coastal livelihoods at risk from inundation events.

2. Research sites

The Aceh province is located in northern Sumatra, straddling the Indian Ocean and the Straits of Melakka (Fig. 1). The province is 58,000 square kilometers, with a population of approximately 5 million as of 2015.[2] Situated four degrees north of the equator, the climate is tropical. The province is mountainous, with most of the population living on narrow coastal plains. Before the 2004 tsunami, Aceh's GDP was 3.7 billion USD. It increased to 9.6 billion USD by 2015 – growth largely resulting from the opening of Aceh's economy following the end of a long running separatist conflict in 2006.[3] As of 2015 agriculture, forestry, hunting and fishing represent 29% of the GDP, increasing steadily from 25% in 2010. Nearly half the work force in Aceh works in agriculture, forestry, hunting and fishing (44.83%), a decrease from 48.47% in 2008. The unemployment rate in Aceh was 9.35% in 2004. After the tsunami, it increased to 14.0% in 2005. It decreased to 8.71% in 2009 and 7.57% in 2016, but is still higher than national unemployment rate of 5.61%.

When the tsunami hit, 28.37% of Aceh's population was below the poverty line, as compared to the overall national average of 16.66%. Poverty in Aceh increased slightly in the aftermath of tsunami to 28.69% in 2005. It fell to 21.80% by the end of post-tsunami rehabilitation period in 2009. The poverty level in 2016 was 16.43%. Although Aceh's current poverty rate is below its pre-tsunami level, it is still higher than the national level of 10.70% (Badan Pusat Statistik, 2017). Given the complex political dynamics over the past decade, it is not possible to clearly isolate how much of the economic changes in tsunami-affected regions are the result of reconstruction aid, and how much is related to wider macro-trends. However, the data suggests that Aceh as a province has made considerable economic strides since the ending of the conflict in 2006, with the share of GDP from agriculture and fisheries increasing slightly, and the related work force in these sectors decreasing slightly. This provides a crude baseline for relating rehabilitation of agriculture and aquaculture in tsunami-affected areas with province-wide trends.

This study focuses on three zones along the north and west coast of Aceh (Zones 1–3, Fig. 1). The zones were selected to provide a representative sample of areas impacted by the 2004 tsunami,

[1] The BRR was the Indonesian reconstruction agency that was established to coordinate the delivery of aid in Aceh until April 2009.

[2] The data in this section come from publically available data from the Aceh government and Indonesian national government (Badan Pusat Statistik, 2017; Statistics of Aceh Province, 2009; 2016).

[3] The Aceh province was mired in a decades long conflict between the *Gerakan Aceh Merdeka* (GAM), a militant separatist group, and the Indonesian army. This severely limited development opportunities and local governance structures within Aceh, and was especially difficult for people living in rural areas. The conflict ended in 2006, partly as a result of the tsunami and international aid effort (Daly et al., 2012; Miller, 2009; Reid, 2006).

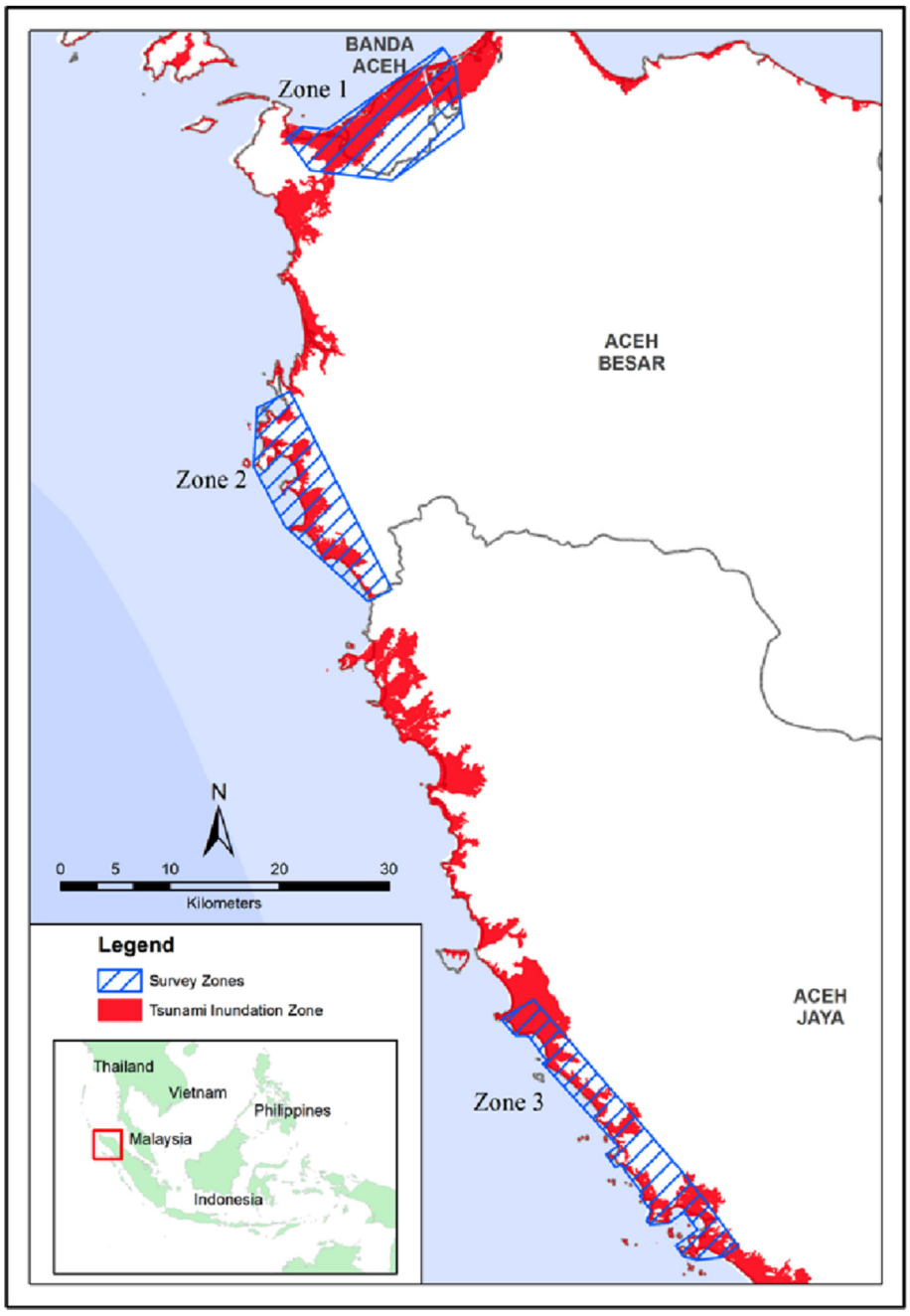

Fig. 1. Location of survey zones in Aceh, Indonesia. The 2004 tsunami inundation is indicated in red.

and to include a mix of urban and rural settings. Zone 3 is situated at the furthest point from the major aid distribution centers of Banda Aceh to the north and Meulaboh to the south, to control for proximity to aid distribution points. All three zones were decimated by the tsunami, with near total destruction in the inundation zone, and received substantial reconstruction aid, as discussed below. Following the tsunami, the reconstruction policy endorsed by the Indonesian Government, and supported by international donors, generally favored preserving pre-tsunami patterns of land ownership and use. Most tsunami survivors initially returned to their pre-tsunami land, received aid to rebuild and rehabilitate pre-tsunami infrastructure and livelihoods.

Over 40 million USD was spent in the three zones on livelihood rehabilitation. Aid consisted of cash-for-work to clear land and rebuild infrastructure, provision of assets, financing, and training programs (details of aid projects are provided in Supplementary Tables 1–4). Table 1 shows a summary of aid received for each zone, divided into assistance for small businesses & micro-enterprises, agriculture, fisheries & aquaculture, general economic infrastructure, and other. The distribution of aid broadly reflects pre-tsunami livelihoods, with the urban Zone 1 receiving more support for small businesses, fisheries, and large-scale physical capital projects such as market places, and fish processing plants. Most of the aid for rural Zones 2 & 3 was for agriculture.

Table 1
The total post-tsunami livelihood aid received for each Zone and percentage of funding allocated by main livelihood category. See Supplementary Table 4 for a more detailed breakdown.

Zone	Total	% Small Business	% Agriculture	% Aquaculture Fisheries	% General Economic Infrastructure	% Other
Zone 1	29,302,360	22.8	6.5	18	51.6	0.8
Zone 2	6,653,473	14	76	7.8	1.6	0.3
Zone 3	5,769,128	7.4	61.5	0.49	22.7	7.8
Total	**41,724,961**					

2.1. Zone 1

Zone 1 includes the city of Banda Aceh, the administrative capital of the province, and home to over 200,000 people at the time of the tsunami. The main sources of livelihood before the tsunami were small businesses, informal day labor, government civil service, fisheries, and rice agriculture. Most of the neighborhoods/villages along the coast engaged in aquaculture. Rice fields ringed the city and extended far to the south. The tsunami penetrated up to 2 km inland, causing almost complete destruction to the built environment, massive loss of life, and significant alteration to the natural environment. All aquaculture features and large tracts of rice fields were damaged.

Between 2005 and 2008, 65 registered livelihood projects spent just over 29 million USD in tsunami-affected villages in Zone 1 (Supplementary Table 1). Seven projects spent almost 2 million USD rehabilitating agriculture. These supported cash-for-work to clear agricultural lands, training and capacity building programs, and provision of equipment, seeds, fencing and fertilizer – most of which was dedicated for rice cultivation. Seventeen projects spent over 5 million USD rehabilitating the fishing industry (Supplementary Table 1). This was spilt between providing equipment such as boats and nets for fishermen, building fish processing and selling facilities, and clearing and repairing damaged aquaculture infrastructure.[4] Half the livelihood aid in Zone 1 was used for large economic infrastructure projects such as markets, ports, and manufacturing & processing facilities.

2.2. Zone 2

The villages in Zone 2 occupy a narrow coastal plain, ranging from 100 to 3000 m wide - abutting heavily forested mountains. Zone 2 is predominantly rural, with respondents stating that up to 90% of pre-tsunami livelihoods involved rice cultivation, tree-crop plantations, fishing and aquaculture. Due to the separatist conflict, and poor transportation infrastructure, Zone 2 villages had long been isolated and disconnected from Banda Aceh. All inhabited areas were inundated by the tsunami, causing heavy damage to rice fields and aquaculture, and major loss of life.

Between 2005 and 2008 17 registered livelihood rehabilitation projects were carried out by donors in Zone 2, totaling more than 6.6 million USD (Supplementary Table 2). Seventy six percent of the aid was allocated for agricultural rehabilitation (approximately 5 million USD), most of which was for rice cultivation. Aid supported cash-for-work to clear rice fields, rebuild rice field and irrigation infrastructure, distribution of inputs such as seeds, fertilizer, fencing and farming equipment, and capacity building. Zone 2 received very little dedicated aid for rehabilitating aquaculture.

2.3. Zone 3

Zone 3 consists of a shallow coastal plain abutting jungle-covered mountains, often no more than 1500 m wide. As this area serves as the administrative center of the Aceh Jaya district, a significant number of the residents within tsunami-affected villages were government civil servants or manage small businesses. Subsistence livelihoods were a secondary part of the overall economic strategy. The tsunami destroyed the entire built environment, caused massive loss of life, and damaged most rice fields. There was no aquaculture in the zone before the tsunami.

Between 2005 and 2008, 16 registered livelihood projects were carried out by donors in Zone 3 villages, totaling more than 5.7 million USD (Supplementary Table 3). Slightly more than 60% of the funding (3.5 million USD) was allocated for agriculture rehabilitation, mostly for rice cultivation. These projects provided funding to clear debris and rebuild basic agricultural infrastructure (mainly through cash-for-work schemes), provision of agricultural inputs such as seeds, fertilizer, and equipment, and training/capacity building. The rest of the livelihood aid went towards infrastructure and small business support programs.

3. Methods and materials

The data in this paper draws from a multidisciplinary survey of the sustainability of post-tsunami aid, carried out between 2013 and 2015 by a large team of Acehnese and international researchers.[5] Data on land use change derives from GIS analysis of high-resolution (typically 1 m) satellite images. The use of GIS and satellite imagery is a proven method for analyzing land use change over time, and has increasingly been used for assessing impacts of disasters, and post-disaster reconstruction (Contreras et al., 2016; Dionisio et al., 2015; Guo et al., 2011; Joyce et al., 2009; Tralli et al., 2005; Tsai et al., 2010; etc.).

We acquired high-resolution satellite images for each zone, covering the pre-tsunami period (2003–2004), immediately following the tsunami (2005), and following the end of the official reconstruction period (2011–2013).[6] For each zone and time period, land used for rice cultivation and aquaculture was visually identified by land use experts and manually digitized in ArcGIS. We

[4] While we don't include it in our study, the impact of the tsunami and aid efforts on the off-shore fishery industry in Aceh has received significant attention (Alexander et al., 2006; De Silva and Yamao, 2007; Dixon and McGregor, 2011; Garces et al., 2010; Tewfik et al., 2008; Thorburn, 2009; etc.).

[5] The data was collected as part of the Aftermath of Aid project, a joint research initiative of the International Centre for Aceh and Indian Ocean Studies, and the Earth Observatory of Singapore. The project involved over 150 researchers and field staff, looking at the sustainability of aid, and transformation across seven sectors: housing, demographics, livelihoods, disaster risk reduction, governance, relocation, and gender. The project conducted in-depth fieldwork in over 130 tsunami affected villages and neighborhoods, some of which are featured in this paper.

[6] The scope of the analysis was in part influenced by the availability of satellite images for the 3 study areas. It was not possible to obtain images for all three zones at exactly the same times, which limits comparison between the sectors, but does not diminish the overall patterns within each sector. Analysis for Zone 1 used 2004 IKONOS; 2005 IKONOS; 2009 Quickbird; and 2013 GeoEye images. Analysis for Zone 2 used 2003 Google Earth image; 2005 IKONOS; and 2011 Worldview. Analysis for Zone 3 used 2003 IKONOS; 2005 IKONOS; and 2012 Worldview.

used the digitized polygons to measure the surface area for rice cultivation and aquaculture for each time period, and calculated the net change from the pre-tsunami state. Given the lack of pre-tsunami baseline data to compare productivity and yields, we use surface area clearly dedicated for rice fields (rice cultivation) and fishponds (aquaculture) as a proxy for estimating the extent of damage and rehabilitation.

To better understand how reconstruction aid influenced the rehabilitation of rice cultivation and aquaculture, we analyzed records of 83 registered livelihood aid projects supported by donors in the three study zones between 2005 and 2009. This provides a detailed look at the types of projects, as well as funding allocated for rice cultivation and aquaculture rehabilitation.

We collected qualitative data about livelihood rehabilitation from all three zones, including focus group discussions (FGDs), and interviews with village leaders, Acehnese aid workers involved in implementing and monitoring livelihood aid projects, and beneficiaries whom received livelihood aid.[7] All interviews were conducted using semi-structured, open-ended questionnaires. The selection of respondents was purposeful, targeting both respondents knowledgeable about livelihood rehabilitation projects, as well as a selection of people involved in rice cultivation and aquaculture. Detailed information about respondent selection and structure of qualitative survey instruments is provided in the accompanying supplementary material (Supplementary Section 1). All interviews were conducted in either Acehnese or Indonesian (depending on the respondent), with complete audio recordings and transcriptions produced. The transcriptions were coded and analyzed using MAXQDA software.

The aim of this paper is to identify larger-scale patterns of destruction and rehabilitation, and discuss the factors that have helped, or hindered, the rehabilitation of rice cultivation and aquaculture. It is not our intention to conduct a detailed monitoring and evaluation of specific livelihood aid projects, but rather identify changes over time, and contextualize these within aid efforts and broader processes of adaption in the post-disaster environment.

4. Results

4.1. Zone 1 – urban and peri-urban Banda Aceh and Aceh Besar

4.1.1. Zone 1 rice cultivation

Results from the GIS analysis show that there were 748.19 ha under rice cultivation in Zone 1 before the tsunami [417 ha in the inundation zone and 331 ha outside the inundation zone] (Table 2). The tsunami destroyed 386.36 ha (92%) of rice fields in the inundation zone, with a pronounced impact upon clusters of villages to the east and west of the city center. Most of the rice fields lying to the north-east of the city were destroyed, affecting the villages of Blang Krueng, Kajhu, Suleue, Klieng Cot Aron and Rukoh. Similarly, a large area of rice fields to the west of the city center was heavily damaged, affecting the villages of Lam Manyang, Lamteeh, Lam Awee, Surien, Lamteumen Timur, Lam Rukam, Emperom, Lampoh Daya, Lam Jamee, Punge Blang Cut, Gampong Baro, Lam Lumpu, Bitai, Lam Hasan and Paya Tieng. More than 320.53 ha (42.8%) of rice fields in Zone 1, mostly located outside the inundation area, were in use in 2005 (Fig. 2b). These were largely concentrated around the back (inland) side of the city center.

By 2013 only 28% of the pre-tsunami area of rice fields in Zone 1 was under cultivation (Table 2 & Fig. 2c). When segregating the data to account for tsunami inundation, we found that just over 40% of the total area of rice fields inundated by the tsunami was under cultivation almost a decade after the tsunami. This was mostly concentrated in 9 villages, with the highest rates of recovery in Ajun Jeumpet; Blang Krueng, Kajhu, Lam Manyang; Lamteh and Suleue (Table 2). All of these villages, except Ajun Jeumpet, received significant support for agricultural rehabilitation – largely cash-for-work to clear land, seeds and farming equipment. However, in 17 out of 28 villages less than 30% of the pre-tsunami rice fields were back under cultivation, with 15 of these villages having no rice fields by 2013.

Analysis of satellite images, ground inspection and interviews with respondents suggest three main factors limited the rehabilitation of rice cultivation in Zone 1. Land degradation was significant, with former rice fields transformed into brackish marshland. In some cases the damage was irreparable, or beyond the ability of aid to affect change [R1-8[8]]. The high mortality rate caused by the tsunami led to a loss of labor and changes in land ownership, with some rice fields inherited by relatives who were not interested in rice cultivation [R9-11]. Finally, access to alternate forms of employment, especially during the reconstruction period, reduced motivation to resume rice farming [R12-17]. Many former rice fields are fallow and overgrown with weeds and pests [R18-20].

Unexpectedly, we found that areas in Zone 1 *not impacted* by the tsunami suffered much higher levels of reduction in rice field acreage than areas that were damaged by the tsunami (Table 2). Only 13% of the pre-tsunami rice fields outside of the inundation zone was under cultivation in 2013. There was a reduction of approximately 75% rice cultivation between 2005 and 2009 – during the main years of the reconstruction (Table 2). Out of 29 non-tsunami inundated villages, 22 lost all of their rice fields, and only 3 villages had more than 50% of the pre-tsunami rice fields. Inspection of satellite images, verified by field visits and ground confirmation, reveal that in the decade since the tsunami rice fields outside the inundation zone were re-purposed for residential and commercial use. This can be seen in Batoh village, where large tracks of pre-tsunami rice fields are now developed (Fig. 3a and b). While a common occurrence around Asia, it seems that the conversion of rice fields for urban development was greatly accelerated by the tsunami, as there is now a clear preference by people to live and invest outside the tsunami zone. As we elaborate on elsewhere, this is not the result of an official government policy, but rather the response of property markets to new perspectives of risk (McCaughey et al. In Prep.).

4.1.2. Zone 1 aquaculture

Fisheries and related industries have long been an important part of the economy around Banda Aceh, and prior to the tsunami most of the villages along the coast and/or the rivers feeding into the sea made extensive use of aquaculture, with 1075.5 ha of fishponds in 2004 in Zone 1 (Fig. 2a). Villages located in low-lying coastal areas such as Cadek, Baet, Tibang, Deah Raya, Lampulo, Lambaro Skep, Gampong Pande and Gampong Baro, contained large concentrations of fishponds. All of these areas were heavily impacted by the 2004 tsunami.

All of the 1075 ha of aquaculture in Zone 1 before the tsunami were destroyed (Table 3). By 2009, 583.9ha (54.3%) were back in

[7] We reviewed a total of 180 interview transcripts for this paper. Respondents were purposefully selected, and no claims are made that data is representative. Zone 1 [40 FGDs; 22 village leader key informant interviews; 82 livelihood beneficiary interviews]. Zone 2 [8 FGDs; 6 village leader key informant interviews; 6 livelihood beneficiary interviews]. Zone 3 [8 FGDs; 4 village leader key informant interviews; 4 livelihood beneficiary interviews].

[8] Sources of qualitative data are coded in the main text with a unique number assigned to each interview transcript. Refer to Appendix Table 1 for details about respondents.

Table 2
Total land for rice cultivation from 2004 to 2013 for Zone 1, showing percentages of change over time for all villages, villages inundated by the tsunami, and villages not inundated by the tsunami.

Village	Total ha. in use in 2004	Total ha. in use in 2005	Total ha. in use in 2009	Total ha. in use in 2013	Net Change	% of 2004 ha in use in 2005	% 2004 ha in use in 2009	% 2004 ha in use in 2013	% total loss of ha. in use
Zone 1 Villages Inundated by the Tsunami									
Blang Krueng	48.3	0	35.7	30.5	−17.8	0	73.91	63.15	36.85
Lam Manyang	46.3	0	39	31.8	−14.5	0	84.23	68.68	31.32
Kajhu	44.98	0	17.1	22.2	−22.78	0	38.02	49.36	50.64
Suleue	22	7.4	17.8	15	−7	33.64	80.91	68.18	31.82
Klieng Cot Aron	20.86	0	16.4	11.8	−9.06	0	78.62	56.57	43.43
Garot	19.29	9.4	7.8	2.4	−16.89	48.73	40.44	12.44	87.56
Lamteeh	17.66	0	17.3	15.8	−1.86	0	97.96	89.47	10.53
Lam Awee	17.50	0	4.6	4.2	−13.3	0	26.29	24	76
Rukoh	17.2	0	6	5	−12.17	0	34.59	29.24	70.76
Ajun Jeumpet	16.46	14.03	10	9.2	−7.26	85.24	60.75	55.89	44.11
Surien	16.4	0	0	0	−16.38	0	0	0	100
Lampeu Daya	14.54	0	10.2	12.5	−2.04	0	70.15	85.97	14.03
Lamteumen Timur	13.8	0	0	0	−13.79	0	0	0	100
Lam Rukam	13.7	0	1.4	7.4	−6.30	0	10.22	54.01	45.99
Emperom	11.4	0	0	0	−11.38	0	0	0	100
Lampoh Daya	10.9	0	0	0	−10.92	0	0	0	100
Lam Jamee	10.5	0	0	0	−10.51	0	0	0	100
Punge Blang Cut	9.6	0	0	0	−9.6	0	0	0	100
Gampong Baro	8.4	0	0	0	−8.4	0	0	0	100
Lam Lumpu	8.03	0	3.1	3	−5.03	0	38.61	37.36	62.64
Bitai	7.4	0	0	0	−7.35	0	0	0	100
Lam Hasan	7.06	0	0	0	−7.06	0	0	0	100
Paya Tieng	5.66	0	1.9	0	−5.66	0	33.57	0	100
Lamjabat	3.1	0	0	0	−3.13	0	0	0	100
Lamteumen Barat	2	0	0	0	−1.97	0	0	0	100
Cot Paya	1.47	0	0	0	−1.47	0	0	0	100
Lam Gugop	1.4	0	0	0	−1.4	0	0	0	100
Rima Keunerum	1.28	0	0	0	−1.28	0	0	0	100
Zone 1 Village Not Inundated by Tsunami									
Lamdom	41.6	38.4	13.6	4.3	−37.25	92.43	32.80	10.44	89.56
Batoh	33.2	29.2	6.1	2.5	−30.71	88.15	18.42	7.42	92.58
Peunyerat	25.9	24.1	6.4	5.7	−20.22	92.94	24.58	21.99	78.01
Lhong Cut	25	24.7	9.6	8.4	−16.61	98.94	38.46	33.53	66.47
Lhong Raya	24.3	23.1	0.9	0	−24.31	95.19	3.5	0	100
Mibo	21.8	21	11.2	11.1	−10.72	96.11	51.33	50.92	49.08
Lam Ara	20.4	19.2	5.2	0	−20.41	93.83	25.28	0	100
Lambhuk	16.5	16.5	5.6	0	−16.46	100	33.96	0	100
Lampeot	15.1	12.9	0	0	−15.11	85.11	0	0	100
Ateuk Jawo	14.3	10.1	0.4	0	−14.26	70.9	2.88	0	100
Beurawe	13.1	13.1	0	0	−13.13	100	0	0	100
Pango Deah	12.7	12.5	8.6	6.8	−5.88	98.27	67.32	53.70	46.3
Ceurih	7.8	7.8	6	5.8	−2.02	99.49	77.41	74.07	25.93
Neusu Aceh	7.6	2.1	0	0	−7.63	28.05	0	0	100
Doy	7.6	7.6	0	0	−7.6	100	0	0	100
Ateuk Menjeng	7.1	4.4	0	0	−7.14	60.92	0	0	100
Llie	6	5.4	0	0	−6.02	89.53	0	0	100
Cot Mesjid	5	3.4	2.2	0	−5.01	67.47	43.31	0	100
Leung Bata	4.8	0	0	0	−4.81	0	0	0	100
Pineung	4.7	4.7	0	0	−4.65	100	0	0	100
Geuceu Komplek	3.1	2.9	0	0	−3.06	93.79	0	0	100
Lamteh	2.3	0	0	0	−2.33	0	0	0	100
Geuceu Inem	2.3	1.9	0	0	−2.29	80.79	0	0	100
Lam Lagang	2.2	2.1	0	0	−2.19	96.8	0	0	100
Pango Raya	2.2	2.2	0	0	−2.16	100	0	0	100
Ie Masen Kayee Adang	1.7	0	0	0	−1.72	0	0	0	100
Lam Glumpang	1.4	0	0	0	−1.39	0	0	0	100
Lampaloh	0.9	0	0	0	−0.9	0	0	0	100
Blang Cut	0.4	0.4	0	0	−0.35	100	0	0	100
Total Inundated Villages	**417.19**	**30.83**	**188.3**	**170.8**	**−246.39**	**7.39**	**45.14**	**40.94**	**59.06**
Total Non-Inundated Villages	**331**	**289.7**	**75.8**	**44.6**	**−286.4**	**87.52**	**22.9**	**13.47**	**86.53**
Total All Villages	**748.19**	**320.53**	**264.1**	**215.42**	**−532.77**	**42.84**	**35.29**	**28.79**	**71.21**

use, with 573.7 (53.3%) operating in 2013. This is a loss of 46.6% of pre-tsunami aquaculture capacity. It is clear from inspection of satellite images, coupled with ground proofing and discussions with local stakeholders, that the sheer scale of the environmental

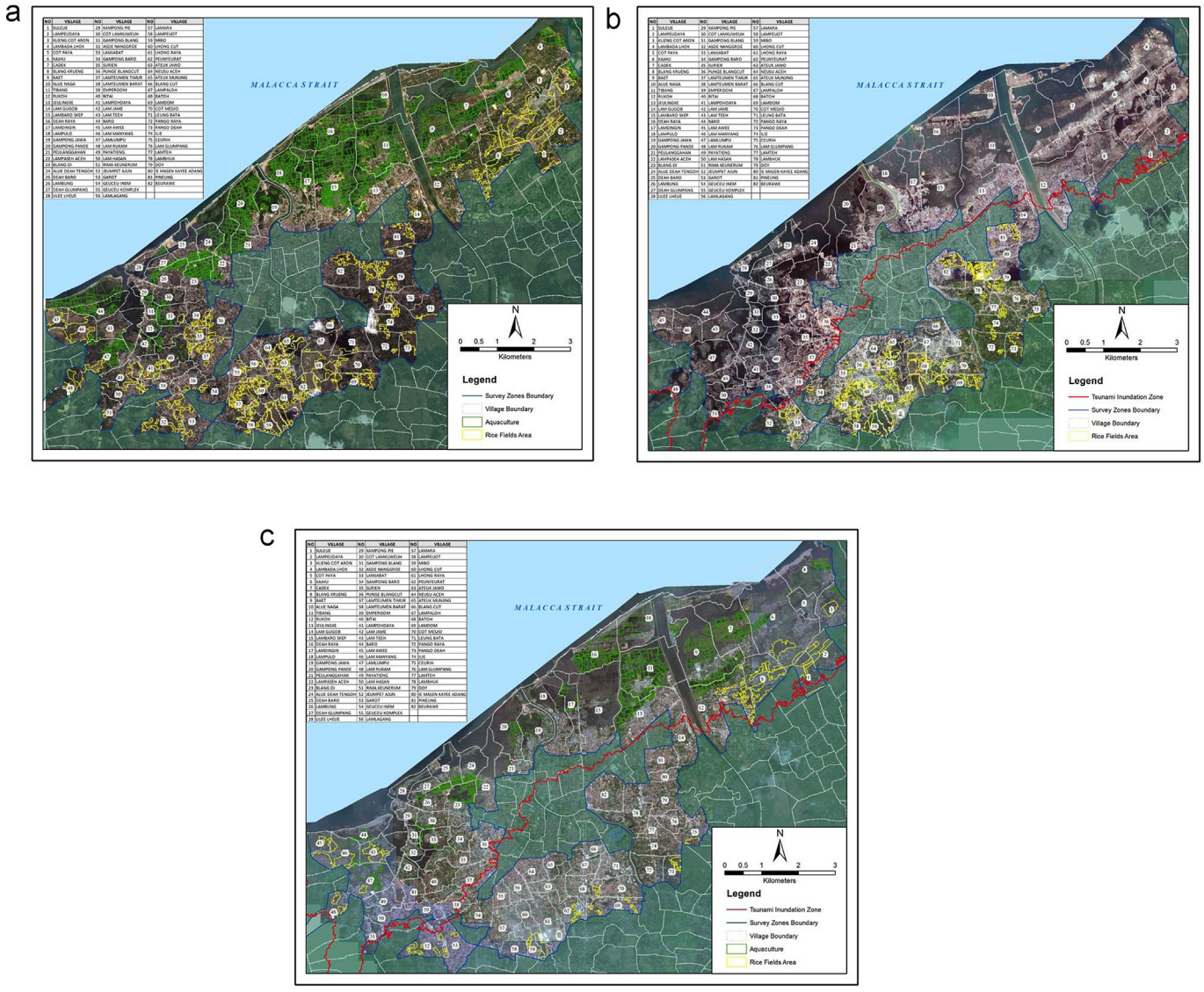

Fig. 2. a: Zone 1 showing total area dedicated for rice cultivation and aquaculture in 2004, before the tsunami. b: Zone 1, 2005, showing destruction post-tsunami, and the extent of rice cultivation immediately following the tsunami. c: Zone 1 showing state of rice cultivation and aquaculture in 2013, four years after the official end of the reconstruction period.

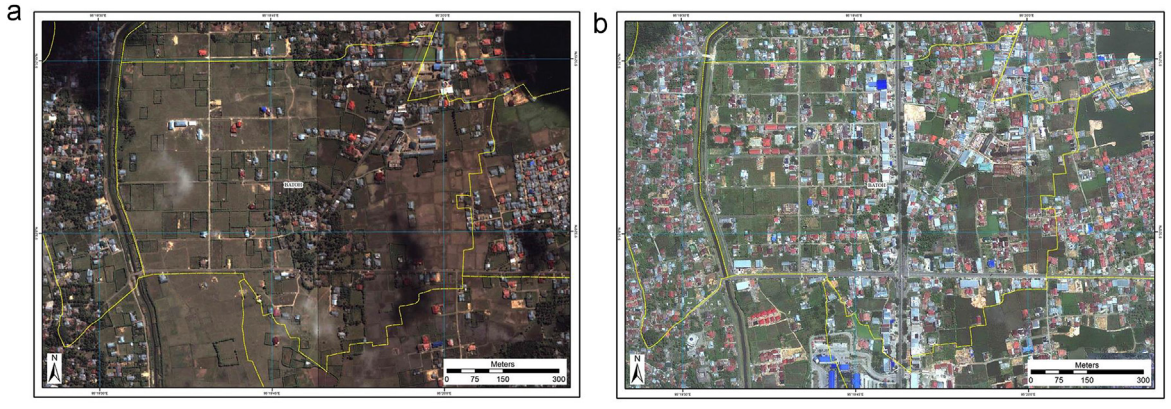

Fig. 3. a: Close up of area around Batoh village 2004 (pre-tsunami) showing low density residential settlement and accompanying rice fields. This area was not hit by the tsunami. b: Close up of area around Batoh village 2013 (post-reconstruction) showing encroachment of residential construction into former rice fields. This occurred after the tsunami, in part because of residents moving out of tsunami-affected areas.

Table 3
Total land for aquaculture from 2004 to 2013 for Zone 1, showing percentages of change over time for all villages with pre-tsunami aquaculture.

Village	Total ha. in use in 2004	Total ha. in use in 2005	Total ha. in use in 2009	Total ha. in use in 2013	Net Change	% 2004 ha in use in 2009	% 2004 ha in use in 2013	% total loss of ha. in use
Lambaro Skep	134	0	77	81.4	−52.55	57.48	60.77	39.23
Tibang	106	0	93.5	93.88	−12.07	88.23	88.61	11.39
Alue Naga	85.8	0	65.6	51.95	−33.8	76.50	60.58	39.42
Deah Raya	83.3	0	46	46.93	−36.37	55.26	56.34	43.66
Baet	78.8	0	81	65.3	−13.48	102.78	82.89	17.11
Kampung Baro	73.5	0	3.1	5.7	−67.83	4.2	7.7	92.30
Gampong Pande	61.2	0	10	10	−51.19	16.3	16.34	83.66
Lampulo	49.7	0	2.7	21.99	−27.72	5.33	44.24	55.76
Jeulingke	49.6	0	38.3	37.57	−12.05	77.15	75.72	24.28
Kajhu	39	0	13.4	12.6	−26.35	34.35	32.35	67.65
Lampaseh Aceh	38.1	0	0	0	−38.1	0	0	100
Cadeuk	37	0	50.9	44.6	7.58	137.63	120.5	−20.5
Blang Oi	30.6	0	14.2	16.97	−13.63	46.41	55.46	44.54
Lamdingin	27.4	0	0	9.72	−17.67	0	35.49	64.51
Alue Deah Teungoh	23	0	5.1	5.04	−17.94	22.19	21.93	78.07
Peulanggahan	21.6	0	2.5	2.23	−19.37	11.44	10.32	89.68
Lam Lumpu	19	0	18.8	12.1	−6.85	99.31	63.85	36.15
Lambada Lhook	17.9	0	9	9	−8.9	50.17	50.39	49.61
Rukoh	17.6	0	18.9	19.07	1.48	107.56	108.41	−8.41
Deah Glumpang	12.5	0	4.3	4.52	−7.98	34.56	36.16	63.84
Lam Awee	9.8	0	0	0	−9.79	0	0	100
Deah Baro	9	0	9.2	8.97	−0.03	102	99.67	0.33
Gampong Blang	6.8	0	4.3	3.1	−3.68	63.13	45.72	54.28
Lam Jamee	6.7	0	0.7	0	−6.72	10.12	0	100
Klieng Cot Aron	5.7	0	2.6	2.5	−3.18	45.95	44.01	55.99
Gampong Jawa	4.8	0	5.2	0.9	−3.89	108.14	18.79	81.21
Gampong Pie	4.1	0	2.1	0.61	−3.53	50.72	14.73	85.27
Cot Lamkuweuh	3.8	0	2.64	2.7	−1.08	69.47	71.58	28.42
Surien	3.7	0	0	0	−3.68	0	0	100
Asoe Nanggroe	3.2	0	0.2	1.42	−1.74	7.59	44.94	55.06
Ulee Lheue	3.2	0	0	0	−3.15	0	0	100
Lam Jabat	2.8	0	0	0.94	−1.89	0	33.22	66.78
Lamteh	2.3	0	0.9	0.6	−1.69	39.91	25.88	74.12
Lam Manyang	1.8	0	1.4	1.4	−0.41	75.27	77.47	22.53
Bitai	1.5	0	0	0	−1.47	0	0	100
Lampoh Daya	0.5	0	0.5	0	−0.53	101.89	0	100
Lambung	0.5	0	0	0	−0.5	0	0	100
Total	**1075.5**	**0**	**583.9**	**573.7**	**−501.75**	**54.3**	**53.34**	**46.66**

damage caused by the tsunami has been a major impediment to full rehabilitation [R21-24]. In many villages, such as Kampung Baro, Gampong Pande, Alue Deah Teungoh, Peulanggahan, Gampong Jawa, Gampong Pie, Cot Lamkuweuh, and Ulee Lheue, a combination of post-earthquake subsidence (recorded in the area of up to .5 m) and heavy erosion degraded the coastal areas and resulted in major land loss which has yet to recover. Additionally, respondents reported that when they tried to resume prawn farming after the tsunami, their stock died off from disease [R25]. Residents suspect that the tsunami altered the ecology of the coastal area, preventing cultivation of certain species. While many respondents reported receiving aid, the lack of capital was a commonly cited reason for failure to fully rehabilitate fishponds, especially if beneficiaries suffered initial set-backs such as a failed harvest [R26-27].

Since the end of the reconstruction period in 2009 there has been a steady increase in aquaculture, largely in heavily eroded wetlands created by the tsunami. Ground inspection suggests that this involved the adaption of new methods, species and business models. As aquaculture provides substantial economic benefit, it is likely that it will continue to slowly expand in the areas where it existed before the tsunami. However, this is largely driven by entrepreneurs with support from the provincial government, and is not directly linked to reconstruction aid. In interviews, respondents noted that new aquaculture initiatives are controlled by a small group of businessmen, often from outside the village - a marked difference from the more family-level aquaculture that existed before the tsunami [R28-32]. This shows an organic process of adaption, but does not necessarily benefit residents who depended upon aquaculture before the tsunami.

4.2. Zone 2 – rural areas of Aceh Besar and Lhoong

4.2.1. Zone 2 rice cultivation

Prior to the tsunami, all 18 villages in Zone 2 had rice fields under cultivation (total of 514.3 ha) – most of which were destroyed or heavily damaged by the tsunami (Fig. 4a and b). There was no rice cultivation in 2005 (Table 4). By 2011, rice cultivation had resumed in almost all areas where it existed pre-tsunami, with 398.8 ha (77.5%), of rice fields rehabilitated and back in use – a remarkable success rate given what we see in the other two zones in this study (Fig. 4c). Eleven villages had at least 75% of pre-tsunami acreage of rice under cultivation by 2011, with only three villages below 50% of the 2003 cultivation area (Table 4). Jantang lost 65.7% of its rice fields, due to difficulties rehabilitating land between the village and the coast, and because a large stone quarry was opened post-tsunami, in part to provide materials for post-

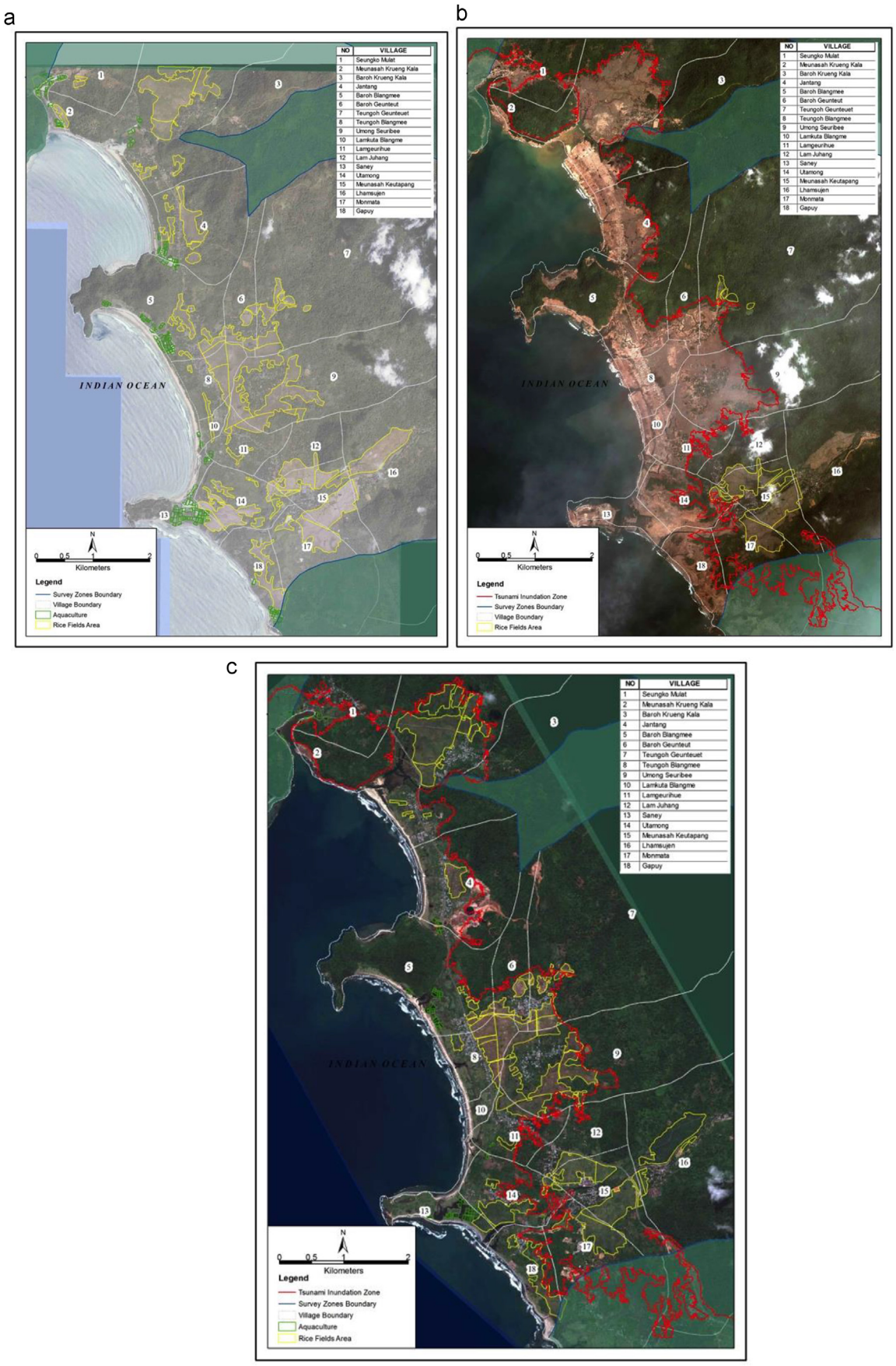

Fig. 4. a – Zone 2 showing total area dedicated for rice cultivation and aquaculture in 2004, before the tsunami. b – Zone 2, 2005, showing destruction post-tsunami, and the extent of rice cultivation. c – Zone 2 showing state of rice cultivation and aquaculture in 2011, two years after the official end of the reconstruction period.

Table 4
Total land for rice agriculture from 2003 to 2011 for Zone 2, showing percentages of change over time for all villages.

Village	Total ha. in use in 2003	Total ha. in use in 2005	Total ha. in use in 2011	Net Change	% of 2004 ha in use in 2005	% of 2004 ha in use in 2011	% total loss of ha. in use
Umong Seuribee	99.6	0	94.5	−5.1	0	94.8	5.2
Keutapang	50.5	0	40.1	−10.4	0	79.4	20.6
Lamsujen	37.1	0	35.6	−1.5	0	95.9	4.1
Lamjuhang	37	0	28.6	−8.4	0	77.4	22.6
Utamong	35.3	0	20.5	−14.8	0	58.1	41.9
Jantang	33.2	0	11.4	−21.8	0	34.3	65.7
Mon Mata	29.3	0	27.5	−1.8	0	93.8	6.2
Meunasah Krueng Kala	27.8	0	10.8	−17	0	38.8	61.2
Gapuy	24.5	0	24	−0.5	0	98	2
Teungoh Geunteut	24.2	0	15.3	−8.9	0	63.2	36.8
Baroh Blang Mee	22.9	0	8.6	−14.3	0	37.6	62.4
Baroh Geunteut	19.7	0	14.1	−5.6	0	71.6	28.4
Lamgeuriheu	19.6	0	18.8	−0.8	0	95.9	4.1
Lamkuta Blang Mee	17.8	0	11.2	−6.6	0	63	37
Teungoh Blang Mee	15.1	0	16.3	1.2	0	116	−16
Tunong Krung Kala	12.7	0	14.7	2	0	116	−16
Saney	6.4	0	5.3	−1.2	0	81.7	18.3
Baroh Krueng Kala	1.5	0	1.5	0	0	100	0
Total	**514.3**	**0**	**398.8**	**−115.5**	**0**	**77.5**	**22.5**

disaster construction projects. In the two other villages that experienced significant reduction, Meunasah Krueng Kala and Baroh Blang Mee, pre-tsunami rice fields were situated near small rivers that drained into the ocean. This land became brackish wetland after the tsunami, unsuitable for rice cultivation.

Analysis of satellite images, coupled with ground visits and interviews with respondents, verify that the tsunami did not cause extensive permanent degradation of rice fields. Most pre-tsunami residential lands could be re-built upon, limiting re-purposing of rice fields for post-disaster housing (as seen in Zones 1 & 3). Additionally, villagers in Zone 2 are dependent upon rice cultivation, and respondents reported the lack of alternative livelihood options was an added incentive to return to rice farming, leading the livelihood profiles in Zone 2 villages in 2011 to closely resemble the pre-tsunami situation [R33-34].

Interviews with villagers in Zone 2 highlight several additional factors that facilitated the rehabilitation of rice cultivation. First, respondents in a number of villages cited the insistence of village elders to return to fishing and rice cultivation, given the importance of these to pre-tsunami livelihoods [R34]. Second, some village leaders enacted policies to encourage people from outside the village to clear and work available rice fields, incentivized by collecting three harvest cycles of rice before having to pay rent or share a portion of the crop with the land owner [R33-35]. This brought in outside labor and facilitated the rehabilitation process, and laid down the foundation of rice farming still in use today. Finally, respondents reported that aid provided a strong starting point for the rehabilitation – with useful inputs and training provided, infrastructure upgraded, and with donors doing a good job targeting beneficiaries and monitoring progress [R36-39].

4.2.2. Zone 2 aquaculture

Prior to the tsunami, 7 of the villages in Zone 2 had aquaculture, which was an important source of supplementary income in Saney, Baroh Blang Mee, Meunasah Krueng Kala, and Jantang villages (Table 5; Fig. 4a). Fishponds were located along the coast and on the banks of inlets. The tsunami destroyed all of the physical infrastructure needed for aquaculture, and in some cases, such as in Meunasah Krueng Kala, Jantang, Baroh Blang Mee, and Saney, eroded away considerable amounts of land (Fig. 4b). During the reconstruction, records indicate that only Mon Mata, which does not have any coastal fronting, and did not have aquaculture before the tsunami, received aid for the fishery sector (Supplementary Table 2). By 2011, 15.5 ha of fishponds were in operation – a loss of almost 70% of the pre-tsunami area. Respondents cited heavy erosion and lack of donor/government support as the main factors limiting rehabilitation [R40]. It is not clear from project records why villages in Zone 2 did not receive more assistance for aquaculture. Unlike in Zone 1, there is no indication that people are investing in aquaculture post-reconstruction – possibly because of the distance to markets in the city and the lack of local capital.

4.3. Zone 3 Aceh Jaya

4.3.1. Zone 3 rice cultivation

Prior to the tsunami, 10 of the 13 villages in Zone 3 cultivated rice, all of which were heavily damaged by the tsunami (Fig. 5 a & b). All of the 448.42 ha under cultivation in 2004 were inundated, with no cultivation in 2005 (Table 6). By 2012 only 99.3 ha (22.1%) of rice fields were back under cultivation - a net loss of 349.12 ha (77.9%) from 2004 (Fig. 5c; Table 6).

Inspection of satellite images, coupled with discussions with respondents, suggest that the reduction in rice cultivation was the result of a combination of extensive and irreparable damage to the land, and the reconfigured use of space during the reconstruction period for housing and major infrastructure projects. In Lhok Timon, Keutapang, and Mon Mata, former rice fields were either totally submerged, or brackish wetland in 2012. Furthermore, degradation of land areas used for pre-tsunami housing, such as in Panton Makmur, Kampung Blang, and Dayah Baro, necessitated building post-tsunami housing on former rice fields.

Respondents stated that while some aid was useful (such as cash-for-work), the targeting of aid was not effective, with people receiving aid who were not interested in putting time and effort into rice cultivation [R41-47]. This was in part because people who were not previously involved in agriculture were given agricultural aid. Additionally, because Zone 3 is the administrative center for the district government, many residents are civil servants, with rice cultivation a secondary source of income. Similar to what we found in Zone 1, the availability of other economic opportunities lessened the motivation to rehabilitate rice fields.

Table 5
Total land for aquaculture from 2004 to 2011 for Zone 2, showing percentages of change over time for all villages.

Village	Total ha. In use in 2003	Total ha. In use in 2005	Total ha. In use in 2011	Net Change	% of 2004 ha in use in 2005	% of 2004 ha in use in 2011	% total loss of ha. in use
Saney	15.9	0	5.8	−10.2	0	36.2	63.8
Baroh Blang Mee	10.1	0	4.8	−5.3	0	47.9	52.1
Meunasah Krueng Kala	9.7	0	3	−6.7	0	31	69
Jantang	7.4	0	1.3	−6.1	0	17.4	82.6
Gapuy	4.1	0	0	−4.1	0	0	100
Lamkuta Blang Mee	0.9	0	0	−0.9	0	0	100
Lamgeuriheu	0.8	0	0.5	−0.3	0	62.7	37.3
Utamong	0	0	0.2	0.2	0	0	0
Total	**48.7**	**0**	**15.5**	**−33.2**	**0**	**31.8**	**68.2**

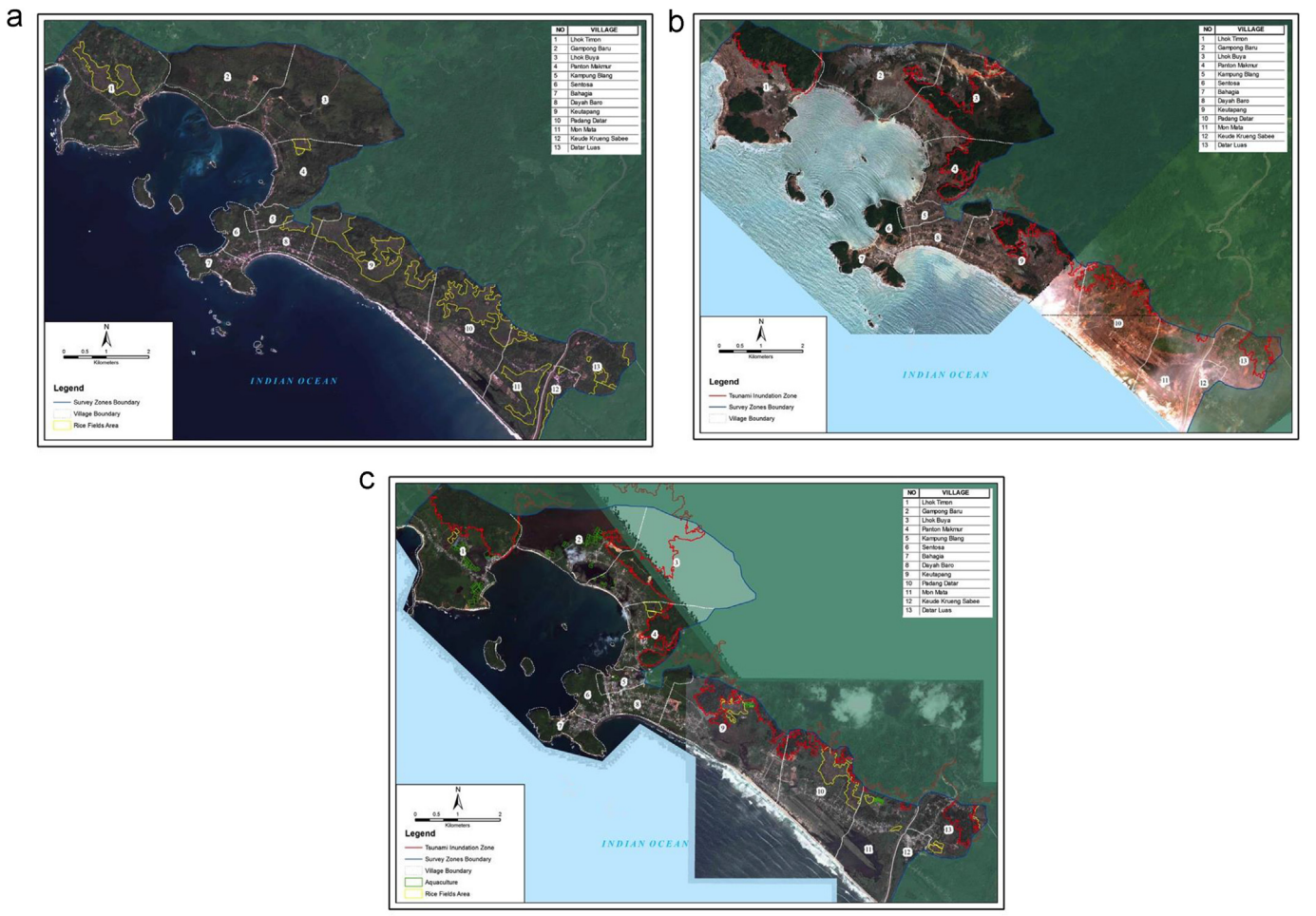

Fig. 5. a – Zone 3 showing total area dedicated for rice cultivation and aquaculture in 2004, before the tsunami. b – Zone 2, 2005, showing destruction post-tsunami, and the extent of rice cultivation and aquaculture. c – Zone 2 showing state of rice cultivation and aquaculture in 2012, three years after the official end of the reconstruction period.

4.3.2. Zone 3 aquaculture

Inspection of satellite images and statements from respondents indicate that there was no aquaculture in Zone 3 prior to the tsunami (Fig. 5a) [R48]. One minor project carried out by Caritas (Czech Republic) provided inputs for aquaculture in three villages, Datar Luas; Mon Mata; and Padang Datar – but it is unclear why these villages were targeted (Supplementary Table 3). By 2012, there were 40.4 ha of new fishponds, which were constructed in the post-reconstruction period (after 2009) (Fig. 5c & Table 7). The majority of the new fishponds are in two villages, Lhok Timon and Gampong Baru, with smaller holdings in four other villages. Most of the new fishponds are located in areas where the tsunami caused extensive land degradation (Fig. 6a and b).

It is interesting to note that 26 out of 28 ha of fishponds were constructed in villages that did not receive any aid for aquaculture. We were not able to determine conclusively why this is the case. It seems that aquaculture has been developing with local government support and private capital after the reconstruction ended, with areas of wetland created by the tsunami converted to productive use for aquaculture. We speculate that local market demand, driven by salaried civil servants, has encouraged this development.

Table 6
Total land for rice cultivation from 2004 to 2012 for Zone 3, showing percentages of change over time.

Village	Total ha. in use in 2003	Total ha. in use in 2005	Total ha. in use in 2012	Net Change	% of 2004 ha in use in 2005	% of 2004 ha in use in 2012	% total loss of ha. in use
Keutapang	122.2	0	16.2	−106	0	13.3	86.7
Padang Datar	97.1	0	48	−49.1	0	49.4	50.6
Mon Mata	72.5	0	4.4	−68.1	0	6.1	93.9
Lhok Timon	68.8	0	3.7	−65.1	0	5.4	94.6
Lhok Buya	22	0	0	−22	0	0	100
Datar Luas	20.4	0	17	−3.4	0	83.3	16.7
Dayah Baro	17	0	0	−17	0	0	100
Panton Makmur	16.1	0	10	−6.1	0	62.1	37.9
Keude Krung Sabee	9.73	0	0	−9.73	0	0	100
Kampung Blang	2.59	0	0	−2.59	0	0	100
Total	**448.42**	**0**	**99.3**	**−349.12**	**0**	**22.1**	**77.9**

Table 7
Total land for aquaculture from 2004 to 2012 for Zone 3, showing percentages of change over time.

Village	Total ha. in use in 2003	Total ha. in use in 2005	Total ha. in use in 2012	Net Change
Lhok Timon	0	0	22.2	22.2
Gampong Baru	0	0	12.9	12.9
Keutapang	0	0	1.8	1.8
Mon Mata	0	0	1.6	1.6
Lhok Buya	0	0	1.5	1.51
Kampung Blang	0	0	0.4	0.4
Total	**0**	**0**	**40.4**	**40.4**

5. Discussion and mangagement implications

This paper reveals a significant reduction in both rice cultivation and aquaculture yields from their pre-tsunami levels ten years after the tsunami, contrasting optimistic assessments made during the reconstruction phase (Thorburn, 2009; World Bank, 2008). Our data suggest that a number of factors have limited rehabilitation, and in some cases contributed towards a further decline of rice cultivation and aquaculture yields.

The physical degradation of the landscape caused by the tsunami was a major, and sometimes insurmountable, obstacle. Large tracks of rice fields were eroded away, subsided, and/or turned into brackish wetlands. The tsunami caused extensive damage to the physical infrastructure needed for aquaculture, and there are indications that ecological changes have prevented return to productive shrimp farming. Severe land degradation has proven difficult to overcome as the costs of rehabilitation exceed available resources and economic benefit.

The loss of land used for pre-disaster residential structures forced villages to re-purpose rice fields for residential and commercial purposes during the reconstruction phase, as seen in Zones 1 & 3. This has significantly decreased the amount and quality of land available for rice cultivation, and is negatively impacting lower income residents who rely upon small-scale agriculture and aquaculture for household consumption and income. Governments and donors need to ensure that adequate provisions are made so that economically vulnerable coastal communities can resume subsistence livelihoods, and plans for rebuilding the built environment are sensitive to household livelihood needs.

During the reconstruction period short-term employment opportunities drew significant numbers of farmers and fisherpersons away from traditional livelihoods (Thorburn, 2009; Tinning, 2011). The wide range of non-subsistence livelihood programs supported by donors presented residents with a menu of alternative professions. It is common to encounter pre-tsunami farmers or fishers who now drive pedicabs, work in shops, run small businesses or are involved in day labor. While changing profession might lead to a net economic benefit for some individuals, it is essential for aid providers to carefully consider how livelihoods might adjust post-disaster to avoid wasting resources on implementing potentially incompatible projects in the same area. Assessments need to be made in conjunction with local communities about how to balance different forms of livelihood.

Surprisingly, we found that large areas of rice fields outside the inundation zone around the urban center of Banda Aceh were repurposed for residential and commercial building in the post-disaster period. This was driven in part by the new awareness of risk of coastal hazards brought by the tsunami, which has resulted in a pattern where wealthier and better-educated residents are buying up rice fields and moving out of the tsunami zone (McCaughey et al. In Prep.). Planners need to consider coastal areas from a wider regional perspective to better understand how the consequences of coastal hazards can extend inland beyond coastal zones as market forces may alter land use dynamics.

While rice cultivation has continued to decline in spite of rehabilitation efforts, in some areas there have been notable increases in aquaculture production. There is evidence that people are adapting to the post-tsunami landscape, taking advantage of new wetlands for aquaculture. This has involved the introduction of new species and farming methods and occurred after the reconstruction period, supported by a range of government assistance and private investment. Businessmen are buying or renting coastal areas for commercial aquaculture ponds. While potentially a positive development, it is questionable at present how much economic benefit this brings to former fishers.

Our data shows that in spite of significant amounts of aid spent on rehabilitating rice agriculture and aquaculture, rehabilitation in all three zones was limited. However, we find that aid did play an important role. Cash-for-work programs to clear land and rebuild water management infrastructure were essential for both rice

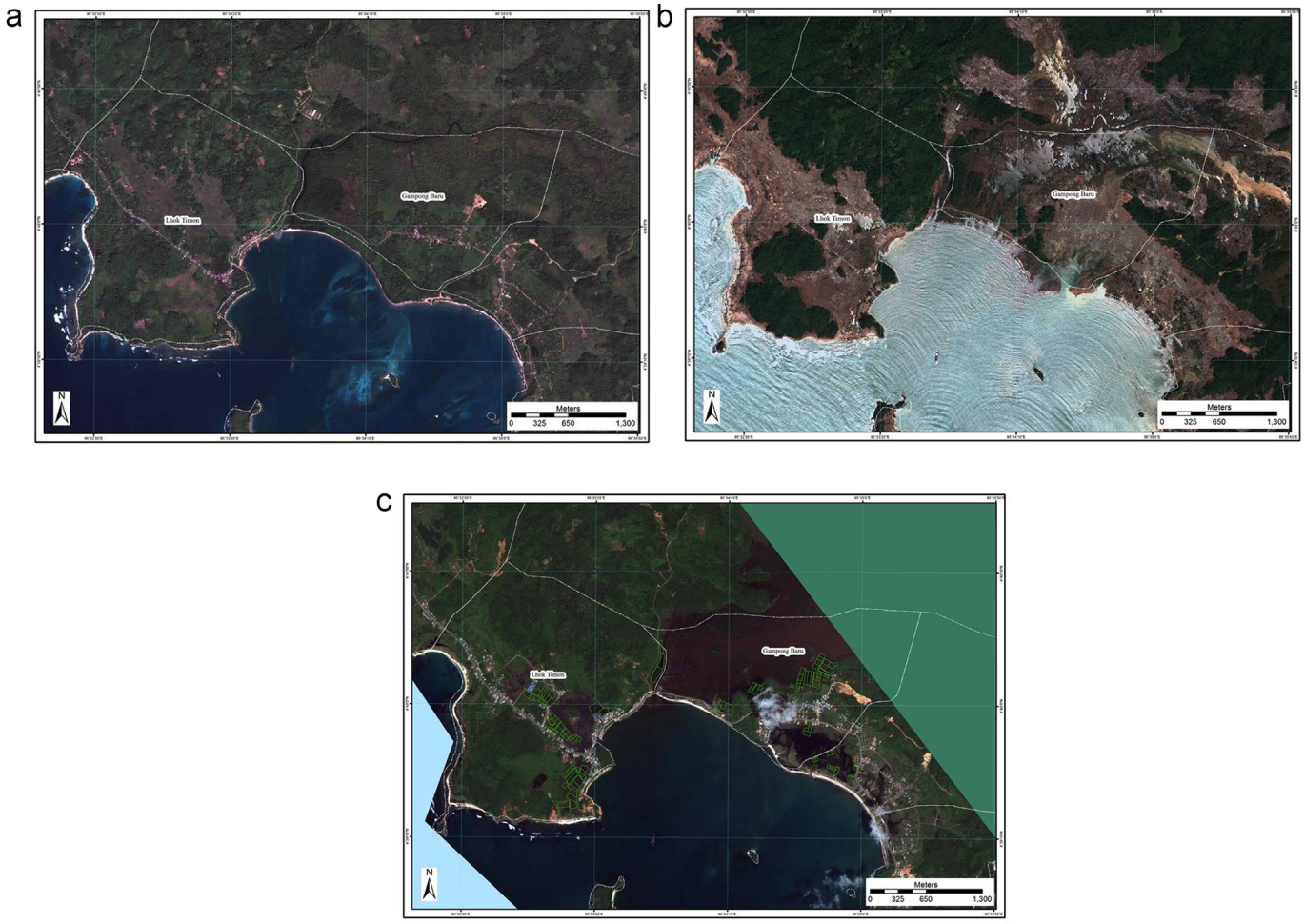

Fig. 6. a, b & c: Close up of Lhok Timon and Gampong Baru in Zone 3 for 2003, 2005 and 2012 showing increase of wetland areas, and growth of new aquaculture ponds.

agriculture and aquaculture, and should be a standard part of responses to coastal hazards which affect subsistence livelihoods. Replacing and/or upgrading physical assets lost during the tsunami were generally helpful for beneficiaries with relevant pre-tsunami livelihood experience. Providing similar assets to people lacking pre-tsunami experience was not effective. Shifts in labor related to loss of life, population movement, and alternative employment opportunities during the reconstruction period impeded rehabilitation efforts. Aid providers need to work with local communities to carefully balance rehabilitation of subsistence livelihoods with diversification into new livelihoods. For aquaculture rehabilitation, sufficient financing is required to buffer beneficiaries against initial set-backs, and to prevent them from utilizing start-up capital for short-term needs. Just supporting the first harvest cycle will not lead to successful outcomes for beneficiaries with limited financial means.

While our study provides a big-picture look at the rehabilitation of rice cultivation and aquaculture for tsunami-affected areas in Aceh, there are some important limits. Respondent recall was a significant problem, with few people able to provide very detailed information about how projects were designed and rolled out. Additionally, aside from the RAND database, it was difficult to obtain detailed blueprints, including objectives, work flow, itemized budgets, and monitoring data for livelihood rehabilitation projects carried out by aid actors. This prevents more robust analysis of the effectiveness of specific categories of aid inputs provided to different categories of beneficiaries.

6. Conclusion

The 2004 tsunami caused catastrophic damage to coastal livelihoods. Extensive efforts were made by government agencies, international donors, and local residents to rehabilitate rice cultivation and aquaculture. We found that financial and material support for clearing debris, rebuilding vital infrastructure, and providing inputs such as seeds, tools, and fertilizer had an important, but limited impact on coastal livelihood recovery. Our study suggests that the likelihood of successful rehabilitation is higher where rice cultivation and aquaculture are the main sources of livelihood and thus beneficiaries have strong incentives to restore fields and ponds as quickly as possible. Furthermore, local environmental, social and economic factors may be stronger determinants of the rehabilitation than external aid.

The scale of the physical damaged caused by major inundation events, and the social and economic changes that occur within post-disaster situations, raise questions about whether it is possible, or even desirable, to attempt to fully rehabilitate coastal livelihoods to their pre-disaster state. Governments and donors involved in post-disaster livelihood rehabilitation need to consider the changes to the physical environment caused by inundation events, how these landscapes will develop naturally over time, and the social and economic dynamics that arise during a post-disaster reconstruction period, to anticipate how to direct limited aid resources. It is not an efficient use of resources to roll out large-scale, standardized livelihood rehabilitation projects without considering

the often highly localized environmental and social conditions that will most likely determine the success or failure of such projects.

Given the possible increase in the frequency and intensity of coastal inundation events over the next several decades, and recent findings suggesting future possible tsunami hitting Aceh (Sieh et al., 2015) it is imperative to understand that damage to coastal livelihoods can lead to permanent changes and have consequences outside immediate coastal areas. It is common for studies of coastal livelihoods to focus on marine resources. The situation in Aceh shows this needs to be expanded to factor in the terrestrial livelihoods of coastal communities. While this paper presents some initial observations about the transformation of coastal livelihoods caused by the 2004 tsunami in Aceh, longer-term monitoring is necessary to better understand how coastal communities adjust to large-scale inundation events, and the extent to which aid can ensure vulnerable communities don't get forgotten in the resultant transformations.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2017.03.027.

Appendix

Appendix Table 1
This table identifies the sources of qualitative data used in the paper. Each code represents a unique interview transcript. During the analysis, we distilled out relevant illustrative data from focus group discussions (FGDs), village leader key informant interviews, and livelihood beneficiary key informant interviews. The FGDs included between 8 and 12 respondents on average. Key informant interviews were usually conducted with individuals, but some involved multiple respondents. The majority of the respondents referenced in the paper are male. This reflects the gendered nature of village leadership, and employment within agriculture and aquaculture common in Aceh. As part of our research ethics agreement, we refrain from publishing the names and specific leadership jobs of respondents to allow our respondents to speak candidly.

Transcript Code	Interview Type	Village	Gender	Date Conducted
R1	Livelihood Key Informant	Lamteumen Timur	Male	22 Aug 2014
R2	Village Leader Key Informant	Lamjabat	Male	18 June 2014
R3	Village Leader Key Informant	Lamteumen Timur	Female	19 Aug 2014
R4	Village Leader Key Informant	Lamteumen Timur	Male	22 Aug 2014
R5	Village Leader Key Informant	Lamteumen Timur	Male	19 Aug 2014
R6	Village Leader Key Informant	Lamjabat	Male	18 Jun 2014
R7	Village Leader Key Informant	Lamteumen Timur	Female	19 Aug 2014
R8	Livelihood Key Informant	Lamteumen Timur	Male	22 Aug 2014
R9	Livelihood Key Informant	Punge Blangcut	Male	12 Aug 2014
R10	Livelihood Key Informant	Lam Jame	Male	25 Aug 2014
R11	Livelihood Key Informant	Lampoh Daya	Male	19/08/2014
R12	Livelihood Key Informant	Lam Jame	Male	25 Aug 2014
R13	Livelihood Key Informant	Lampoh Daya	Male	19 Aug 2014
R14	Livelihood Key Informant	Lam Jame	Male	25 Aug 2014
R15	Livelihood Key Informant	Gampong Baru	Male	13 Oct 2014
R16	Livelihood Key Informant	Lam Jame	Male	25 Aug 2014
R17	Livelihood Key Informant	Lam Jame	Male	25 Aug 2014
R18	Livelihood Key Informant	Lamteumen Timur	Male	19 Aug 2014
R19	Livelihood Key Informant	Lampoh Daya	Male	19 Aug 2014
R20	Village Leader Key Informant	Lamteumen Timur	Male	22 Aug 2014
R21	Livelihood Beneficiary	Lamdingin	Male	02 Sept 2014
R22	Focus Group Discussion	Lampaseh Aceh		07 Aug 2014
R23	Livelihood Beneficiary	Lamdingin	Male	2 Sept 2014
R24	Livelihood Beneficiary	Lambaro Skep	Male	05 Sept 2014
R25	Livelihood Beneficiary	Alue Deah Tengoh	Male and Female	06 Jun 2014
R26	Livelihood Beneficiary	Lamdingin	Male	02 Sept2014
R27	Livelihood Beneficiary	Lambaro Skep	Male	05 Sept 2014
R28	Livelihood Beneficiary	Lamdingin	Female	04 Sept 2014
R29	Livelihood Beneficiary	Lamdingin	Male	02 Sept 2014
R30	Livelihood Beneficiary	Lambaro Skep	Male	05 Sept 2014
R31	Livelihood Beneficiary	Alue Deah Tengoh	Male and Female	06 Jun 2014
R32	Village Leader Key Informant	Deah Baro	Male	05 Jun 2014
R33	Focus Group Discussion	Baroh Blangmee	Male	16 Sept 2014
R34	Livelihood Key Informant	Baroh Blangmee	Male	19 Sept 2014
R35	Focus Group Discussion	Baroh Geuntet		18 Sept 2014
R36	Livelihood Key Informant	Lhok Geulumpang	Male	13 Oct 2014
R37	Livelihood Key Informant	Bahagia	Male	26 Sept 2014
R38	Livelihood Key Informant	Lhok Geulumpang	Male	13 Oct 2014
R39	Focus Group Discussion	Baroh Geuntet		18 Sept 2014
R40	Village Leader Key Informant	Baroh Blangmee	Male	19 Sept 2014
R41	Livelihood Key Informant	Sengko Mulat	Male	19 Sept 2014
R42	Focus Group Discussion	Baro Geunteut		16 Sept 2014
R43	Focus Group Discussion	Seungko Mulat		21 Sept 2014
R44	Focus Group Discussion	Umong Seuribee		17 Sept 2014
R45	Livelihood Key Informant	Baroh Blangmee	Male	19 Sept 2014
R46	Livelihood Key Informant	Gampong Baru	Male	13 Oct 2014
R47	Livelihood Key Informant	Bahagia	Male	26 Oct 2014
R48	Village Leader Key Informant	Gampong Baro Patek	Male	15 Oct 2014

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