Title
The Reconstruction of Post-Tsunami Banda Aceh, Indonesia: A spatial analysis of the rebuilding of structures, roads, and productive land

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Publication Date
2016

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Los Angeles

The Reconstruction of Post-Tsunami Banda Aceh, Indonesia:

A spatial analysis of the rebuilding of structures, roads, and productive land

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Urban Planning

by

Joseph Perman

2016

ABSTRACT OF THE DISSERTATION

The Reconstruction of Post-Tsunami Banda Aceh, Indonesia:

A spatial analysis of the rebuilding of structures, roads, and productive land

By

Joseph Perman

Doctor of Philosophy in Urban Planning

University of California, Los Angeles 2016

Professor Leobardo F. Estrada, Chair

Post-disaster reconstruction is an essential activity for restoring the health and wellbeing of affected communities. Therefore, the ability to monitor and evaluate the rebuilding and repair of the physical environment is critical for assessing the reconstruction process and its outcomes. This dissertation utilized satellite imagery, spatial data, and geographic information systems (GIS) to examine the reconstruction of Banda Aceh, Indonesia after the 2004 Indian Ocean Tsunami. The reconstruction process was assessed by the quantities and spatial distributions of structures, roads, and aquaculture ponds (*tambaks*) in two specific regions of the city from 2005 to 2008. While there were gains in some areas, there were also substantial losses in others. In comparison to the pre-tsunami baseline (2004), there were more structures, a greater total length of roads, greater access to roads, and an equivalent amount of *tambak* area in the southern region of interest by the end of the study period. In the northern region, there was a return to a state similar to that of its

2004 baseline with respect to structures and roads; however, total *tambak* land area was still far below that of the pre-tsunami period. While both regions saw increases in road network access, both regions may have suffered from the redistribution of structures, higher structure densities, and smaller structure sizes. Yet, despite those and other noted difficulties in the process, the reconstruction of structures, roads, and *tambaks* was successful in returning the examined portions of Banda Aceh to, or above, its baseline state, restoring means of shelter, transportation, sustenance, and employment.

The dissertation of Joseph Perman is approved.

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2016

DEDICATION

This dissertation would not have been possible without the support of several key individuals, each of whom I owe endless thanks.

My doctoral committee members Randy Crane, Tom Gillespie, Lois Takahashi, and committee chair, Leo Estrada, provided invaluable knowledge and guidance throughout my graduate school career. In particular, I want to thank Leo for giving me the opportunity to join the Urban Planning Department, and his patience, mentorship, and support.

I must also extend my greatest gratitude to my family, and my grandparents in particular, without whom my entire education would not have been possible. This dissertation is dedicated to Charles and Marjorie – thank you so very much for everything you've done for all of us.

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ACKNOWLEDGEMENTS

This dissertation utilized satellite imagery licensed from DigitalGlobe, Inc., for educational purposes. Funding was provided in part through a Small Seed Grant from the UCLA California Center for Population Research. In addition, this research was supported by the Southeast Asian Studies program at UCLA, made possible by a generous donation from the Robert Lemelson Foundation.

VITA

Joseph Perman attended University of California, Berkeley for a Bachelor of Arts in Political Economy in Industrialized Societies, during which time he participated in a study abroad program at Kyoto University in Japan. Following this degree, he spent several years with the California Public Utilities Commission working on infrastructure issues, including the state of the telecommunications market, and the rollout and expansion of broadband internet. He then earned a Master's degree in Public Policy at the University of California, Los Angeles, with a focus on infrastructure and disaster preparedness and response. Upon completion of the M.P.P., he began the PhD program in Urban Planning at UCLA, specializing in GIS and spatial analyses, in addition to pursuing substantial course work in the field of Public Health.

CHAPTER 1: INTRODUCTION

I. STATEMENT OF THE PROBLEM

Post-disaster reconstruction is a complex and monumental task. Following the initial disaster response period, reconstruction begins months after the event, and can last for many months or years to follow (Hogg 1980). The afflicted country may receive vast sums of aid from around the world, and donors have vested interests in the uses and efficacy of their contributions. The amount of aid a county receives does not guarantee the quality of results however, as both the United States (post-Katrina) and Haiti (post-earthquake) have encountered significant problems in their reconstruction and recovery efforts.[1]

Yet, Indonesia stands out as a model example due to its great achievements in relatively little time, while other countries, such as Haiti, have been slow to respond or have struggled to produce the same level of results (Pyles, Svistova, and Andre 2015; Ramachandran and Walz 2015; Weiss et al. 2014). The goal of this research is to better understand the mechanisms and results of this singular case of post-disaster reconstruction. Several broad issues will be examined in order to address Indonesia's

[1] The short- and long-term responses of the United States to post-Katrina Louisiana have been criticized and the subject of much debate. The Haitian reconstruction efforts, despite receiving billions of dollars in aid, have been faulted for extremely slow progress and "band-aid solutions" that do little to rectify the real problems (Trasberg 2012, USGAO 2011, USGAO 2013).

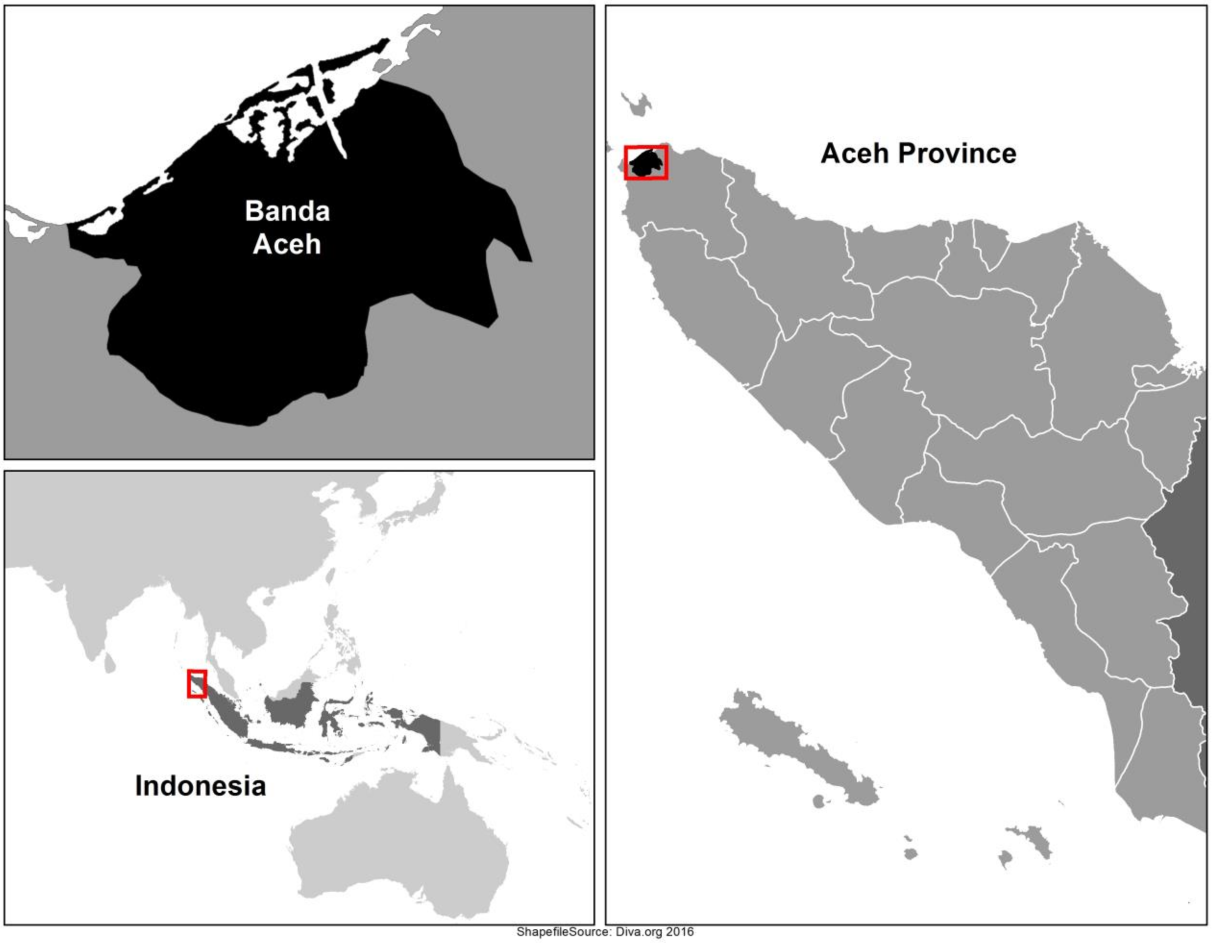
accomplishments: In what ways did institutional systems improve the reconstruction process? Did geographic location within Aceh impact reconstruction results? Was the reconstruction effort able to meet or exceed the pre-disaster state of Banda Aceh? Through an understanding of the context in which such a massive project was able to succeed, elements may be gleaned and replicated in future post-disaster scenarios in other developing countries.

II. BACKGROUND

A. THE INDIAN OCEAN TSUNAMI

On December 26, 2004, a magnitude 9.2 earthquake off the coast of Indonesia resulted in a massive tsunami that killed over 280,000 people along the coastlines of the Indian Ocean (Lay et al. 2005). While only one of the thirteen countries affected by the 2004 Indian Ocean tsunami, Indonesia was struck especially hard. In the northern city of Aceh, local tsunami run-up heights reached 30m, and traveled as far as 5 km inland. The coastal city of Banda Aceh is the provincial capital of Aceh Province, at the northern tip of Sumatra, and one of the closest locations to the earthquake (magnitude 9.2) that spawned the 2004 Indian Ocean tsunami. Roughly 800km of Aceh's coastline was destroyed, resulting in massive loses in both housing and the local economy. Roads, bridges, and various infrastructure were also heavily impacted, including the damage or loss of hospitals, schools, airports and seaports (Ananta and Onn 2007; Jayasuriya and McCawley 2008).

Banda Aceh, Aceh Province, Indonesia



Indonesia, and Aceh in particular, faced a monumental task for rebuilding citizens' livelihoods and well-being. The tsunami resulted in more than 120,000 to 170,000 deaths and 500,000 displaced persons (BRR and Partners 2006; Wegelin 2006). While estimates vary, at least 125,000 homes were destroyed and an additional 120,000 were partially damaged. Entire economic sectors were crippled or disrupted from the event, including fishing (over $500 million in damage), agriculture ($225 million), and small enterprise ($218 million). Nearly 350,000 people in Indonesia lost their sources of income, as the means by which individuals make their living were destroyed, including two-thirds of all fishing boats, 20,000 hectares of aquaculture ponds (*tambaks*), and over 28,000 hectares of agricultural land (Ananta and Onn 2007; Jayasuriya and McCawley 2008). The loss of homes, productive land, infrastructure, and roads was estimated to impact eighty percent of Aceh's annual economic activity (World Bank 2006).

B. Indonesia's Reconstruction

Following the response to the immediate needs of the population, the longer-term task of recovery began. Multiple levels of the Indonesian government took on roles in the post-disaster reconstruction: coordinating efforts; determining where it could/could not occur; and providing support to others in the provision of housing. In its response, the Indonesian national government created the *Rencana Induk* (Master Plan) [2, 3] to provide a framework for the recovery and reconstruction processes. Through official policy, the government emphasized the importance of housing, its role in redevelopment, and an emphasis on reconstruction carried out by the communities affected. To support community reconstruction efforts, the Master Plan provided financial assistance for those needing to rebuild and those needing to repair their homes ($3,000 and $1,000, respectively). While such a program was estimated to cost $280 million, international aid was expected to

[2] "Presidential Instruction Number 1 Year 2005 concerning Emergency Relief Efforts and the Planning and Preparation of the Rehabilitation and Reconstruction for the Regions and People of the Provinces of Nanggroe Aceh Darussalam and Nias Islands, North Sumatra, in the Aftermath of the Earthquake and Tsunami, issued on 2 March 2005."

[3] Prior to 2009, Aceh was known as Nanggroë Aceh Darussalam (NAD), although its name has since been shortened.

ensure that "sufficient funds would be available" (Wegelin 2006). The international community was highly responsive, and in addition to funding, 463 actors worked on 2,200 reconstruction projects of all kinds (not only housing) in Aceh: 152 by the Indonesian government, 397 by donors, and 1,643 by NGOs. The housing sector also garnered one-quarter of all reconstruction aid, providing over $1.6 billion (Masyrafah and McKeon 2008).[4]

Along with the Master Plan, the Government of Indonesia (GOI) also established the *Badan Rehabilitasi dan Rekonstruksi* Aceh-Nias (hereafter "BRR"), or Agency for the Rehabilitation and Reconstruction of Aceh and Nias. The BRR was first formed via special bill *Peraturan Pemerintah Pengganti Undang Undang No.2/2005*, and formalized in *Undang Undang No.10/2005*. The specially-created agency was charged with the mandate of coordinating and managing the multi-organizational reconstruction effort. Two of the primary tasks confronting the BRR were allocating the domestic and international funding to reconstruction efforts, and helping to ensure that all participants in the process would comply with the Master Plan (BRR 2009; World Bank 2005). The agency required a common format for reconstruction proposals, which would be reviewed based on uniform procedures to streamline the process and ensure proper evaluation. To monitor project implementation and assess existing successes or obstacles, partner organizations were required to submit regular, detailed reports. The BRR and Aceh's provincial government sponsored weekly working groups for all participating organizations to aid in the coordination of activities, as well as review draft BRR policies with those involved (Wegelin 2006). Community participation was also a core component of the reconstruction effort,

[4] Total reconstruction funding amount was estimated at US$7 billion.

with the formal inclusion of tsunami survivors throughout the process and an emphasis on community-driven reconstruction (Government of Indonesia 2005; World Bank 2005).

In the first year following the tsunami 15,000 homes were rebuilt, and by December 2007, three years after the tsunami, this total rose to 100,000. By the end of the reconstruction program, 140,000 homes had been built. The reconstruction did take several years, but an Indonesian official astutely recognized that the process would not be completed overnight: "if you want community participation it takes time…community involvement in the project means skills need to be upgraded" (Giles 2012). On the whole, the process was deemed a success by many of its participants, including the government of Indonesia (GOI), the World Bank, and the Asian Development Bank. Beyond the task of rebuilding and repairing structures, another significant outcome of the reconstruction effort was that it provided an opportunity to reduce socio-political tensions in the region. The disaster and the response by the GOI and community both served as the impetus for a peace agreement to end the long-standing conflict between the Free Aceh Movement guerillas and the Indonesian central government, which likely would not have occurred without the external pressure.

However, problems did exist. The large amount of donor funds available stimulated a competitive environment between NGOs and aid sectors, which worked against some organizations coordinating or cooperating with each other (Cosgrave 2007; Masyrafah and McKeon 2008; Telford and Cosgrave 2007). Many participating NGOs simply did not have the capacity, experience, or skills needed for reconstruction, which caused quality issues (Kennedy et al. 2008; Masyrafah and McKeon 2008). Although a large number of units were built fairly quickly, many of them were found to be of poor quality or totally lack sanitation infrastructure. Households were faced with leaking septic tanks, problems in the link between toilets and the tank, and the lack of secondary waste treatment. As a result, some of the homes stayed unoccupied as their intended residents refused to live there (United Nations Children's Fund 2007). In addition to quality issues, the social, cultural, and structural appropriateness of rebuilt structures came into question, including construction materials and methods, building design, and location (Kennedy et al. 2008; Masyrafah and McKeon 2008; Wegelin 2006).

III. Purpose

Although much has been written about a large variety of aspects of the tsunami's impacts, and the domestic and international response efforts, gaps still do exist in the literature. Reports of the quantity and rate of the Indonesian reconstruction process have lacked specificity regarding location beyond the province or city levels. Therefore, one goal of this research is to use a standard, replicable practice to quantify and locate reconstruction using remote sensing (RS) and geographic information systems (GIS). In addition, spatial analyses will be utilized to provide information about patterns or trends in the quantity and location of the reconstruction's outcomes.

IV. Significance

Based on the prevalence of natural disasters occurring in Indonesia, the ability to perform successful reconstruction is critical. Between 1980 and 2010, 321 events impacted over 21 million people and caused nearly 24 billion dollars (USD) in damage (Reliefweb 2014). The incidence of disasters in 2010 and forward has not slowed, and has included floods, volcanic eruptions, and an earthquake rapidly followed by a tsunami. Given this frequency of events and the potentially very high need for reconstruction, the approach of this study is two-fold: first, to identify ingredients of success in the Indonesia case, which may be applied to other post-disaster scenarios; second, to validate a widely-applicable post-disaster reconstruction assessment and guidance instrument.

There is a critical need for measurement in reconstruction programs. Foreign nations and international donors have vested interests in the uses and efficacy of their funds. Likewise, monitoring and evaluation have been repeatedly noted as crucial for the implementation and outcomes of such programs (Ganapati 2012; UNEP 2010; UNJIU 2011). There are a number of factors that may be taken into account to judge the relative success of reconstruction programs. One traditional set of measures has simply been the extent and rate of rebuilding homes and structures.[5] However, published estimates of reconstruction outcomes can vary greatly, making evaluation and assessment somewhat difficult. A lack of accessibility, resources, or other constraints may make timely, direct monitoring difficult; however, remote sensing allows for the measurement of the extent and rate of reconstruction.

While remote observation through satellite imagery has been harnessed in damage assessment for disasters worldwide, this method of quantification and categorization has thus far not been used in the research on reconstruction. Not meant to replace field

[5] Additional measures often include appropriateness, community input/participation, and disparities of outcomes, which will be addressed further (Ingram et al. 2006) (Jigyasu 2004; Kennedy et al. 2008; Schilderman 2004).

surveys or “ground-truthing” efforts, remote sensing offers a replicable tool for domestic governments, funders, and other key actors to monitor and evaluate reconstruction. Aerial or satellite imagery is captured by a number of providers at regular intervals, as well as being able to be tasked for specific times and locations. This technology offers a practical and replicable process with temporal, financial, and resource benefits, which can complement or, if needed, substitute for on-site measurements. My proposal aims to fill the void in the literature on the use of remote sensing for post-disaster reconstruction, demonstrating a powerful alternative for scenarios where on-site evaluation is not feasible or estimates are needed in a rapid fashion. I will also test its ability to measure and evaluate reconstruction and verify existing reports and outcome estimates.

CHAPTER 2: LITERATURE REVIEW

This chapter provides a background on the fields relevant to the rebuilding of Banda Aceh following the 2004 Indian Ocean Tsunami. The research conducted in this study is grounded in the literatures on post-disaster reconstruction, and decentralization. In addition to peer-reviewed journal articles, this study also relied on books, conference presentations/proceedings, and official reports by the Indonesian government, international institutions, and aid organizations.

I. POST-DISASTER RECONSTRUCTION

A. POST-DISASTER PROCESSES

In order to orient oneself in the literature on reconstruction, it is necessary to understand the different post-disaster processes. General terms can be applied to the phases following a disaster, including "relief," "recovery," and "reconstruction," each stressing a different aim or focus (Fengler, Ihsan, and Kaiser 2008a; Hogg 1980; Peacock, Dash, and Zhang 2007; Quarantelli 1999). Disaster "relief" often refers to the actions taken following the crisis in order to meet immediate human needs, and tends to be short-term and well-defined. Matters of public health and safety are at the forefront of disaster relief, including providing medical aid, water, sanitation, and temporary shelter. These efforts are often conducted by multiple levels of government, militaries, and NGOs such as Médecins Sans Frontières and Mercy Corps. In contrast, disaster "recovery" is the most grand in scale of these terms, with the goal of returning the affected community to a state of acceptability or pre-disaster levels (Cosgrave 2007). Since it is so broad in nature, recovery may consist of a mix of activities and can overlap across the post-disaster periods/phases (see Hogg 1980 or Quarantelli 1999). For example, post-disaster "reconstruction" may be a component of the overall recovery process, and is more finite in scope. It has the specific goal of rebuilding and repairing the environmental and physical aspects of a community, such as homes, buildings, and infrastructure (Fengler, Ihsan, and Kaiser 2008a). A variety of actors participate in this process, including governments, bilateral/multilateral institutions, non-governmental organizations (NGOs), and communities. This task is longer in duration than disaster relief, lasting for weeks, months, or years (Hogg 1980). The participants may vary across post-disaster phases, with some specializing only in immediate relief, while others work towards longer-term solutions.

WHY RECONSTRUCTION MATTERS

This dissertation is focused specifically on the process of reconstruction, operationalized as the rebuilding and repairing of housing, roads, and productive land. Physical structures are necessary for communities to thrive and function. Shelter and housing not only safeguard human health and safety, but also have larger consequences for livelihoods and local economies. Studies have noted the importance of the "home" for individuals to perform daily life activities and maintain (or return) to a routine, which is in itself important for a feeling of normalcy. However, there are subtle differentiations within post-disaster housing types, separating emergency shelter, temporary housing, and permanent housing. The type of post-disaster shelter/housing impacts a community's ability and rate of recovery; the more temporary relocations that take place, and the longer the establishment of permanent housing, the more prolonged the community's return to normalcy (Quarantelli 1999). A sense of normalcy and stability provide the opportunity for economic activity to resume. Housing and workspace are crucial components, and are necessary for individuals and families to hold jobs, create and run businesses, and be active parts of the local economy (Peacock, Dash, and Zhang 2007).

On a larger scale, economic productivity may also be hampered when populations are displaced or rendered homeless, compounding any harm due to the loss of life and capital (e.g., fishing boats), productive land, and major infrastructure. Productive land in the form of agriculture and aquaculture (e.g., Indonesian fish ponds called *tambaks*) provide employment and livelihoods for residents through cash crops, as well as well as a local source of food and raw materials (Albala-Bertrand 2007). Similarly, roads, bridges, and transportation networks also contribute significantly, both in the delivery of aid and supplies, as well as granting access to local and regional markets for locally-supplied goods and services.

The speed of reconstruction is also important for markets to resume or recover and minimize further losses for the economy (Rubin 1985). Therefore, domestic governments have strong motivation to restore a state of normalcy, resettling residents in homes, rebuilding basic infrastructure, and enabling them to contribute to the nation's economy. Political leaders are also under great pressure to undertake high-visibility projects to retain their standing or public backing. Rebuilding housing is a way of providing immediate or near-term benefits for the public, versus longer-term projects like physical infrastructure, and the government is seen as supporting and looking after its people (Freeman 2004).

B. The Reconstruction Process

1. Key Institutional Actors

A range of actors may be involved in the reconstruction process in low-income countries, including: domestic governments; foreign governments (e.g., as bilateral donors); multilateral institutions like the World Bank; UN agencies; international and national non-governmental organizations (NGOs, e.g., OXFAM or World Vision); and the affected households/communities. In any given situation, the combination and composition of participating actors may depend on contextual factors. Among the determining elements are: the size/scale of disaster impacts; the scope of reconstruction to be carried out; governmental capacity; and accessibility to the location of the event (Fengler, Ihsan, and Kaiser 2008a). The focus of a reconstruction program may also depend on the type of organization(s) heading it: For example, in programs following the 2001 Gujarat earthquake, the Indian government concentrated on homeowners, NGOs focused on specific sub-populations (e.g., households in poverty or squatters), and community groups centered exclusively on their own members (Mukherji 2010). The level of visibility of the event may result in more/fewer participants, as well as the level of international support and aid. Similarly, the attitude of the local government regarding aid could facilitate or hinder the involvement of others, such as rejecting aid or preventing access to the afflicted areas. In addition, the same international donors and institutions will not necessary be involved in each and every event and will likely change based on their resources and agendas. The following sections will elaborate on the key institutions and organizations that play can a role in post-disaster reconstruction.

a. The Domestic Public Sector – Multiple Levels

In some countries, post-disaster responsibilities may belong to the national government, such as those with strong central governments or those with centralized authority over public works, finance, and public health. In general, governments have been cited as being more able to bear the risk of such large programs based on their ability to collect revenues and pool independent risks to minimize costs (Freeman 2004). That said, state, regional, and municipal governments can also play a role in, or be entirely responsible for, reconstruction efforts. For example, India has utilized state governments to handle reconstruction programs, with some oversight and support from the central government, while in post-Suharto Indonesia, the national, regional, and local levels have been involved to varying extents (Kaur 2006; Kennedy et al. 2008; Sharma 2003). Special agencies may also be created for the purpose of coordinating the process, either integrated into existing governmental structures or as completely separate entities. These agencies are often given specific responsibilities/authorities, though this does not necessarily include the task of implementation.

In addition to humanitarian motivations, there are strong political and economic factors influencing this process. Domestic governments have strong motivation to restore a state of normalcy, resettling residents in homes and rebuilding infrastructure, enabling communities to resume contributing to the nation's economy. Political leaders are also under great pressure to undertake high-visibility projects to retain their standing or public backing. In particular, rebuilding housing is a way of providing immediate or near-term benefits for the public, versus longer-term projects like physical infrastructure, and the government is seen as supporting and looking after its people (Freeman 2004).

In some reconstruction efforts, the program design and decision-making processes are done in a top-down manner by the domestic government, either at the national level or decentralized to lower levels. Some programs have also included varying extents of public participation, such as local mayors working with community leaders[6] (Delaney and Shrader 2000). Social and political considerations can shape the reconstruction process, such as through favoritism and clientelism, which can benefit political supporters or certain groups disproportionately to the rest of the public (Quarantelli 1999).

i. The Role of the State

Historically, domestic governments have performed the role of delivering basic services and aid to their populations. The Hyogo Framework for Action 2005-2015 further concretized this role of the state, declaring that "disaster risk reduction is a national and local priority." States may directly provide humanitarian assistance, as well as interfacing with and coordinating external aid programs/organizations (Harvey 2009). The past decade has shown that this is an iterative process, with countries learning from prior experience and evolving their disaster systems along the way. Examples of such change include Sri Lanka following the 2004 tsunami and Pakistan following the 2005 earthquake (Asian Disaster Preparedness Center (ADPC) 2007; Harvey 2009; National Disaster Management Authority (NDMA) 2007). In addition, UN Resolution 46/182 recognizes the significant roles domestic

[6] Even with the involvement of local officials and community representatives, subpopulations may still be ignored or excluded.

governments play in post-disaster humanitarian assistance, and requires that the affected-country's government formally request aid from the international community.[7,8]

Countries in South and Southeast Asia have also passed legislation and established bodies at the national level for the purpose of disaster preparedness and response. Again, in post-earthquake Gujarat, India, the responsibility for the post-disaster response was functionally decentralized from the national level to the state governments, with funding provided primarily by the central government (hereafter "GOI") (Sharma 2003). At the state-level, the Gujarat State Disaster Management Authority was charged with the coordination the post-disaster operations (Sanderson, Sharma, and Anderson 2012). Similarly, Pakistan established the National Disaster Risk Management Ordinance and National Disaster Management Commission (NDMC) to oversee all disaster management. Overseen by the NDMC, many government organizations are involved in the various phases and tasks of mitigation/prevention, preparedness and response, and recovery and reconstruction (National Disaster Management Authority (NDMA) 2007). In Bangladesh, the Standing Orders on Disasters established a single ministry (the Ministry of Food and Disaster Management) to coordinate all domestic disaster management programs. Three

[7] "Each State has the responsibility first and foremost to take care of the victims of natural disasters and other emergencies occurring on its territory. Hence, the affected State has the primary role in the initiation, organization, coordination, and implementation of humanitarian assistance within its territory." (http://www.un.org/documents/ga/res/46/a46r182.htm)

[8] However, there may be barriers to requesting aid, such as a local mistrust of foreign actors or fear of losing political face/standing.

smaller bodies manage the more specific tasks of establishing guidelines (the NMDC), implementation/ monitoring/evaluation (the IMDMCC), and creating post-disaster plans and advising other governmental bodies (the NDMAC).[9] After suffering the impacts from the 2004 Indian Ocean tsunami, Sri Lanka enacted the Disaster Management Act No. 13 of 2005, which established the legal mandate for and creation of the National Council for Disaster Management.

ii. Government Limitations

However, due to their often-limited or nonexistent funds for reconstruction, low-income countries are highly-reliant on other countries, international banks and aid organizations for assistance (Fengler, Ihsan, and Kaiser 2008b; Freeman 2004; Kulatunga 2011). There may also be problems in low-income countries regarding government capacity, the pace of the response, and conflicting/overlapping roles across different official agencies and organizations (Fengler, Ihsan, and Kaiser 2008b). Post-tsunami Sri Lanka suffered from departmental rivalries, and a lack of capacity and available land; meanwhile, in post-earthquake Maharastra, India, training was hindered by time pressures, as well as the lack of community involvement (Ingram et al. 2006; Schilderman 2004). Such capacity issues will be addressed further in the discussion of factors affecting performance. In most cases, however, regardless of whether facing an abundance or a paucity of resources, the State of the afflicted nation is nearly always involved in post-disaster processes to extent.

[9] The National Disaster Management Council (NDMC), the Inter-Ministerial Disaster Management Coordination Committee (IMDMCC), and the National Disaster Management Advisory Committee (NDMAC), respectively.

b. Bilateral Government Aid

Historically, foreign governments have been significant contributors of aid, with 158 total recognized donor countries as of 2010 (Taylor et al. 2012). In particular, the countries belonging to the OECD's Development Assistance Committee (25 in total) provide the majority of international funding for disasters. There has also been an increase in non-DAC donor countries, including China, India, and Turkey (Burall, Maxwell, and Menocal 2006). Funding mechanisms include bilateral loans (concessional and non-concessional) and grants, as well as contributions to international pooled funds (described below).[10] These bilateral grants and multilateral funds make up 80% of direct aid for emergencies (Taylor et al. 2012). Specifically, such funding may come from governmental aid agencies like USAID, USOFDA, the United Kingdom's DFID, and AUSAID. The European Union, through the European Community Humanitarian Office (ECHO), is the world's single largest humanitarian donor, providing over €14 billion in disaster aid between 1992 and 2012 (European Union/ECHO 2016). Despite its tremendous value, bilateral aid has been criticized for past efforts' demonstrating politically-motivated aid, such as the US and UK favoring aid for countries in their former colonial ties. Conversely, aid may be withheld from countries with opposing political views/administrations, or funds being restricted via earmarks for particular types of aid/projects (Adunga 2009; Balogh 1967). While often essential to the domestic country to fund post-disaster efforts, not all aid is created equal,

[10] While donor countries may also provide assistance through in-kind transfers, this paper is being limited solely to the transfer of funds in various forms.

and individual situations may dictate the appropriateness of bilateral aid or joint international pooled funds.

c. Multilateral and Regional Development Banks

Another significant source of aid for reconstruction programs has been the various development banks, both global and regional. The World Bank (WB) provided $14 billion in loans to low-income countries for post-disaster reconstruction in a two-decade span, much of it dedicated specifically for housing (Freeman 2004). Similarly, it has also provided technical assistance, outcome evaluation, and the coordination of multiple sources of financing, e.g., Multi-Donor Funds and Multi-Donor Trust funds (MDFs and MDTFs, respectively). These joint efforts can apply greater leverage for achieving funding goals versus the attempts of individual donors acting on their own, also allowing for greater efficiency through coordination and lower administrative and transaction costs (Fengler, Ihsan, and Kaiser 2008b). While they have been used for a variety of goals (e.g., poverty relief or post-conflict settings), the MDF for post-tsunami Aceh and Nias, Indonesia garnered $655 million, roughly 10% of the total reconstruction funds (World Bank 2012).

Additional funding has also been available from regional financial institutions, such as the Asian, Caribbean, and African Development Banks. The Asian Development Bank has provided assistance for numerous post-disaster projects through grants and loans, particularly via the creation of the Asia Pacific Disaster Response Fund. Similarly, the African Development Bank provides grants and loans through its Special Relief Fund, such as its assistance to Togo following massive flooding in 2007. Last, the Caribbean Development Bank has utilized grants, loans, and trust funds, such as in 2012 following

Hurricane Tomas to St Lucia (Caribbean Development Bank (CDB) 2012). However, while the demand for aid has skyrocketed, the development banks' ability to supply it has not risen commensurate with the demand (Freeman 2004).

d. United Nations Agencies

Various branches of the United Nations also participate in disaster reconstruction, each of which playing different roles in post-disaster settings. In particular, the Office for the Coordination of Humanitarian Affairs (OCHA) aids in the coordination of national and international participants, while the United Nations Development Program (UNDP) works to improve the built environment in the reconstruction process. Other involved agencies may include the United Nations Human Settlements Programme (UN-Habitat), United Nations Disaster Assessment and Coordination (UNDAC) and Office of the United Nations High Commissioner for Refugees (UNHCR).

The UN has also been instrumental in fundraising for disaster relief through its Consolidated Appeal Process and Flash Appeals, such as those following the 2004 Indian Ocean tsunami, 2009 Philippines tropical storm, and the 2010 Haitian earthquake (Fengler, Ihsan, and Kaiser 2008b; Office for the Coordination of Humanitarian Affairs (OCHA) 2013). Like the World Bank, UN agencies may also perform the important function of coordinating joint funding mechanisms, such as Central Emergency Relief Funds (CERF), Common Humanitarian Funds (CHF) and Emergency Response Funds (ERF). Intended to complement UN funding appeals, the CERFs provides donor countries a single outlet for foreign financing, with the accumulated funding (as grants and loans) going to organizations providing aid, including the WHO, WFP, UNICEF, and UNHCR

(Office for the Coordination of Humanitarian Affairs (OCHA) 2013; Taylor et al. 2012). Similarly, the CHFs are financed primarily by bilateral donors, intended to provide rapid and flexible funding to the UN, the Red Cross Movement, and other international/national NGOs. Last, OCHA disperses ERFs, which are country-specific and received by UN agencies and the aforementioned group NGOs (Office for the Coordination of Humanitarian Affairs (OCHA) 2013).

e. International and National NGOs

Funding, supplies, and on-the-ground assistance are also provided by an array of humanitarian aid organizations, such as Oxfam International, CARE International, and a myriad of secular and religious organizations. While the humanitarian sector has been estimated to have around 4,400 NGOs overall, a small group of large, international NGOs provide the bulk of the aid. In 2010, Médecins Sans Frontières (MSF), Catholic Relief Services (CRS), Oxfam, the International Save the Children Alliance, and World Vision International alone spent approximately $2.8 billion (out of sector total of $7.4 billion) on humanitarian programming (Taylor et al. 2012). Smaller organizations can partner with others in order to qualify for funding from the financial institutions that would otherwise be unavailable to them (Winchester 2000).

NGOs fulfill a number of different roles, both short- and long-term. Individual organizations will often specialize in sub-fields such as water and sanitation, emergency healthcare, or nutrition. Despite their lack of expertise in the area, some NGOs have engaged in reconstruction efforts not only due to a desire to help, but also the large pools of available funding (Kennedy et al. 2008). NGOs played significant roles in the two case studies addressed below. In Gujarat, India, the domestic branch of CARE International built homes following the 2001 earthquake (Taylor et al. 2012). The 2004 Indian Ocean tsunami garnered worldwide attention and support, in the form of financial support for Indonesian communities and NGOs, and on-site aid (e.g., medical and shelter/housing). Among the INGOs that participated in rebuilding and repairing housing were World Vision, Habitat for Humanity, Catholic Relief Services (CRS), and Muslim Aid (which partnered with Oxfam International). For instance, CRS contributed to the housing efforts by providing assistance and resources to local NGOs, employing local engineers, and skills training

f. The Red Cross Movement

The International Federation of Red Cross and Red Crescent Societies (IFRC), one of the Red Cross Movement's three constituent divisions, was designated as the official "cluster lead" for the Global Shelter Cluster (discussed further, below) (International Federation of Red Cross and Red Crescent Societies (IFRC) 2016; Jha et al. 2010; World Health Organization (WHO) 2016). As such, it participates in the provision of immediate and transitional shelter, as well as supporting owner-driven / community-driven reconstruction approaches with cash, tools, and materials. In addition, the IFRC may aid in the coordination of in-country sheltering activities and resources, technical assistance, pre-positioning of supplies, and training for other shelter agencies (International Federation of Red Cross and Red Crescent Societies (IFRC) 2016). For example, following the 2007 earthquake in Peru, the IFRC provided technical capacity building (e.g., training and workshops) and rebuilt housing in thirteen communities (International Federation of Red Cross and Red Crescent Societies (IFRC) 2010).

g. Private Sector – International and Domestic

There are various private sector participants operating at multiple levels of the reconstruction process. According to the Active Learning Network for Accountability and Performance in Humanitarian Action (ALNAP), there are three major roles the private sector generally plays in humanitarian assistance: 1) providing cash or material aid; 2) acting as contractors to deliver aid; and 3) acting as facilitators for the receipt and distribution of grants (Taylor et al. 2012). For instance, small, domestic or large, international commercial contractors may be used in reconstruction programs where governments or agencies lack the means to handle the task themselves. Mexico, Iran, and Turkey have all used private companies for post-disaster reconstruction, as well as supporting local builders (Lyons 2009). Domestic or foreign firms may also provide raw building materials and supplies, or even prefabricated housing. While local entrepreneurs may also find opportunities in the reconstruction process, they may lack the means to conduct large-scale developments, which tend to favor established contractors (foreign and domestic) (Bray 2009; Lyons 2009). There has been growth in private-sector philanthropic contributions to disaster response efforts (particularly for the 2010 Haitian earthquake), from individuals, corporations and foundations. This has coincided with an increase in donor governments using private contractors in reconstruction projects (Taylor et al. 2012).

h. The International Shelter Sector

i. The Global Shelter Cluster

Following the Humanitarian Response Review commissioned by the UN in 2005, the international humanitarian system was broken into "clusters" according to aid type (Inter-

Agency Standing Committee 2006).[11] As the name implies, the Global Shelter Cluster (GSC) provides coordination mechanisms for shelter efforts, with the IFRC as the designated lead agency for natural disasters. The declared aim of the GSC is to improve humanitarian response and "enable its partner agencies to take a strategic approach to collective response" (Global Shelter Cluster 2012). In order to achieve this goal, the GSC's thematic priorities for 2013 were: 1) Enhanced Shelter Cluster Coherence; 2) Engagement with local and national actors; 3) Accountability; 4) Shelter in Recovery; and 5) Regulatory barriers to the provision of shelter (Global Shelter Cluster 2013). An advantage of the GSC's structure is the composition of the Strategic Advisory Group that approves the Cluster's priorities and strategies, which is comprised of those directly involved in shelter construction and reconstruction. Among the organizations in this group are Care International, Habitat for Humanity International, Oxfam GB, UNHCR, UN Habitat, and World Vision International (Global Shelter Cluster 2013).

An evaluation by the Inter-Agency Standing Committee (IASC) revealed that, while some problems exist, the introduction of the Cluster System has been beneficial overall. Among the Clusters' positive impacts are: improvements in identifying gaps, reduced duplication of effort, predictable leadership, and greater coordination and inter-organizational partnership. Similarly, humanitarian actors report improved flows of information, as well as the adoption or creation of standards in local settings. Despite these benefits, problems have arisen in the Cluster approach, including: poor inter-cluster coordination; poor

[11] The Sector Approach comprises one-third of the "Humanitarian Reform," which also includes Humanitarian Coordinators and Humanitarian Financing (GSC 2013)

integration of Clusters with (or even undermining) local systems; sub-optimal needs assessments; and instances for poor/non-existent community participation (Inter-Agency Standing Committee 2006). Meanwhile, some reviews of the cluster focus specifically on the performance of the GSC Lead, the IFRC. As with the entire Cluster System, the IFRC is credited with maintaining good communication and information flows. The IFRC's response to the 2009 Bangladeshi cyclone was perceived extremely well by other shelter organizations, and was deemed central to the coordination of the shelter efforts (Walton-Ellery, S. 2009). In Haiti, despite an array of difficulties, the IFRC fielded and coordinated teams across the affected areas, while also able to separate its coordinating activities from its operational ones (S. Davidson 2011). In a meta-review of the IFRC, the Federation was also found to be responsible for increasing the roles of non-UN organizations in the GSC and improving the Cluster's overall "credibility, capacity and legitimacy" (S. Davidson and Price 2011). Yet, challenges encountered by the IFRC have included the lack of coordination from the outset of the response, joint planning, and community consultation (Walton-Ellery, S. 2009).

ii. Minimum Standards

The Sphere Project ("Sphere") emerged in 1997, following the humanitarian sector's evaluation of the response to the Rwandan genocide. This coincided with the development of two other standards – the People in Aid (PIA) program and Humanitarian Accountability Project (HAP) (Austin and O'Neil 2013). Sphere's purpose was to establish minimum standards across the key areas of humanitarian assistance, culminating in the Sphere Handbook in 2000 (revised in 2011). The Sphere Project is governed and maintained by members of the humanitarian sector, and represented the best practices across the various sub-sectors. Sphere uses a uniform format, is explicit about each standard and how to achieve it, and has become the most commonly-known set of humanitarian requirements (Austin and O'Neil 2013; The Sphere Project 2013). More recently, the Joint Standard Initiative was established to examine these sets of standards, particularly via stakeholder consultation. Among the key findings was the need to improve awareness, knowledge/training is critical for standard implementation, the importance of verification of compliance, and a request for streamlined and simplified standards. Recommendations were made in order to address such concerns, such as the development of a core set of standards, harmonization of the three existing systems, and donors' consistent approach for humanitarian organizations' use of standards (Austin and O'Neil 2013).

g. Criticisms of the Humanitarian Aid System

Problems present in the larger humanitarian aid system reflect those occurring in the narrower field of post-disaster reconstruction. The lack of coordination between and among governments, donor agencies, and aid organizations has been cited as a major problem for the humanitarian sector (Burall, Maxwell, and Menocal 2006; Hilhorst 2002; Taylor et al. 2012). There has also been a criticism for an emphasis on "bandage solutions," providing aid for immediate responses, but not for long-term impacts or reducing community vulnerability (Curtis 2001; Taylor et al. 2012). In addition, the sector also suffers from contributing to differential outcomes across countries and populations. The context, visibility, or lack of proper need assessments of affected populations can impact the delivery of aid, which has yielded a system of uneven outcomes. For example, certain displaced populations have received assistance while others have not. Likewise, there have been delivery gaps across Africa, and there were vast differences in the availability of funds for post-earthquake Haiti in 2010 versus for the 2011 floods in Pakistan (Curtis 2001; Taylor et al. 2012; United Nations 2010).

The humanitarian aid sector has also experienced increasing politicization, characterized as "the convergence between humanitarian action and politics" or the "pursuit of domestic and foreign policies of donor states by humanitarian means" (Curtis 2001, Duffield 2001). As a result, political pressures and agendas have influenced the availability and direction of aid. Aid may be withheld or limited by donor agencies and governments from counties that do not comply with certain economic or political aims, policies, or positions (e.g., liberalization or structural readjustment) (Curtis 2001; Hilhorst 2002; United Nations 2010). Alternatively, organizations may take on humanitarian programs with ulterior motives, such as political agendas or desires for financial gain (Hilhorst 2002). Each of these criticisms may apply to reconstruction programs, as will be described below.

2. Factors Influencing Performance

Public sector, private sector, NGO, and community efforts do not occur in a vacuum and can be heavily-influenced by local circumstances and context. This may include factors *external* to the reconstruction process, such as the overarching political or regulatory environment. It may also include factors *internal* to the reconstruction efforts, i.e. those arising from the key actors and the programs involved. These categories are not intended to be iron-clad or mutually exclusive; some factors might fall in both categories, or classification may be subjective. This framework is merely being used to assign some structure, albeit not perfect, to the myriad contributing factors. The following sections will first address "external" examples, followed by "internal" ones, and last, issues of outcomes and performance.

a. External Factors

Although highly-influenced by the "internal" factors addressed below, the broader domestic and international context can shape or constrain post-disaster reconstruction. The prevalent social, economic and political landscape in disaster-afflicted countries can impact the speed or efficacy of reconstruction. Disaster and development planning (or the lack thereof) can guide reconstruction, or potentially hinder it or lead it astray. Instances of ineffectiveness and corruption have been pervasive in governments in the developing world, which can funnel down to affect all levels of the post-disaster efforts. Domestic regulation and legislation, such as those regarding land tenure and land use, may similarly impact the way institutional actors conduct their activities, govern who can/cannot participate, or even prevent reconstruction altogether.

i. Governance

The domestic political environment can impact the public sector's disaster response, as well as those of the other key actors. Low levels of government capacity, or political/economic instability, can impede work at all levels. As a result, local, regional, and federal governments may not be equipped to handle essential tasks, such as disaster management or reconstruction planning prior to a disaster occurring (Masyrafah and McKeon 2008; Taylor et al. 2012). Local politics and the agendas of the existing government are also significant factors. A lack of political will and insufficient organizational capacity can limit government actions, such as the imposition and enforcement of building codes, which can directly influence disaster mitigation or reconstruction outcomes (Schilderman 2004). Compounding such problems, governments may also engage in clientelism in the allocation of resources, program planning, or regulatory policies.

ii. Corruption and Clientelism

Both corruption and preferential treatment (i.e. clientelism) by government agencies have been cited in the provision of basic services and disaster mitigation planning, and may be endemic even before a disaster strikes (Davis 2004; Jayasuriya and McCawley 2008; Schilderman 2004). The preexisting political system may already be embedded with corruption in order for organizations and agencies to do "business as usual." Such behaviors have been noted to occur between private parties (e.g., customers, contractors, municipal corporations) and multiple levels of government, including water agencies, local governments, state development departments, and elected/unelected leaders (Davis 2004; Jigyasu 2004). As Quarentelli notes in his study of the research, corruption is a common phenomenon in post-disaster scenarios, primarily in the construction and building sectors (Quarantelli 1999). In post-tsunami Sri Lanka, corruption and favoritism by government ministries played a role in the awarding of contracts for housing construction (Kennedy et al. 2008). Opportunities for corruption may also arise in situations of extensive competition (e.g., in the sourcing of labor or materials), or where there is a lack of oversight and accountability of donor agencies (Kulatunga 2011).

Corruption in the reconstruction process can take many forms, including bribery, kickbacks, and "markets for desirable posts." Within public institutions, desirable posts may be those that place the staff member(s) close to their home, or allow them to have regular contact with parties that provide kickbacks (e.g., the exchange of money for favors). Although corruption has been accepted to a degree by the donor community, sometimes seen as a means to expedite the provision of services, it has at the same time been noted as a central challenge to development (Davis 2004). Increasingly recognized as harmful, attempts must be made to prevent or mitigate corruption in any reconstruction or recovery processes. Corruption has been cited as a potential cause of additional problems, such as a general lack of enforcement, misallocation of resources, or decreasing the number of opportunities for developing countries to attract and receive foreign investment and aid (Davis 2004; Fengler, Ihsan, and Kaiser 2008a; Sanderson 2000). Suspicions of its occurrence can discourage donor interest or commitment; therefore, corrective measures against corruption are critical for both funding and the perceived legitimacy of the reconstruction efforts (Fengler, Ihsan, and Kaiser 2008a; Kulatunga 2011). To combat corruption and mismanagement, some governments have instituted multiple levels of control (e.g., national, regional, and local councils), or a tight governing structure for involved agencies, so that fiduciary discretion does not reside within only one organization (Hogg 1980; Kulatunga 2011).

iii. Government Policies and Regulation

Existing government policies on development and disaster planning can also have impacts on post-disaster efforts (Kennedy et al. 2008; Quarantelli 1999). Disasters simply may not be on the political agenda, incorporated into other policy realms (e.g. housing or development), or recognized as a priority. Likewise, governments may not account for important variables or population subgroups (through lack of attention or economic/social/cultural favoritism), thereby potentially impacting any post-disaster efforts

(Ingram et al. 2006; Mukherji 2010; Quarantelli 1999). Examples include India's National Slum Policy, which fails to acknowledge slum dwellers' vulnerability, and areas of Africa, where disaster management is centered on rural food security and not natural hazards (Sanderson 2000). These preexisting policies may shape future post-disaster responses, preventing reconstruction-related capacity building or planning before an event occurs.

iv. Land Tenure

Policies regarding land tenure can significantly impact the reconstruction process and its results. In and around metropolitan centers, low-income populations may lack ownership of the land on which they live, which is especially true for the very poor, and squatters in particular. Home ownership status has been used in the past to determine what kind of aid a household receives, which can then dictate whether or not a household's home is rebuilt or repaired. In some cases, only those with the title to their plot have been given aid, as in Bhachau, India following the 2001 Gujarat earthquake (Mukherji 2010). Policies that result in providing or withholding tenure can also impact how structures are built and rebuilt on non-titled land, as it has been found that lack of land tenure can lead to poor quality shelter (Sanderson 2000). However, possessing title to one's land is not wholly protective or will ensure the reconstruction of a damaged home. There are instances where those with tenure were forced to give up their plots and relocate elsewhere when the land was expropriated by the government (Hogg 1980; Oliver-Smith 1990). In such cases, broader government action or intentions usurped the ability to repair or rebuilt (or reside in) one's home even when title was possessed.

v. Residential Location Policy

Policies that impact residential location can also affect how reconstruction takes place, determine what standards it must follow, and govern where the construction/reconstruction may occur. Where households locate their homes is in part dictated by government policy, such as specific laws regarding land tenure (including land use and zoning regulations), as well as land/home affordability, and household preferences. The lack of proper regulations preventing residential location in hazard-prone areas, such as flood zones or unsafe hillsides, can lead to the reconstruction of homes and communities on dangerous land (Sanderson 2000). This may disproportionally affect low-income households, particularly squatters, who may settle wherever open land exists, regardless of government policy or potential hazards (Green 2008). Conversely, the imposition of regulations that establish and enforce safe zoning standards and building codes would benefit the reconstruction process; such policies can aid in disaster risk reduction through the enforcement of safer building standards in the repaired and rebuilt homes (Sanderson 2000).

b. Internal Factors

In addition to the overarching economic and political environments in which they operate, the specific characteristics of reconstruction programs and key actors also affect how the process works and to what degree it is successful. This may include program design and planning, the lack of attention to critical factors (e.g., the social/cultural landscape), program accountability and management, and community involvement. These issues are certainly not limited only to reconstruction aid and can be found elsewhere in the humanitarian sector; however, the focus here is that these contributing factors occur in the reconstruction process versus the overarching landscape.

i. Problems in Program Design

The shape, scope, and goals of reconstruction efforts are critical in influencing community outcomes. The matters of *who* receives aid, *where* it occurs, *when* it will take place, *what* kind of aid, and *how* it is delivered may be determined by reconstruction program design. While humanitarian aid overall has been faulted for unclear or competing objectives, the goal of the reconstruction programs are somewhat more straight-forward: to rebuild or repair homes for those affected (Fengler, Ihsan, and Kaiser 2008a; Overseas Development Institute 2002). However, despite a fairly focused goal, reconstruction objectives have still been criticized for treating the symptoms but not causes or contributors to disaster impacts (as with the humanitarian sector at large), sometimes even exacerbating the hazardous conditions (Schilderman 2004).

Different types of reconstruction may be given more or less priority from case to case, country to country. In Nicaragua following the devastating events of Hurricane Mitch, road infrastructure was prioritized over all other concerns, to the extent that roads received 60 percent of reconstruction resources, versus 10 percent for housing. The national government's priorities did not match those of the people, as more than 30 percent felt that housing was their most important need versus a mere 5 percent who prioritized roads (Delaney and Shrader 2000). Such a mismatch between communities' wants and needs can severely diminish the overall utility and satisfaction of reconstruction programs.

Program Management

Reconstruction programs not only need to be well-designed, but must also be implemented and maintained in a way to provide the best possible outcomes. Project management should include performance measures to ensure that funds are used as intended, and that the reconstruction work is done equitably and of equal quality, especially for those with the greatest need (Fengler, Ihsan, and Kaiser 2008a; Kulatunga 2011; Overseas Development Institute 2002). However, there are significant challenges to doing so. The functional capabilities of government agencies may be severely impaired from the disaster, such as deficits in communication and monitoring, making management even more difficult (Kulatunga 2011). Yet, even if fully functional, the domestic government may be operating in a "state of exception," bypassing normal or proper protocols. Crises often require immediate responses, and the need for rapid spending may override or circumvent financing controls, further complicating or reducing accountability (Bray 2009; Overseas Development Institute 2002). Effective management is needed to balance the need for urgency without sacrificing public safety or the quality of structures built.

Attention to Existing Policy

Lack of attention to crucial factors has also been a significant problem in post-disaster reconstruction, ranging from inattention to government policy to the needs of various population sub-groups. Reconstruction can take place with total disregard to existing regulations, which may sometimes result of the "state of exception" mentioned above. Reconstruction programs' lack compliance with domestic regulations can negatively affect aid outcomes, resulting in incompatible/undesirable land-uses or negative environmental impacts (e.g., deforestation resulting from rapid reconstruction) (Ingram et al. 2006). Governmental plans and programs may be enacted for the reconstruction of the areas affected, but lack of enforcement or subsequent changes in policy may halt or undo any positive results attained. For example, the creation of a "buffer zone" was created along the Sri Lankan coastline following the 2004 tsunami, but was enforced selectively. In addition, nearly a year after the disaster, the Sri Lankan government altered its rebuilding policies, resulting in confusion regarding when and where to perform the reconstruction (Ibid.).

Accountability

Proper resource allocation also plays a fundamental role in providing appropriate outcomes. Donors' earmarking of funds can result in some sectors or programs receiving aid (often those with the highest visibility), while leaving others with little or nothing at all (Overseas Development Institute 2002). Poor monitoring and misallocation of funds can not only result in waste, but in the case of Sri Lanka, when combined with suspicions of corruption, can also lead to a decrease in the amount of future aid available. As a potential solution, public financial management (PFM)[12] systems can improve allocative efficiency, dispersing funds to the intended beneficiaries, for the intended purposes (Fengler, Ihsan, and Kaiser 2008a). Such systems can increase transparency and accountability throughout the process, while also creating more appealing (i.e. "safer") environments for aid organizations, donors, and foreign investment (Kulatunga 2011).

There are, however, real challenges to maintaining accountability. The absence of universally-accepted monitoring measures or systematic documentation methods may prevent comparability across donors and recipients, as well as hampering the ability to gauge aid program effectiveness (Overseas Development Institute 2002). In order to provide some means of accountability, formalized monitoring systems must already be in place, particularly for domestic and foreign governments, donors, and NGOs. Benchmarks,

[12] "Public financial management entails the development of laws, organizations and systems to enable sustainable, efficient, effective and transparent management of public finance." (World Bank 2013)

reporting mechanisms and monitoring systems provide some accountability of funding and program performance. Frameworks, such as that of the UN Joint Inspection Unit, could be used as models for achieving greater accountability among donors, NGOs, and governments (UNEP 2008, UN JIU 2011). The UN framework stresses the following elements: transparency' mutual accountability between participants; internal controls to ensure a proper working environment and procedures; the use of complaints and response mechanisms (UN JIU 2011). Such a system is general enough to be adapted for use in the reconstruction context and its diverse range of participants.

Public Participation & Excluded Populations

A major focus of modern urban planning, the issue of equity also arises in post-disaster reconstruction. The causes for differential access or consumption of aid may be multifactorial, including poor planning, time constraints, elite capture, exclusion/discrimination, or lack of knowledge in the affected populations. Rapid disaster response and recovery are often high priorities, thereby placing time pressures on the actors involved. As a result, reconstruction may suffer from the "tyranny of the urgent" or "state of exception," operating with a top-down approach and lack of public involvement (Bray 2009; Delaney and Shrader 2000; Jigyasu 2004; Schilderman 2004). Post-disaster programs have been faulted for failing to include and consult with average residents and local community groups during the planning stages, relying instead on political and local leaders to represent the public interest (Jayasuriya and McCawley 2008; Schilderman 2004). Problems such as corruption, political interference, and poor program targeting can distort the process, providing aid to those least affected (i.e. higher income groups/classes), while the most-affected (i.e. marginalized groups) benefit far less (Schilderman 2004).

Women are also often ignored or fail to be included since leadership positions are often exclusively held by males, and women's needs tend to be grouped under "family well-being," rather than as a category of their own (Delaney and Shrader 2000). The poor, marginalized population sub-groups, or those at odds with the political leadership may suffer from a lack of voice in post-disaster processes, their needs failing to be recognized or accounted for.

Even if unintentional, the lack of public participation can have significant consequences. It fails incorporate local knowledge and needs, which can result in poor quality or inappropriate solutions, as well as failing to instill a sense of ownership in the local populace (Sanderson 2000; Schilderman 2004). Worse, this has included the inequitable distribution of aid, such as providing the least help to those with the most need (Schilderman 2004). One potential solution may be to utilize top-down methods to respond to the most urgent needs and immediate after-effects of the disaster, while a bottom-up approach may be used in the longer-lasting reconstruction phase. Community participation in the needs assessment, planning, and implementation stages would help to obviate such problems (Lyons 2009).

Housing Appropriateness

The lack of community consultation or involvement in the planning and implementation of reconstruction can result in poor or inappropriate outcomes. The concept of "better" housing is subjective and can have a variety of meanings; in the context of post-disaster reconstruction, one important facet may be improved resident safety through appropriate building materials and methods (Kennedy et al. 2008). As stated, the reconstruction process may conducted in a top-down manner and without local knowledge or community involvement, lacking attention to conditions on the ground or to the preferences or practices of those whom the reconstruction is supposed to benefit (Delaney and Shrader 2000; Kennedy et al. 2008). Reconstruction is also viewed by some merely as a process that creates "physical products ruled by technical criteria," ignoring the ties of housing to residents' economic livelihoods and social/cultural practices (Jigyasu 2004). Therefore, problems can arise with the logistics and design of the homes to be rebuilt, such as the use of inappropriate materials, the floor layouts of the homes, and the arrangement and location of the settlements themselves. The aesthetic and physical designs of the structures may be incompatible with local preferences, such as being "too urban" for residents with more traditional lifestyles. In some instances, new settlements have even been abandoned and residents returned to the sites of their original homes (Boen and Jigyasu 2005; Jigyasu 2004).

Externalities of Household Relocation

In cases where housing reconstruction requires household or village relocation, issues of appropriateness can be compounded by additional factors that may impact residents' well-being (Kennedy et al. 2008). Relocation may be necessary if the original land is deemed too hazardous or is expropriated by the government for other purposes (Hogg 1980). However, moving households and communities away from their previous locations may be based on purely technical measures without consideration to social, cultural, and economic factors. Communities may become divided and livelihoods disrupted from arbitrary and poor planning (Ingram et al. 2006; Jigyasu 2004; Kennedy et al. 2008). Some village or settlement layouts (often designed by foreign experts and/or without community involvement) have been discordant with traditional community practices. Relocated or reconstructed settlements may lack spaces for artisans and others to work or areas for cultural/religious services to be performed. Households have also abandoned relocated housing on the basis of neighborhood composition, as occurred following the 1992 earthquake in Flores, Indonesia. Whereas before the event Catholics and Muslim populations lived separately, they were forced to reside together in a relocated settlement, and thus many returned to and rebuilt on their previous housing sites (Boen and Jigyasu 2005). Another important spatial component is a site's proximity to resources for residents' health and livelihoods. These may include water for drinking/washing, the ocean for fishing, or arable land for agriculture, as well as the distance from home to workplace (which can change dramatically, consuming both time and financial resources) (Hogg 1980; Ingram et al. 2006).

ii. Intra-Organizational: Capacity

Labor and Material Resources

Organizational capacity is another contributing factor in the performance of key actors in the reconstruction process. Governments and aid organizations may face problems in resource management and procurement (e.g., labor, materials, and equipment), as well as shortfalls in staff knowledge, training, and technical skills (Bray 2009; Kulatunga 2011). A lack of resources can hinder and delay reconstruction, while competition for limited supplies can increase overall costs. Procurement guidelines and supply chain management can therefore be instrumental in preventing such problems. Governments and organizations can use multiple suppliers to reduce the risk of supply shortages, although this may demand greater oversight or transaction costs. Alternatively, they may use a single supplier, which provides the potential benefits of better quality control and accountability, yet can also be a bottleneck or roadblock if it becomes a single point of failure (Kulatunga 2011). Organizations engaged in reconstruction may face deficiencies in labor, including having insufficient personnel, understanding and knowledge of the problem, or experience to handle the tasks at hand. Staff in aid organizations may be forced into roles or situations outside of their norm or to which they have not been trained (Quarantelli 1999). Whether it is materials and supplies, the number of personnel, or knowledge and skills, such resources are critical ingredients, the lack of any of which can severely impair any the reconstruction process.

Financing

Even before a disaster, governments in the developing world may suffer from limited funds, constrained budgets, poor or nonexistent revenue collection, and high debt. Each of these conditions could result in delaying or limiting public investment in reconstruction since there is simply little money available to spend (Freeman 2004; Hogg 1980; Kulatunga 2011). Once a disaster occurs, the already-precarious financial situation may be compounded by the large investments needed for the response and reconstruction, leaving the country in an even worse economic state. The destructive events may also rob countries of their tax base and available economic resources through their impacts on the population, infrastructure, and industry. Following Hurricane Mitch, Honduras lost 41% of its GDP and 292% in annual tax revenues, denying access to potential funds (Freeman 2004). A sense of urgency to make progress with the reconstruction, in addition to the many actors involved, pose real obstacles in maintaining proper financial management. As a result, rectifying the funding process and improving “donor harmonization” have become high priorities in post-disaster environments (Fengler, Ihsan, and Kaiser 2008a).

iii. Inter-Organizational: Coordination

The lack of coordination has been repeatedly found to have deleterious effects on both humanitarian aid and reconstruction outcomes. Consequences include duplicated efforts, completely neglected populations/areas, inefficient uses of resources, and inter-organizational conflict (Fengler, Ihsan, and Kaiser 2008a; Jayasuriya and McCawley 2008; Kulatunga 2011; Quarantelli 1999; Sanderson 2000; Seybolt 2009; Telford and Cosgrave 2007). However, coordination may be difficult to achieve due to the logistics of having multiple actors involved and their potentially conflicting agendas. Monitoring and managing the varying roles of organizations operating at multiple scales (e.g., international/ national/regional/local) has proven to be a significant challenge (Barakat 2003; Kulatunga 2011; Sanderson 2000).

Yet, inter-organizational coordination among the key actors is extremely important in post-disaster situations for several reasons: the widespread lack of planning and resources in developing countries; the large scope and complex nature of housing reconstruction; and the number and varied composition of participating organizations (both domestic and international) (Fengler, Ihsan, and Kaiser 2008a; Kennedy et al. 2008; Kulatunga 2011). Coordination between actors benefits the reconstruction process, helping the key actors to work together and work more effectively. The horizontal and vertical flows of information, as well as the alignment of activities and supply chains are critical for reconstruction outcomes. Inter-organizational agreements can yield improved trust and understanding between actors, produce more predictable and timely results, and establish mechanisms for a mutual exchange of information (Alam 2008; Oliver-Smith 1990). Although it may be difficult to achieve, coordination can help minimize community dissatisfaction, provide consistent products, and ensure adherence to domestic or international building standards (Kennedy et al. 2008).

In some cases, agencies have been created or assigned to oversee the recovery and reconstruction processes, with the express purpose of playing a coordinating function (Fengler, Ihsan, and Kaiser 2008a). The coordination of activities and resources conducted by organizations other than domestic governments/agencies, including the World Bank's Multi-Donor Trust Funds, have been successful in improving coordination, program effectiveness, and donor confidence in the reconstruction efforts (Fengler, Ihsan, and Kaiser 2008a). One potential cost of cooperative arrangements, however, is the time-intensive nature of negotiating between the various parties, as well as the administrative costs of systems of checks and balances to preserve project goals and objectives (Oliver-Smith 1990).

3. Performance and Disparities in Outcomes

While housing units may be rebuilt and target goals reached, unevenness in reconstruction outcomes can still occur. The pace of the process is highly variable across events, and is not necessarily equal across populations and sub-populations. Social, economic, political, and cultural factors may play a role in who receives how much and what form of aid. Yet, reconstruction and post-disaster policies may also exacerbate societal inequalities or household vulnerability (Cosgrave 2007; Ingram et al. 2006; Lyons 2009).

a. Household Income / Socioeconomic Status

Disasters have often been found to have differential impacts according to socioeconomic status, more greatly affecting those with fewer resources. This is typically based on low-income households' more hazardous residential locations, poor housing materials, and lower levels of preparedness (Delaney and Shrader 2000; Ingram et al. 2006). There are similarly unequal outcomes in post-disaster reconstruction, as socioeconomic status can be a determinant of whether one's home can be repaired or must be completely rebuilt. Households with higher incomes may live in more structurally-sound housing, which may be habitable following a disaster, or have resources with which to repair or rehabilitate their homes. Low-income households are more likely to live closer to hazards (e.g., on hillsides or flood plains) and less sound structures, resulting in greater risk of complete destruction and necessitating reconstruction and possibly relocation (Ingram et al. 2006). Compounding such problems, poor and medium-income households may also lack the resources with which to rebuild their homes, thus requiring external sources of aid.

However, despite higher-income households having more resources available and potentially less risk of total home destruction, reconstruction aid may still be "captured" by the upper classes (Lyons 2009; Mukherji 2010). Preferential treatment towards the elite in the distribution of aid represents a significant misallocation of limited resources away from those who likely have greater need. The economic livelihoods of the poorest households can be especially hard it and impaired through the destruction of household assets and resources. For instance, the destruction of boats and infrastructure used in fishing communities can leave already low-income households in worse standing. In Sri Lanka, this was further exacerbated when these households were displaced from their land, and prohibited from living near the ocean through the institution of a coastal "buffer zone." Yet, the policy did not affect all populations equally, as the upper classes and hotel/resort owners benefited from the situation. The coastal areas experienced gentrification and an expansion of tourist destinations and lodging in the same kinds of coastal areas that fishing communities were forced to abandon (Ingram et al. 2006; Kennedy et al. 2008).

b. Location

Geographic location can impact reconstruction outcomes through circumstances tied to the land on which households reside. Physical location and geography can affect the feasibility or attractiveness of certain projects, as high-visibility (and highly-accessible) programs or developments are often a priority of government and officials. It is therefore unsurprising that the most accessible areas may receive more funding than their distant counterparts (Freeman 2004). The more reachable areas, which may include regional capitals, may even receive more aid than is actually needed (e.g., Aceh, Indonesia), while those who are isolated benefit far less. Logistical concerns, rather than political ones, may dictate this spatially-based distribution of aid, such as in Afghanistan, where security concerns prevented aid from reaching isolated areas, instead focusing on the more accessible city of Kabul (Fengler, Ihsan, and Kaiser 2008a).

c. Process & Outcome Assessment

Process and outcome evaluation may be a critical step in gauging any reconstruction program's success. As mentioned, funding often comes from a variety of sources, and it is important to both the recipient governments and donors to be able to track resource flows and identify gaps or causes of delay. Process evaluation allows an assessment of the reconstruction planning and implementation activities, focused on *how* reconstruction takes place. Process measures may pertain to the extent of inter-agency/organizational collaboration, community participation, and fairness of land acquisition/appropriation.

Meanwhile, outcome evaluation is important not only to assess the number and locations of homes built, but also their quality, durability, equitable distribution, and user satisfaction (e.g., whether or not residents inhabit them) (Ganapati 2012; United Nations Environment Programme 2008; United Nations Joint Inspection Unit 2011).

In order to conduct better monitoring and evaluation ("M&E"), governments and donors do not have to invent something on their own, as they can look to existing evaluation systems from various international organizations (Hilhorst 2002). For example, the UNEP Programme Accountability Framework and 2008 Evaluation Manual provide a core structure and methods that can be employed by the key institutional actors. The UNEP Evaluation system includes determining key performance indicators, progress monitoring, financial monitoring, assigning role/responsibilities, and steps for implementing the M&E systems (UNEP 2005; UNEP 2008; UNEP 2010). Although other standardized tracking mechanisms and databases have also been developed for evaluation purposes, their use is far from universal (Fengler, Ihsan, and Kaiser 2008a). An alternative is result-based management, which provides a method for tracking resources and outcomes used by donor organizations (Overseas Development Institute 2002). A caveat still exists that where assessments do occur, the quality of the evaluations and their results vary, at times yielding little to no relevant information (Barakat 2003).

Both donors and recipients should be involved in the process to ensure the proper flow of resources, timely progress, and appropriate outcomes. Special reconstruction agencies, along with their coordinating role, can also participate in the monitoring process (Fengler, Ihsan, and Kaiser 2008a). Meanwhile, donors can utilize field offices to better understand local needs, the reconstruction operations in play, and monitoring partner organizations and resource allocation (ODI 2002). Several overall recommendations in the literature and NGO publications have also included: independent monitoring structures, regular evaluations of donors programs; system-wide evaluations; and codes of conduct (Fengler, Ihsan, and Kaiser 2008a; Hilhorst 2002; ODI 2002). However, there are real obstacles to doing so. Low-income countries may have preexisting capacity problems, poor data collection, documentation, and monitoring systems, making efficiency and accountability particularly hard to measure or improve (Quarantelli 1999). The lack of coordination or communication between actors may further limit the amount of information available, and organizational capacity again plays a major role in the ability to make use of such data.

C. Conclusion

In summary, the post-disaster reconstruction literature provides a picture of a complex and resource-intensive process. The need for vast sums of money and the participation of domestic and international actors can impact if and how reconstruction occurs in a number of ways. Further, preexisting social, political, and economic conditions in the afflicted areas can work to facilitate or hinder the process.

CHAPTER 3: RESEARCH GOAL & HYPOTHESES

I. RESEARCH GOAL

The research goal of this dissertation is to assess and quantitatively measure the reconstruction of Banda Aceh, Indonesia. Extant literature and official reports predominantly provide large-scale or aggregated measures, therefore, it is the aim of this study to examine spatially precise patterns in the rebuilding and rehabilitation of the city. Specific research questions and hypotheses are detailed below.

II. RESEARCH QUESTIONS

The following research questions aim to determine patterns in the reconstruction in post-tsunami Indonesia and the ways in which an institutional coordinator impacted its relative success.

1) **In what ways did spatial factors contribute to the reconstruction process?**
    - <u>Hypothesis</u>: Increasing **distance** from the coast was associated with higher reconstruction rates

        - Structures located close to the coastline are more like to not have been rebuilt, in part due compliance with the (revoked) mandatory buffer zone
    - Hypothesis: Reconstruction was **clustered** by location, not randomly distributed
        - Geography and economies of scale in building/rebuilding homes will incentivize development in clusters, or pockets of growth
    - Hypothesis: Reconstruction of **road** infrastructure will be positively correlated with structure reconstruction
        - The reconstruction of structures was dependent on supplies that need to be delivered to the site(s), stimulating road construction to those destinations.

2) **Can the extent and rate of reconstruction be measured quantitatively to enable timely monitoring and evaluation?**
    - Reconstruction outcomes will be assessed through objective, replicable methods via **spatial analysis**.
    - These methods will be used to determine:
        - where structures were built/rebuilt within the study areas, as well as overall changes in geographic distribution
        - possible interrelations between the reconstruction of structures, roads, and aquacultural ponds (*tambaks*)

3) **How did domestic and international "coordinators" aid the reconstruction process?**

- Leadership and coordination provided by GOI's **BRR** (functions & funding) and the **World Bank** MDTF (funding) gave direction and supervision to governmental bodies, NGOs, and other actors participating in the reconstruction process
- Reporting mechanisms increased accountability, and allowed for course correction when problems did arise, thereby improving outcomes

This chapter provided the groundwork for this dissertation, introducing the problem and the guiding approach used to investigate it. Included were research questions and specific hypotheses that will be utilized to assess the reconstruction of Banda Aceh, establishing the basis for the analyses to follow.

CHAPTER 4: METHODS

While geographic information systems and satellite imagery have been used to observe changes to the built environment and urban form in a variety of contexts, there are limited examples of this in post-disaster settings (Bhatta, Saraswati, and Bandyopadhyay 2010; Mathieu, Freeman, and Aryal 2007; Yang and Lo 2002). Remote sensing and computer-based mapping have been used to assess the extent of damage following a disaster or tracking settlements of displaced people, but such methods are not yet common practice for studying how disaster-impacted areas recover over time (Chiroiu 2005; Eguchi et al. 2008; Ehrlich et al. 2010; Gillespie et al. 2007; Saito et al. 2004). This section will detail the methods utilized to gauge reconstruction efforts in Banda Aceh.

I. Data

Multiple forms of data were used in this study, both qualitative and quantitative in nature. The following sections will detail the different types of data, how they were created or acquired, and then prepared for analysis. This will lead into a discussion of the methods employed to carry out the analyses.

A. GEOSPATIAL DATA

The term "geographic information systems" ("GIS") refers to the computer hardware, software, and data used in digital mapping and spatial analyses. Although alternatives have arisen in recent years, including open-source programs like QGIS ("QGIS" 2016) and

GRASS GIS ("GRASS GIS" 2016), ESRI's ArcGIS software has been a staple in computer-based mapping for several decades (ESRI 2016; ESRI 2015). While updated versions are released periodically, this analysis relies on ArcGIS version 10.2.

Just as word processing programs use specific file types, so too do GIS software packages. For its mapping applications, ArcGIS uses "shapefiles" to store geographic and tabular "attribute" data[13] that can be displayed visually. Shapefiles can store geographic data in several different formats: points, lines, polygons, and rasters (cells arranged in a grid, such as the pixels that make up an image on a computer screen). Points might be used to indicate individual features such as trees or cities (e.g., when zoomed out on a large scale map), lines for roads or rivers, and polygons for geographic boundaries (e.g., states) or precise shapes like building footprints. Raster data are a separate format than the previous three types, and store and utilize data in a different way to display continuous surfaces. Within these surfaces, each cell has a value for a particular variable, such as elevation in meters or temperature in degrees, and the whole surface displaying that variable as it varies across space.

Shapefiles are created and used by public- and private-sector institutions and individual users alike, and can be made available to the public through official (e.g., government) and

[13] Each item, or "feature," in a shapefile may have "attributes," which are stored digitally in tabular format. Each row represents an individual feature, while the columns ("fields") contain the variables or attributes, which may be in numeric, text, or date formats. Examples of fields may be area in square miles, the date that observation took place, the population count at that location, or the land use category.

unofficial (e.g., internet community) websites. However, for locations outside of the United States, and developing countries in particular, data may be hard to find, if it even exists at all. While some websites specialize in providing international GIS data free of charge (e.g., http://www.diva-gis.org/), the quality or content of the data may be highly variable or inappropriate for the end-users' needs. As a result, GIS users may need to create their own shapefiles, as was the case for this study. This process of data creation and analysis is described below.

1. Creating GIS Data

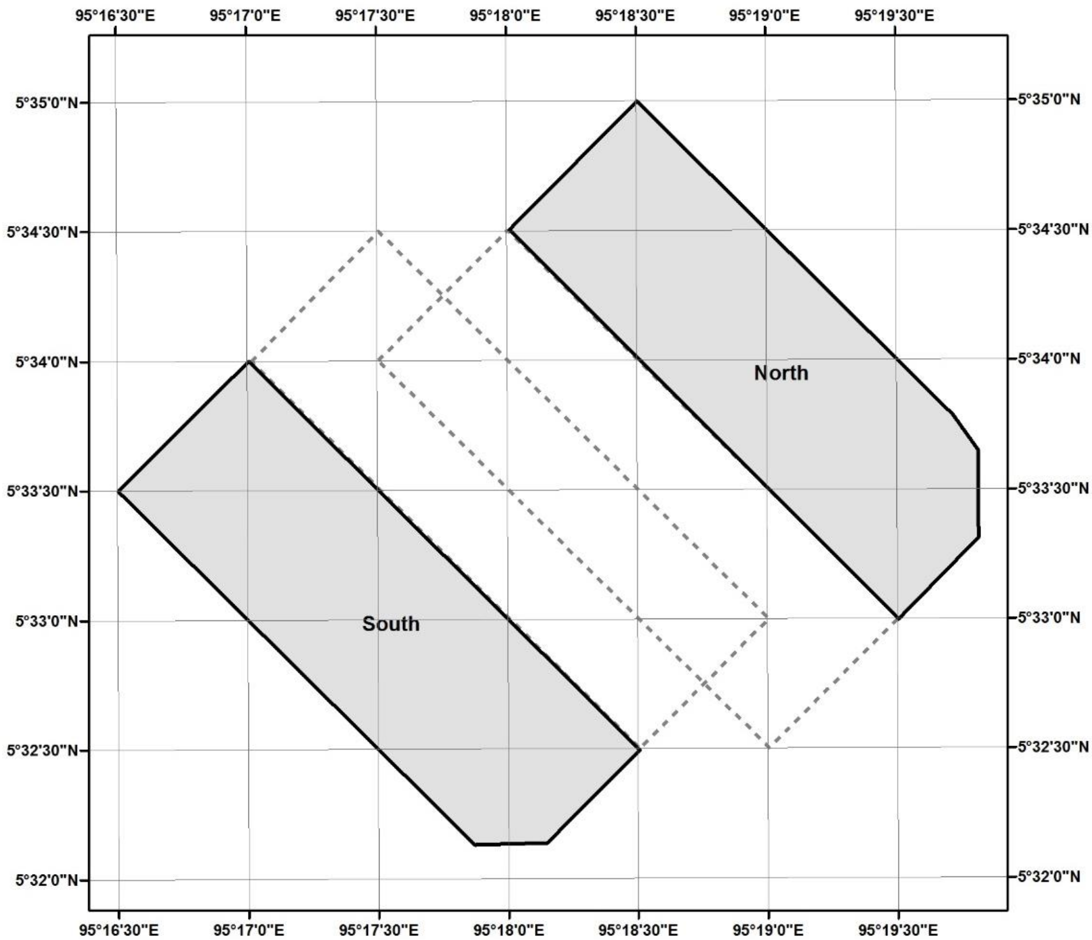
Due to a dearth of accessible, high quality international spatial data, a large number of new files were created for this analysis. Through a process called "digitizing" it is possible to use imagery, scanned paper documents, or other source material as a reference within GIS software to create shapefiles of desired features (Law and Collins 2013). The image is first loaded into the software, as well as a new, empty shapefile, and then using the Editor set of tools in ArcMap, the user can draw or trace the areas or features of interest. In GIS terminology, each individual polygon or each point is a "feature," and there can be one or more features per shapefile.

To begin, the study area in the city of Banda Aceh was divided into four, identical regions of interest (ROIs). These regions were created in a manner that could be easily replicated in an objective manner. First, a 30 arc-second[14] graticule[15] (i.e. a grid made up of squares approximately one kilometer per side) was overlaid on top of the Banda Aceh imagery to provide a standardized foundation based on latitude and longitude. Using this grid as the base, 3 kilometers by 1 kilometer rectangular ROIs were drawn at a 45-degree angle, diagonally connecting the vertices of the grid cells.

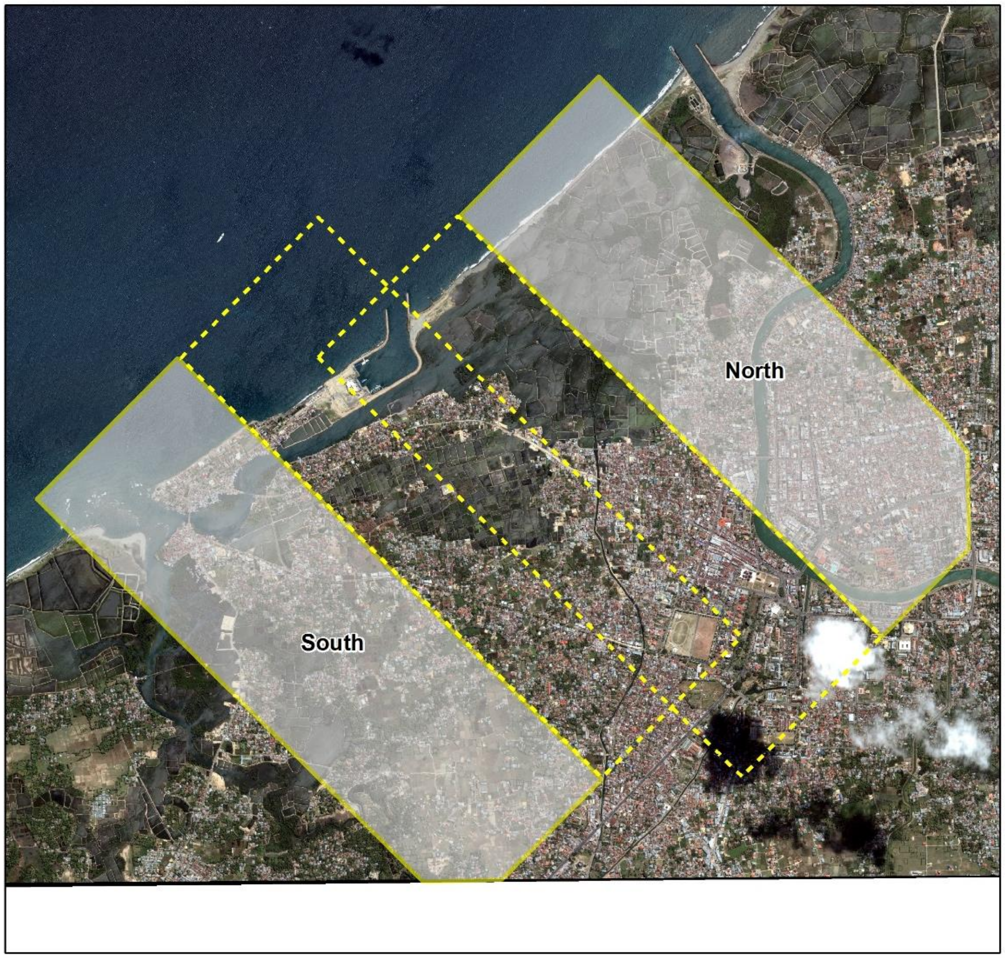
[14] "Measuring in Arc-Seconds" ESRI 2015 http://www.esri.com/news/arcuser/0400/wdside.html

[15] "A network of longitude and latitude lines on a map or chart that relates points on a map to their true locations on the earth." ESRI 2015 http://support.esri.com/en/knowledgebase/GISDictionary/term/graticule

30 Arc Second Graticule with Regions of Interest



Regions of Interest over 2004 Imagery of Banda Aceh



Of the four ROIs that were created, the southern-most and northern-most areas were chosen based on their geography and composition of land uses. In 2004, the southern ROI (or "ROI South") had development along the coastline, and mixed sections of structures and *tambaks* across the rest of the region. Meanwhile, the northern ROI ("ROI North") had tambaks only along the coastal segment, with increasing structure density moving inland. ROI North also contained a dense urban area, while ROI South was predominantly housing and productive land (both agriculture and aquaculture). The two middle ROIs were excluded due to their similarity to the chosen regions and time limitations.

Once the two regions of interest were chosen, shapefiles were created for each ROI using the 2004 imagery as a pre-disaster baseline, limited to those features or portions of features that fell inside of the ROI boundaries. These shapefiles included: roads (line), built structures (polygon), and *tambaks* (polygon). The inclusion criteria for the various features differed between the shapefile types based on the nature of their topology. As a collection of lines, the road features were created for the study areas, and where they exceeded the ROI borders, they could simply be cut (i.e. "clipped") using the ROI North and ROI South boundary shapefiles. However, polygons (structures and *tambaks*) were only included if their "centroids"[16] fell within their respective ROI, and those that met this criterion were then clipped by the ROI boundaries.

2. DIGITIZING

The process of digitizing the structures, *tambaks*, and roads was performed for 2004, 2005, 2007, and 2008 using their respective imagery. During the process of manually digitizing features from an image or other source material into shapefiles, there is a degree of subjectivity exercised by the user. For instance, when digitizing the roads, the decision was made to follow the centerline (or the middle of the road if not visible or demarcated) as closely as possible. An alternative would have been to create polygons for the roads instead

[16] The centroid of a polygon can be understood as the center of mass, or the balancing point of that polygon if it was placed on the tip of a pencil.

of using lines; however, this would have been extremely time-intensive and would not greatly benefit the project. Road width was taken into account during the analyses via buffering, which will be discussed below. In addition to such decisions, user skill is also a factor in how well the features are recreated in digital format. While great care was taken to faithfully represent all features, if one were working at a much smaller scale, and thus zoomed in much closer to the ground, features could be digitized more accurately (or as accurate as the source material allows).

a. Structures, *Tambaks*, and Roads

Digitizing structures required additional user input. When structures are sufficiently spaced apart, they are easily distinguishable in the satellite imagery. However, in areas of high density, structures' roofs appear to meet, overlap, or are actually connected, and greater discretion and interpretation was involved in digitizing each individual structure. Several considerations were involved in trying to distinguish between structures. The first was to look for "obvious" rooftops, such as those that met local, conventional building styles, such as having flat or pointed square/rectangular roofs. A second factor used to differentiate between structures was a change in roof colors or materials. Adjacent structures with different colored roof (e.g., red versus blue) were treated as separate polygons. However, the utility of this method varied from case to case due to multiple materials being used on the same structure, multiple roof heights for one structure, and the lack of clarity in the imagery.[17] In some instances, visible shadows also helped distinguish between structures.

Digitizing *tambaks*, however, was less complicated. This was due in part to their large size, making them much more visible, as well as deliberate inclusion criterion – to include only those bodies of water that had identifiable, man-made walls/barriers. In the 2004 image, the delineation between *tambaks* is quite obvious. However, this is much less clear in the 2005 and subsequent imagery due to the tsunami flooding the coastal region of Banda Aceh, resulting in standing pools of water that are visible in the images but are not *tambaks*.

As lines, digitizing roads was also rather straight-forward. As stated above, the middle of each road was used as the reference for the digitizing process, a task made easier when a center line was painted on the road service. Several types of roads are evident in the satellite imagery: paved roads; non-paved, dirt roads with clear structure; non-paved, informal dirt roads. However, no distinction is being made in this project, although it is my hope to incorporate this into future work.

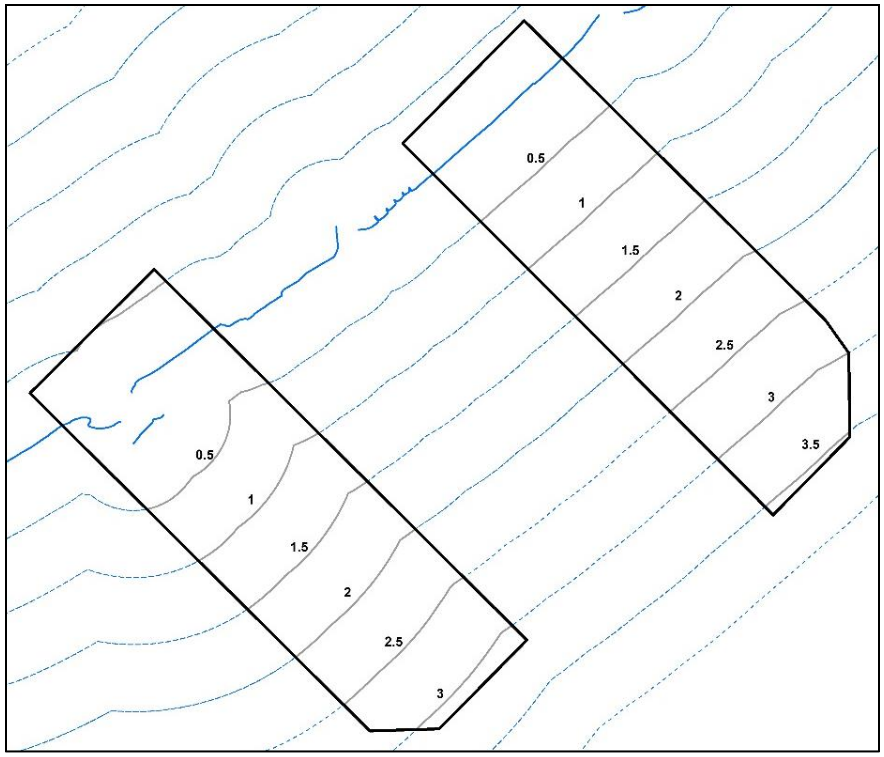
[17] There is a degree of uncertainty when dealing strictly with birds-eye imagery, particularly if the resolution of the image is not high enough. Roofs or roof sections of different colors may simply be additions to an existing building, areas of repair, or they may be structures that are not connected at all. In such cases, "ground-truthing" (i.e. verification at ground level) would be required if exact counts were needed.

b. Coastline and Coastal Buffers:

The 2004 coastline was digitized via visible shoreline and/or breaking waves to indicate a baseline border for the city. In addition, a multiple ring buffer[18] with half-kilometer intervals around the coastline was created, extending up to 4km from the coast. Each individual ring was then exported into its own shapefile in order to isolate half-kilometer bands (that were not inclusive of the previous rings). This allowed for an analysis of the role of distance from the coast for the various features examined. While the buffers created around the coastline extend up to 4km from the shore, the two ROI rectangles do not extend that far inland due to the extent of the imagery used. Therefore, this analysis uses terms such as "beyond 3.0km" or "beyond 3.5km" to describe the zones that are truncated by the ROI boundaries and do not reach the end of the entire buffer.

[18] A buffer is the area around a feature up to a specific distance (using straight line distance). For a five meter buffer around a given point/line/polygon, this includes the area immediately touching the feature and continues up to five meters in every direction.

Banda Aceh ROIs, Coastline, and Half-Kilometer Buffer Zones



The following table includes descriptive statistics for each feature type. All shapefiles in this study use the Universal Transverse Mercator (UTM), Zone 36 North projection due to the its native unit of meters, the ease of use of the UTM system, and Banda Aceh's geographic location. The satellite imagery used in this project was innately set to the World Geographic System 1984 (WGS 1984) for its coordinate system, which is compatible with the UTM system (as it is based on WGS 1984). The table below details the shapefiles used in the analyses, their feature type, and how they were created.

Shapefiles Created by the Researcher for Each Region of Interest: ROI North and ROI South		
Name	**Type**	**File Origination**
ROI Boundaries	Polygon	Created manually based on a 30 arc-second graticule in ArcGIS
Structures	Polygon	Created via manually digitizing structure shapes from imagery
Structure Centroids	Point	Created via Polygon to Point function
Tambaks	Polygon	Created via manually digitizing *tambak* shapes from imagery
Roads	Line	Created via manually digitizing road lines from imagery
Road buffers (10, 15, 20m)	Polygon	Created via Buffer tool
2004 Coastline	Line	Created via manually digitizing the coastline from imagery
Coastline Buffers (.5, 1, 1.5, 2, 2.5, 3, 3.5, 4km)	Polygon	Created via Multiple Ring Buffer tool in based on the 2004 coastline shapefile
ROI Buffer Zones	Polygon	The coastal buffers were clipped to each ROI; individual zones were selected zone and exported it to its own file
Structure Centroids w/in each Buffer Zone	Point	Created via Select by Location tool for centroids intersecting a single buffer zone
Roads w/in each Buffer Zone	Line	Created via Select by Location tool for roads intersecting a single buffer zone; these lines were then clipped to the ROI and their lengths recalculated
Fishnet	Polygon	Created via the Create Fishnet tool, set to 100m per side, clipped per ROI
Fishnet-Structures Join	Polygon	Created via the Join function to obtain aggregated structure data
Fishnet-Roads Join	Polygon	Created via the Join function to obtain aggregated road data
Getis-Ord Hotspots: Structures	Polygon	Created via the Hot Spot Analysis tool (Gi*)
Getis-Ord Hotspots: All/New Roads	Polygon	Created via the Hot Spot Analysis tool (Gi*)

3. Shapefile Modification

After their creation via digitizing or other processes, many shapefiles required further modification. First and foremost, the ROI polygons were originally created as rectangles, as described above. However, the 2004 and 2007 imagery terminates along the southern edge of ROI South, and the eastern edge of ROI North, so the polygon for each region was altered to match the available imagery. Next, the ROI North and ROI South polygons were divided into smaller "buffer zones" in order to examine the data in smaller areal units. This was performed by "clipping" each ROI into half kilometer-wide polygons using the individual coastal buffer polygons (0km – 0.5km, 0.5km – 1.0km, 1.0km – 1.5km, 1.5km – 2.0km, 2.0km – 2.5km, 2.5km – 3.0km, 3.0km – 3.5km, 3.5km – 4.0km).

Certain data were also "joined" together in order to obtain counts of features that fell within other features (e.g., the count of structure polygons/centroids within a buffer zone). Clipping was another common procedure to ensure that only the relevant portions of features were used in the analysis. For example, sections of roads and *tambaks* that extended beyond ROI boundaries were clipped to exclude any portion that fell outside of their ROI boundaries. This process was also repeated for each of the half-kilometer coastal buffer zones to obtain only the features (e.g., structures, roads, *tambaks*) that fell within a specific zone.

Last, some spatial readjustment was necessary for several of the years' shapefiles due to slight alignment issues between different years' imagery. For example, the 2007 roads and structures were realigned with their 2008 counterparts based on 34 "displacement links" (common points between the shapefiles) and use of the Spatial Adjustment tools. After completing this process, the files from 2007 and 2008 were then properly aligned so that one could be correctly placed over the other.

B. Remote Sensing Data

Remotely-sensed data such as aerial (e.g., taken by plane, balloon, or drone) or satellite imagery can be of tremendous utility to those who are not able to directly observe a place or phenomena firsthand. Such data allows the user to study snapshots of a specific geographic location at a specific moment in time. Over the past several decades, both publicly- and privately-owned/operated satellites have been placed in earth's orbit, each satellite carrying its own sensor(s) with varying capabilities. Similar to a standard camera, some satellites use passive data collection, whereby the electromagnetic radiation that is emitted by or reflected off of the earth reach the sensor and are then recorded. A "*panchromatic*" scanner collects multiple wavelengths in only a single band, which can produce a single grayscale image; a "*multispectral*" scanner, however, is able to record multiple wavelengths at once and store each one individually (e.g., band 1 contains data in the blue wavelengths, band 2 the green wavelengths, etc.) and can produce multiple images, each of a single band. Although panchromatic imagery cannot be separated into individual bands, it is often at a higher spatial resolution than multispectral data, and therefore can appear more detailed and clear.

Among a sensor's traits, three are of particular importance. First, t*emporal resolution* indicates the time it takes for the sensor to complete one orbit to pass over, or "revisit," the same location on the earth, such as once every 14 days. Second, *spatial resolution* is the amount of land area on the ground that each pixel in the output image represents, such as 30m x 30m for older *Landsat* imagery, or a much more precise 2m x 2m for *Quickbird*-based images.[19] Last, *spectral resolution* specifies the wavelength intervals (also called "bands") a sensor can detect. For example, the visible spectrum of wavelengths (i.e., visible to the human eye) is comprised of the red, green, and blue (RGB) bands, ranging from 450nm to 690nm, while the near-infrared band ranges from 750nm to 900nm (Jensen 2007). Each of these types of resolution ultimately contributes to the content and quality of the output a sensor can produce.

Remote sensing imagery (specifically satellite imagery) was used in this study to assess the extent and rates of reconstruction in Aceh, Indonesia. Data from the *Quickbird* satellite[20] was acquired for approximately 90km of the city of Banda Aceh for the following dates: 1/23/2004; 08/06/2005; 07/30/2007; and 08/14/2008.[21] Image processing and analyses were

[19] In simple terms, the smaller the amount of area each pixel covers, the more detail of the earth an image may have. With larger areas, such as 10m or 30m, each pixel represents larger swaths of land, and results in images that appear more "blocky" or pixelated.

[20] The *Quickbird* sensing system allows for multispectral (the visible and near infrared bands, at 2.16m spatial resolution) and panchromatic imagery (55cm spatial resolution), with a revisit time of 2 to 12 days depending on the location (Digital Globe 2014).

[21] Partial funding was generously provided by the UCLA California Center for Population Research through a small projects seed grant.

carried out using ENVI (Version 4.5; ITTVIS 2008), as well as ArcGIS (Version 10.2.0.3348; ESRI 2013)

Examining the imagery across time will illustrate changes to land cover, e.g., the destruction and reconstruction of physical structures.[22] The data from 2004 captures the conditions in Banda Aceh before the tsunami occurred. The succeeding time periods were chosen to show annual change in land cover following the event through which to gauge the reconstruction efforts. Data in the visual spectrum will be used to manually classify changes to the built environment by identifying structures present in each time period.

1. Image Pre-processing

Remotely-sensed imagery of Banda Aceh plays a critical foundation in this study, yet, like the GIS data described above, it was not immediately ready for use upon acquisition. In order to provide additional clarity to some of the images, initial modifications were made using a technique called "pan-sharpening," which uses panchromatic data to enhance a multispectral image (Jensen 2005). Although they are limited to gray-scale, panchromatic images have finer spatial resolution (e.g., 60cm) than their color multispectral counterparts (e.g., 240cm). Through the transformation process, pan-sharpening adds increased intelligibility and precision to the multispectral image, while keeping the benefits of having a color image and separate wavelength bands (Jensen 2005).

[22] Imagery for 2006 was unavailable based on cloud cover and poor image quality.

Similarly, adjustments were necessary to ensure that images obtained at different times would align properly. In this study, the data from 2007 was georeferenced[23] to match the 2008 data in ITVIS ENVI. First, recognizable and distinct landmarks from the 2008 image (such as the center of a mosque's dome) were used to create "ground control points." These locations function as anchor points to realign the 2007 image with the one from 2008 since, in reality, they exist at the same geographic coordinates. Once the control points are chosen, the software transforms the input data (2007) so that it (more closely) matches or aligns with the source data (2008). Following such modifications and corrections, the satellite imagery can be used in ArcGIS as templates to create new shapefiles or ITVIS ENVI for remote sensing analyses.

II. Spatial Analysis

A. Measuring Change

1. Quantifying Features by Count, Area, and Length

Once the requisite shapefiles were created, the process of quantitatively measuring reconstruction began. To complement the geographic aspects of the shapefiles (i.e. the features' shapes and locations), attribute data (i.e. data about those features) was then calculated. Using the Calculate Geometry tool within each shapefile's attribute table, land

[23] Georeferencing is a process in which individual pixels in an image are assigned latitude and longitude coordinates for locations on the earth

area (in square meters) was computed for the structures and *tambaks*, as was length (in meters) for roads. The use of both counts and area for structures was intended to help counteract any inaccuracies introduced in the digitizing process. Counts provided an estimate for how many structures there were, while area represented the amount of space was covered by built structures for a given period. If two structures were accidentally digitized as a single polygon, the count would underestimate the actual number; however, the total area would capture the amount of space within the structures' footprints, regardless if it was a single structure or multiple structures. Yet, structure area might still over- or under-estimate the true total land area if the digitized polygons do not accurately reflect the actual structures, so the total count for that period may help balance out any errors. To manage and calculate additional data, such as numeric or percent change from baseline, spreadsheets were created using Microsoft Office 2010.

2. Proximity to Baseline Structure Locations

A proximity analysis was performed to test whether or not structures in 2005, 2007, and 2008 were built or rebuilt in/near the same locations as those in 2004. First, the "intersect" tool was used to establish if structures from the post-tsunami years partially or fully overlapped with structures from pre-tsunami 2004. Although this method does not distinguish between cases where structures were perfectly coterminous or merely overlapped to a small extent, it does indicate if there was a structure in a pre-tsunami location in the second time period. Next, to examine the structures that did not overlap, the "select by location" function was used to determine the number of structures within 5m and 10m distances of 2004 structures. These steps were also repeated with the structures' centroids as well.

3. Proximity of Structures to Roads

Similar steps were used with respect to structures' distances from the road network. First, buffers were created for each year's roads using distances of 5m, 10m, 15m, and 20m. Next, for each year, a spatial join was performed using the centroids for the structures to obtain the number and percent of structures within a given distance of the roads for each time period.

4. Road Network Expansion – "New Roads"

Although the total road lengths were calculated for each ROI and buffer zone for each year, it was important to assess the locations of where roads were being built in locations that did not contain roads in the 2004 baseline. The road shapefiles for 2005 through 2008 were first made comparable to the 2004 roads through two steps. First, the 2004 roads were given a 5m buffer to allow for minor variations or inaccuracies introduced in the digitizing process. Second, the 2005, 2007, and 2008 roads were clipped using that 2004 5m buffer. This step yielded the portions of the roads in the post-tsunami years that coincided with roads that existed before the disaster (these sections were either those that were not destroyed by the tsunami or were rebuilt in the same location). Once completed, the roads that matched those from 2004 were subtracted from the full roads shapefiles, which was done via the "symmetrical difference" tool. The end products of these processes were the "new roads" in 2005, 2007, and 2008, i.e. the sections of road that *did not* exist before the tsunami.

B. Statistical Measures

In addition to the aforementioned measures to quantify land cover change, methods were also used to test for statistically significant patterns in the locations of Banda Aceh's structures and roads. The added value of these methods was the identification of phenomena that were not the result of mere chance.

1. Density

In order to gauge changes in density, nearest neighbor (NN) analysis was performed for the structures in each study year for both ROIs. The average distance of features to their surrounding features was used in this study as an indicator of density. The NN analysis first measured the distance of each feature to its closest neighbor for every feature in the data set; then the process was repeated for a hypothetical dataset with the same number of features that is normally distributed. The outputs of the process included the observed mean distance for the provided dataset, the expected mean distance, as well as a z-score and p-value to indicate the likelihood that the observed distribution could be a result of random chance (Allen 2010; Berry and Marble 1968; Cover and Hart 1967; Fotheringham and Rogerson 2013). Since the Nearest Neighbor tool is based on point pattern analysis, structures' centroids were used to achieve optimal results and to minimize problems. As a result, the nearest neighbor distances will overestimate how far apart structures are on average because they are based on a structure's "center point" and not its edges. This was computed for the structures of each ROI as a whole, and then for the structures within the individual buffer zones.

2. Spatial Distribution

Different measures were also used in this study to examine the presence of any patterns in how features are distributed in space. For a given year, are structures evenly arranged throughout the study area? Are there areas that are more/less dense than others? Are structures grouped together based on an attribute or variable? Is there a pattern or relationship between the clustering of one feature type and another feature type? The methods described below were used to address these types of questions.

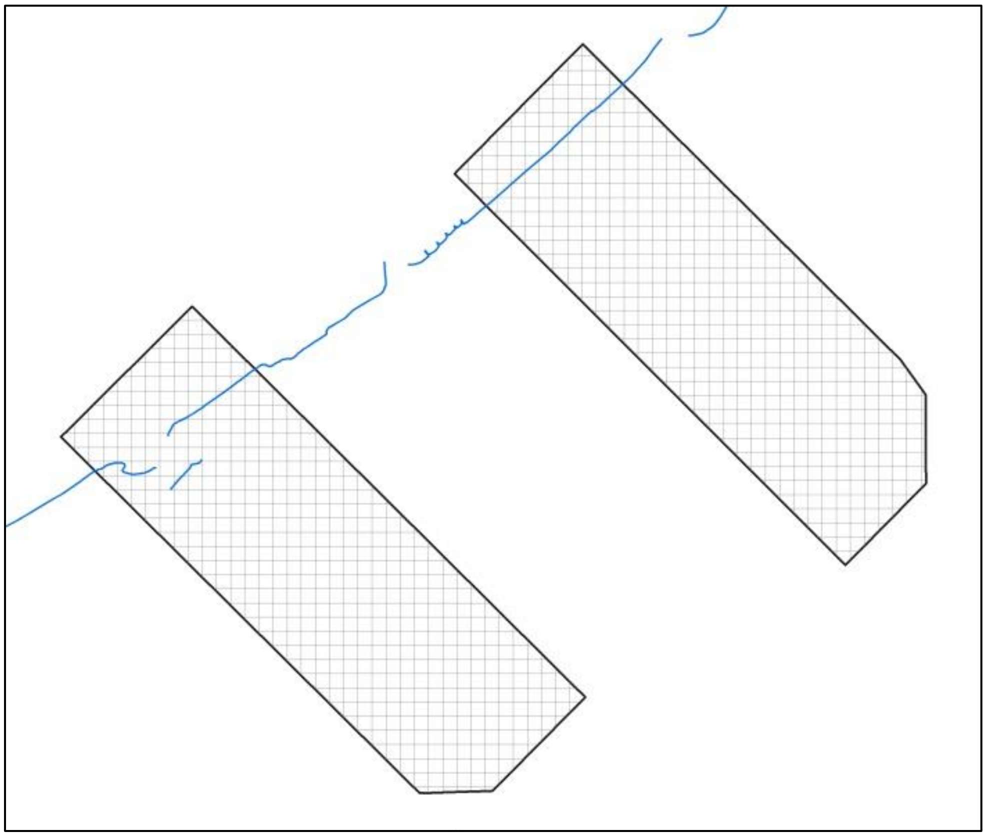
The spatial distribution of features can be categorized into three major, overarching types: uniform, random, or clustered. As their names imply, a random distribution has no clear pattern in the locations of features, a uniform distribution has features located in regular intervals, and clustering refers to groups of features located in close proximity while other events are more dispersed (Berry and Marble 1968; Kalkhan 2011; Lloyd 2011). Nearest neighbor analysis, mentioned above, provides one simple method of assessing the extent of clustering by geographic location and the likelihood of its occurrence compared to a normal distribution. Additional methods that incorporate not just location, but also feature's attributes, are described below.

a. Clustering by Value

In addition to examining clustering based on location through a nearest neighbor analysis, this study also examined "clustering by value," i.e. the value of an attribute for those features. For example, cluster analysis was performed for the *size* variable using the structure polygons. However, to test for statistically significant clustering of structures for the count variable, some abstractions and decisions were made. Analyses for clustering based on a value, such as count, required that individual structure features be aggregated to larger polygons. As individual structure polygons or points, there was no way to test for clustering *by count* since each unit stands on its own (i.e. count = 1). By aggregating the structure data to a larger unit of analysis, such as a cell in a grid, it became possible to test for clustering of these larger polygons based on variables of interest, such as the count of structures within each cell.

To move the count and area data to a larger unit of analysis, a "fishnet" (i.e. a grid of equal sized squares) of 100 meter by 100 meter cells was overlaid on top of each ROI and then clipped so that it would be coterminous with the ROI's edges. Next, a spatial join was performed to provide the fishnet with the count of structures and the total structure land area that fell within a given cell. The centroids of the structures were used instead of their polygons themselves so that each structure would fall within only a single fishnet cell since structure polygon might cross into multiple cells. Although imperfect and perhaps an oversimplification, this step was chosen to prevent double-counting and err on the side of caution. Through this spatial join, the unit of analysis becomes each cell within the fishnet grid, instead of the individual structures. The following sub-sections will outline the processes used to test for clustering by value.

ROIs in Banda Aceh with Fishnet Grid



b. Spatial Dependency and Spatial Autocorrelation

Two terms are inherent in a discussion of clustering: spatial dependency and spatial autocorrelation. Spatial dependency simply refers to the value (i.e. attribute) of a feature at one location being dependent on the value of another feature at another location (Lloyd 2011). This concept runs contrary to the tenet in statistics of the independence of events and the null hypothesis that results are a product of random chance. Spatial dependency is related to Tobler's "First Law of Geography," which states that objects closer together are more likely to affect the objects closest to them (Miller 2004).

The term "spatial autocorrelation" refers to a measure of similarity between neighboring features and their attributes (Kalkhan 2011; Lloyd 2011). There are both global measures for entire datasets as well as local measures that can indicate variation within a dataset. Positive spatial autocorrelation indicates similarity between neighboring features, i.e. similar values being clustered together. Negative spatial autocorrelation indicates the opposite case, where features with similar values are dispersed. Although there is a range of tools and statistics that may be employed to evaluate spatial clustering, this study will rely on the methods described below.

c. Moran's I

The global Moran's I coefficient is an indicator of spatial autocorrelation in a dataset, indicating the clustering of features by both location and a value of those features (Kalkhan 2011; Lloyd 2011). The output, the *I* coefficient, denotes the observed clustering pattern. Negative coefficient values indicate "negative spatial autocorrelation," meaning that observations that are close together are unlike in value; a positive value indicates the opposite, that observations with similar values are close in proximity. A value close to 0 indicates no structured clustering pattern (Lloyd 2011).

The local Moran's I is one of Anselin's local indicators of spatial autocorrelation ("LISA"), sometimes termed "cluster and outlier analysis," and is used to identify variation within a dataset and more precise clustering patterns. The local Moran's I tests for clustering by location, and the *magnitude* of the variable's value, such as high values clustering with other high values. The possible output categories are: high values surrounded by high values (HH); high values surrounded by low values (HL); low values surrounded by high values (LH); low values surrounded by low values (LL); and no significant clustering. (Anselin 1995; Lloyd 2011), Lloyd 2010) The local Moran's I test was first run on the structure polygons using their size variable, without needing to aggregate to the fishnet level in order to display the individual structure polygons by their Moran's I values (HH/HL/LH/LL). This process was then was repeated for the aggregated fishnet-level data, using the total structure count and total structure area per cell as the variables of interest.

d. Getis-Ord G/Gi*

Like Moran's I above, the Getis-Ord global G statistic is another indicator of clustering by value in a dataset. In particular, it provides the foundation for the Getis-Ord Gi* statistic, a more localized measure of clustering by value that identifies "hotspots" (areas with high values), and "cold spots" (areas of low values) (Lloyd 2011; Ord and Getis 1995). As with the Moran's I described above, an attribute of the features is used to test for the clustering by value.[24] For each unit of analysis, the output is an index via the Gi* statistic, which is used to visually display the hot and cold spots. Specifically, the output includes a z-score indicating if the values are high (hot) or low (cold) for that cell, and a p-value indicating its likelihood (90%, 95%, 99% Confidence). For this study, the fishnet for each ROI for each time period was selected as the process' input, using the total structure area (per cell) variable as the value of interest. The process was then repeated using the variable for the structure count per cell, and the total length of all roads per cell, and the total length of only the "new roads" per cell. Last, after creating the shapefiles for structure or road clustering, the data were overlaid in various combinations in a series of maps to evaluate any potential relationship between structure and road reconstruction. These comparisons included: structure count vs. structure area; structure count vs. all/new road length; structure clusters or road clusters and the *tambaks* shapefile.

[24] Additional settings chosen in this analysis include using inverse distance weighting and measuring via Euclidian distances.

e. Correlation (r)

In addition to visual analysis of the significant clusters of structures and roads, Person correlation coefficients were also calculated. Again, using the fishnet cells as the units of analysis, correlation was tested for: the count of structures per cell and total road length per cell; the area of structures per cell and total road length per cell; the count of structures per cell and new road length per cell; and the area of structures per cell and new road length per cell. Pearson coefficients were computed in both Microsoft Excel 2016 and R (Version 3.31; R Core Team 2016) to ensure consistent results.

CHAPTER 5: FINDINGS

This section details the results of the analyses detailed in the Methods chapter. First is a summary of the findings of the structures, then the roads, and last, the *tambaks*, or aquaculture ponds. As described previously, Banda Aceh was divided into distinct study areas in which to do the analyses, referred to here as Regions of Interest (ROIs). Each ROI was then divided into half-kilometer areas based on distance from the coast, described here as "buffer zones." Data from 2004, the period prior to the tsunami, are used as "baseline" data to which the later periods (2005, 2007, and 2008) are compared.

I. STRUCTURES

Temporal change for all built structures was evaluated separately for ROI South and ROI North and will be discussed individually below. This was due to differences in their geographic context and distinct composition and land uses. In addition, aggregating the data of the two ROIs is not intrinsically meaningful as the two regions are not adjacent and do not comprise the entirety of Banda Aceh, preventing city-level observations.

The structures in the ROIs of Banda Aceh were measured in several ways. First, the count and total land area covered by the structures provided indicators for changes in their quantity over time. Mean structure area then allowed for a simple measure of how large structures were. Density of the built environment was evaluated using two different methods: the distance between structures (nearest neighbor analysis), and point density across space (kernel density). Last, cluster analysis was performed to gauge whether or not structures were located in any meaningful patterns.

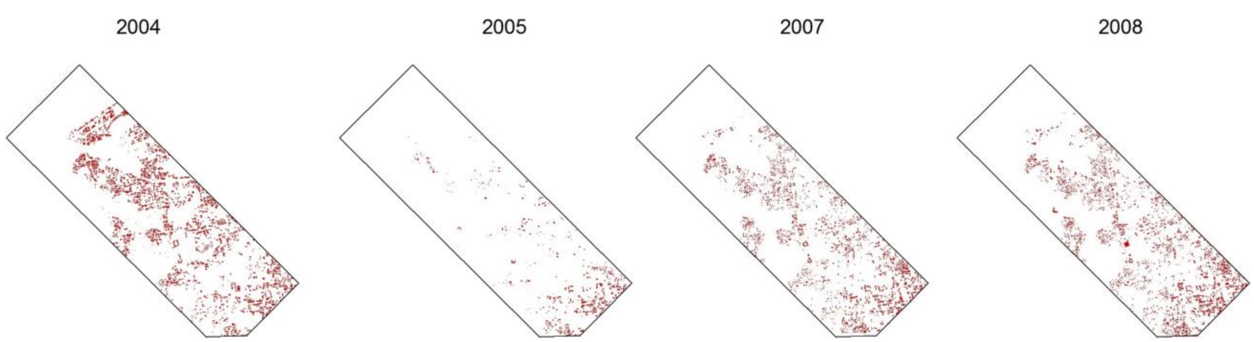
A. ROI SOUTH

1. COUNTS & AREA

a. ROI Totals

In 2004, there were 3,085 structures across the ROI, covering a total of 470,566 sq. m. However, following the tsunami, there was a drastic decline in the number of structures, decreasing 76% to 732 in 2005, along with a 79% loss of total structure area (to 99,885 sq. m). By 2007, there was a rebound in the number of structures, surpassing the 2004 baseline by 5% to total 3,242. However, built land area was still 36.4% below that of 2004, totaling 299,158 sq. m versus the original 470,566 sq. m. By 2008, the count increased further to 3,593, up 16.5% from 2004; structure area increased as well, to 366,522 sq. m, although still 22% below baseline.

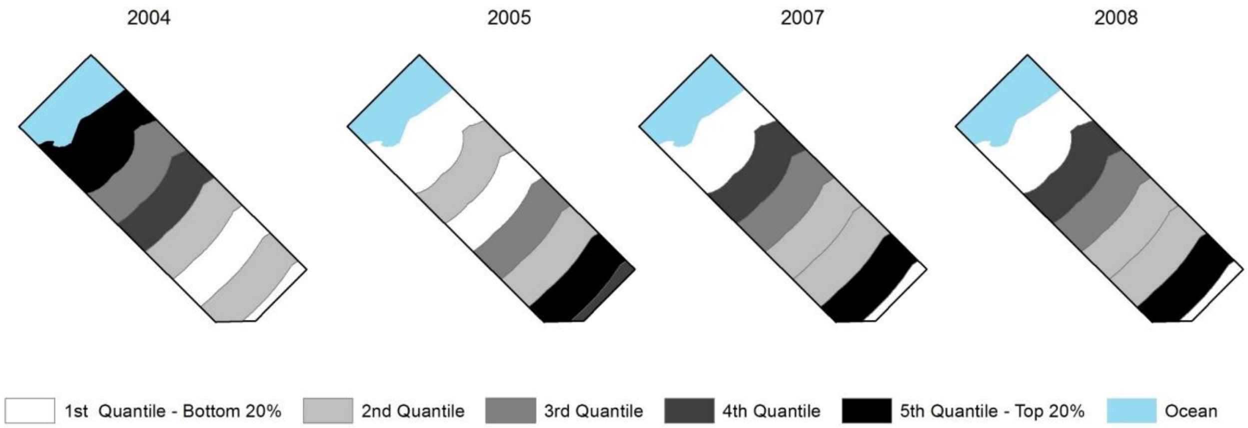
Structures in ROI South: 2004-2008



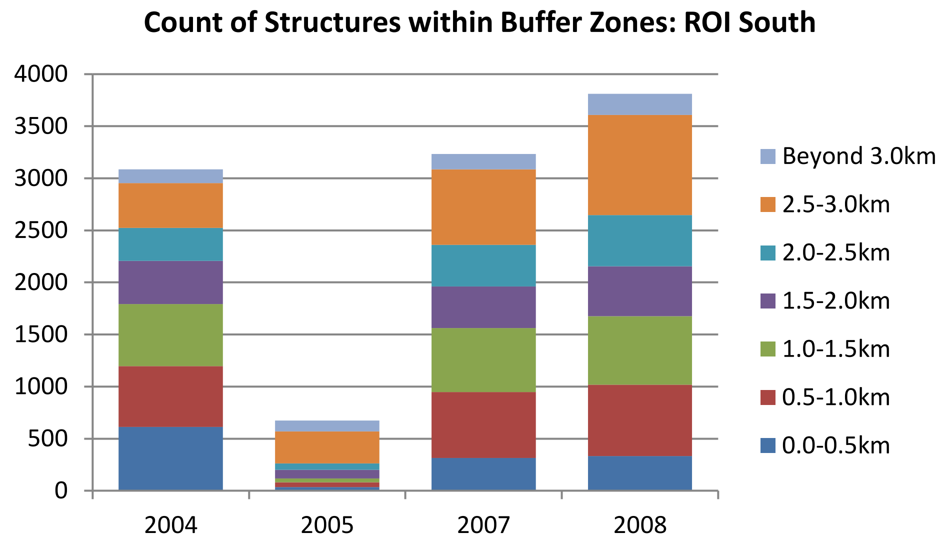
b. Buffer Zones

When the ROI was broken into half-kilometer coastal buffer zones, more specific patterns emerged for both structures' counts and total land areas. At baseline in 2004, the three zones closest to the coast (0 to 0.5km, 0.5 to 1.0km, and 1.0 to 1.5km) had the largest number of structures, particularly between 0 and 0.5km. However, in 2005, the number of structures in the same coastal areas fell more than 90% from baseline, while the two middles zones between 1.5 and 2.5km were down by roughly 80%. By 2007, there was substantial regrowth in the number of structures across the ROI, although the zone closest to the coastline (0 to 0.5km) was still below 50% of its baseline total. The counts for the zones between 0.5 to 1.0km and 1.0 to 1.5km were among the highest for that year (632 and 615, respectively), surpassed only by the inland area from 2.5 to 3.0km (726, up 69% from 2004). All zones continued to grow in number from 2007 to 2008, with total structure counts above their respective baselines, aside from the zone closest to the coastline (0 to 0.5km). This coastal zone consistently had the fewest structures (the lowest 20%, seen in white, below) in all post-tsunami years, while the zone farthest from the coast (2.5 to 3.0km) had the greatest number (the top 20%, seen in black) for all periods.

Structure Count by Quantile: 2004-2008



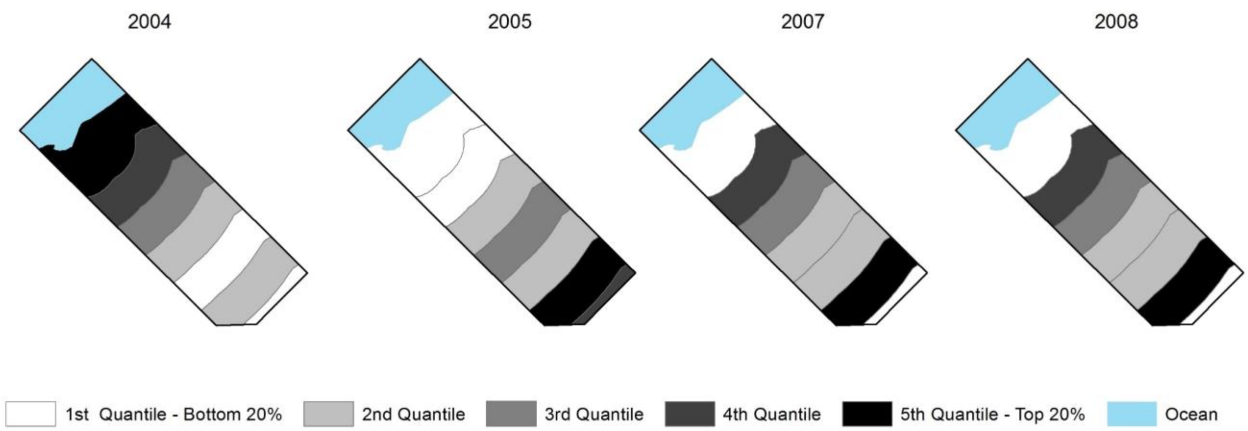
Count of Structures and Percent Change from 2004 Baseline within Individual Buffer Zones: ROI South							
Year	**ROI Total**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**
2004	3,085	611	584	596	416	317	429
2005	673 (-78.2%)	33 (-94.6%)	48 (-91.8%)	38 (-93.6%)	81 (-80.5%)	61 (-80.8%)	307 (-28.4%)
2007	3,242 (5.1%)	314 (-48.6%)	632 (8.2%)	615 (3.2%)	401 (-3.6%)	399 (25.9%)	726 (69.2%)
2008	3,812 (23.6%)	332 (-45.7%)	686 (17.5%)	657 (10.2%)	479 (15.1%)	494 (55.8%)	961 (124.0%)



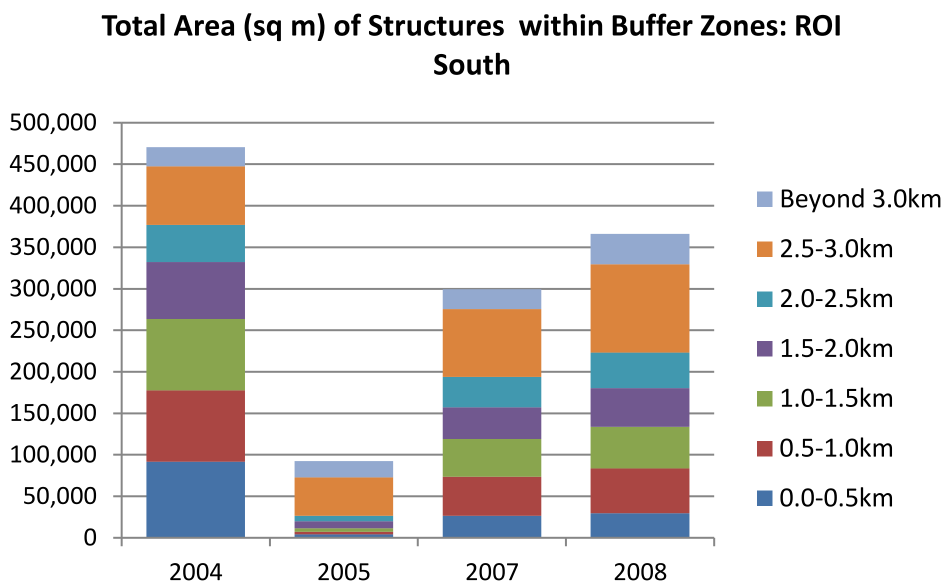
The land area covered by structures within each buffer zone also changed over time. At baseline, the greatest amount of structure area was located in the zone closest to the coast (over 90,000 sq. m), which fell in quantity per zone moving inland. In 2005, the three zones from 0 to 1.5km lost tremendous amounts of structure area, falling in excess of 95% from the year before; meanwhile, the zone farthest inland (2.5 to 3.0km) lost the least amount of structure area, far exceeding the other zones with a total over 46,000 sq. m. By 2007, structure areas per zone rose from post-disaster 2005, although the zone from 2.5 to 3.0km held more total area, and increased to nearly 16% above its baseline amount. By 2008, although all zones continued to increase in total structure area, the zone closest to the coast (0 to 0.5km) remained at one-third of its baseline total (from 91,631 sq. m to 29,563 sq. m). Similarly, the zones from 0.5 to 2.5km had losses ranging from 4% (2.0 to 2.5km) to 41.2% (1.0 to 1.5km). In contrast, the area farthest from the coastline (2.5 to 3.0km) increased by 51.1% above baseline, totaling over 106,000 sq. m.

As illustrated below, the shift in the distribution of the structure areas was substantial. While the top 20% of structure area was initially adjacent to the coast in 2004, the opposite was true after the tsunami. From 2005 onward, the coastal zone contained the lowest 20% of area, while the zone farthest inland held the top 20% of structure areas. Interestingly, in 2007 and 2008, the zone from 0.5 to 1.0km, which was in the second-highest quantile for total structure area in 2004, returned to falling in the top 60th to 80th percentile for area.

Structure Area by Quantile: 2004-2008



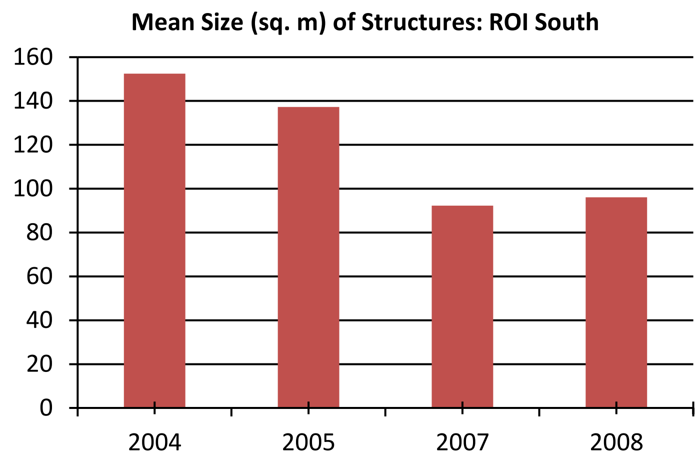
Total Area (sq. m) of Structures and Percent Change from 2004 Baseline within Individual Buffer Zones: ROI South							
Year	**ROI Total**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**
2004	470,566.1	91,631.5	86,060.5	85,798.6	68,585.1	44,827.1	70,412.6
2005	92,434.1 (-80.4%)	4,188.7 (-95.4%)	2,994.0 (-96.5%)	4,375.9 (-94.9%)	8,406.3 (-87.7%)	6,510.9 (-85.5%)	46,451.5 (-34.0%)
2007	299,157.9 (-36.4%)	26,529.8 (-71.0%)	46,881.5 (-45.5%)	45,433.9 (-47.0%)	38,166.3 (-44.4%)	36,870.6 (-17.7%)	81,601.4 (15.9%)
2008	366,521.6 (-22.1%)	29,563.2 (-67.7%)	53,859.1 (-37.4%)	50,420.6 (-41.2%)	46,353.2 (-32.4%)	43,024.9 (-4.0%)	106,414.7 (51.1%)



2. MEAN STRUCTURE SIZE

a. ROI Totals

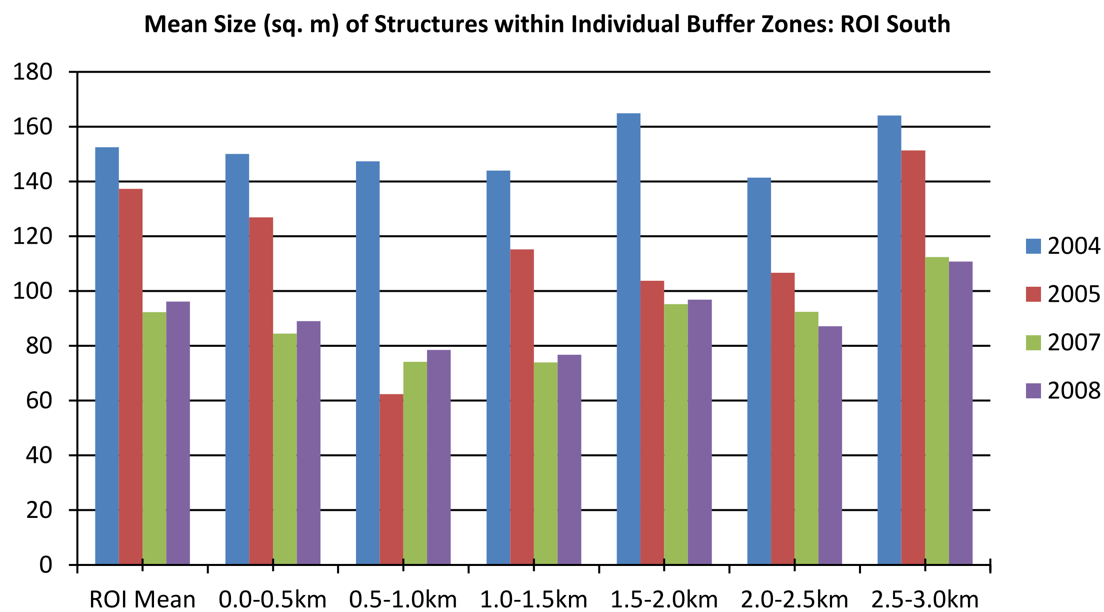
As the region's structure counts and areas changed over time, mean structure sizes varied accordingly. Prior to the tsunami, the average size of structures in ROI South was 153 sq. m. In 2005, although the number of structures dropped substantially, mean size only decreased by 10%, to 137 sq. m. Yet, as structures were rebuilt throughout the ROI, structure size fell to 92 sq. m by 2007, but rose slightly to 96 sq. m by 2008, or 63% of the baseline average.



b. Buffer Zones

Mean structure size also varied by zone within the ROI. At baseline in 2004, structures in the inland areas between 1.5 and 2.0km (165 sq. m), 2.5 and 3.0km (164 sq. m), had relatively large means, while the more coastal zones were all below 150 sq. m. In all three post-tsunami periods, the zone farthest from the coast (2.5 to 3.0kn) had the largest mean structure sizes, while the zones between 0.5 to 1.0km and 1.0 to 1.5km consistently had the smallest mean sizes. In terms of proportional change, while the mean size of structures for the ROI as a whole decreased 37% from 2004 to 2008, the five buffer zones between 0 and 2.5km decreased more than that, ranging from 38.4% to 46.7%. Only the most-inland zone (2.5 to 3.0km) was an exception, decreasing 32.5% below baseline.

Mean Size (sq. m) of Structures and Percent Change from 2004 Baseline within Individual Buffer Zones: ROI South							
Year	**ROI Total**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**
2004	152.5	150	147.4	144	164.9	141.4	164.1
2005	137.3 (-10.0%)	126.9 (-15.4%)	62.4 (-57.7%)	115.2 (-20.0%)	103.8 (-37.1%)	106.7 (-24.5%)	151.3 (-7.8%)
2007	92.3 (-39.5%)	84.5 (-43.7%)	74.2 (-49.7%)	73.9 (-48.7%)	95.2 (-42.3%)	92.4 (-34.7%)	112.4 (-31.5%)
2008	96.1 (-37.0%)	89 (-40.7%)	78.5 (-46.7%)	76.7 (-46.7%)	96.8 (-41.3%)	87.1 (-38.4%)	110.7 (-32.5%)



3. Density

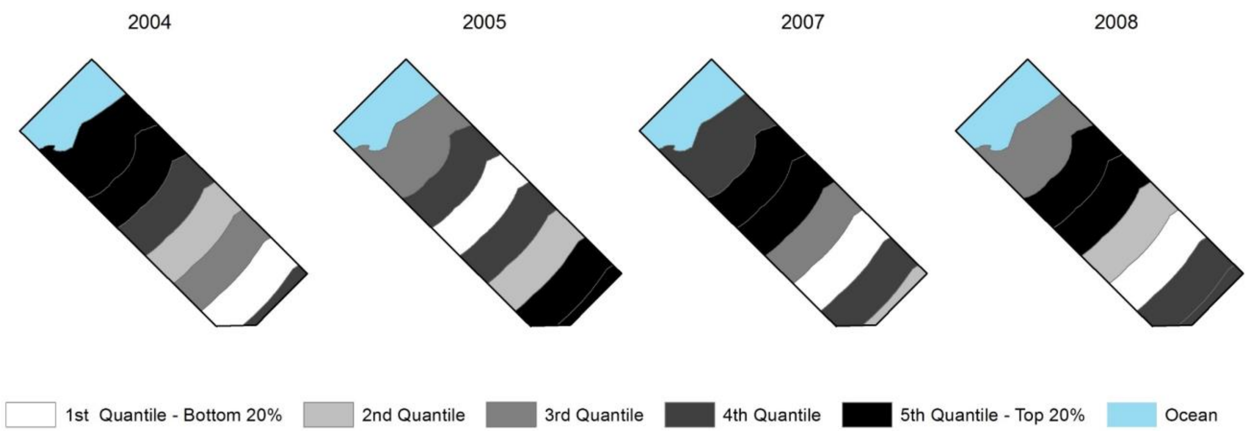
a. ROI Totals

The distance between the center points (i.e. centroids) of structures was used as a measure of density in the pre- and post-tsunami years. At the 2004 baseline, nearest neighbor (NN) analysis indicated that the structures' centroids were 15 meters apart on average for the ROI. However, with the large decrease in the number of structures in 2005, this distance increased to 21m. In the succeeding years, as structures were rebuilt, nearest neighbor distances fell, resulting in rising densities. By 2007, the average nearest neighbor distance shrunk to 13.7m, and then to 13.0m by 2008.

b. Buffer Zones

Nearest neighbor (NN) analyses for the individual buffer zones yielded similar, though not identical, results. At baseline, the zone closest to the coast had the highest density of structures (13.2m between centroids), while those farther inland had the lowest densities (16.9m to 17.7m). In 2005, all zones had greater distances between structures than in 2004. The zones from 0 to 0.5km, and 1.0 to 1.5km, had the largest increases in NN distance, while the zone farthest from the coast (2.5 to 3.0km) had a very small increase above baseline (3.8%). However, in 2007 and 2008, all areas had highest densities (lower NN distances) than in 2004, except for the coastal zone between 0 and 0.5km, where structure distances increased slightly (2.9% and 4.2%, respectively). The densest zones in ROI South in both 2007 and 2008 were those between 0.5 and 1.0km, 1.0 and 1.5km, and 2.5 and 3.0km, all of which had NN distances lower than any zone in 2004. Meanwhile, the least dense zones of were from 1.5 to 2.0km (15 sq. m), and 2.0 to 2.5km (15 sq. m), although their NN distances were still lower than the majority of the zones in 2004. Overall, the three zones closest to the coast remained among the densest in both 2004 and 2008, with NN distances in the top 20% for the ROI.

Structure Density by NN Distance (m) by Quantile: 2004-2008[25]



Nearest Neighbor Distances (m) and Percent Change for Individual Buffer Zones: ROI South							
Year	**ROI Mean**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**
2004	15.4	13.2	14.9	15.4	17.0	16.9	17.7
2005	21.6 (40.8%)	29.3 (122.8%)	25.5 (71.4%)	39.5 (156.2%)	24.1 (41.6%)	31.6 (86.5%)	18.4 (3.8%)
2007	13.7 (-11.0%)	13.5 (2.9%)	12.4 (-16.8%)	12.2 (-20.9%)	15.4 (-9.4%)	16.9 (-0.4%)	13.6 (-23.2%)
2008	13.0 (-15.6%)	13.7 (4.2%)	12.4 (-16.7%)	12.3 (-20.2%)	14.5 (-14.7%)	14.9 (-12.2%)	12.6 (-28.7%)

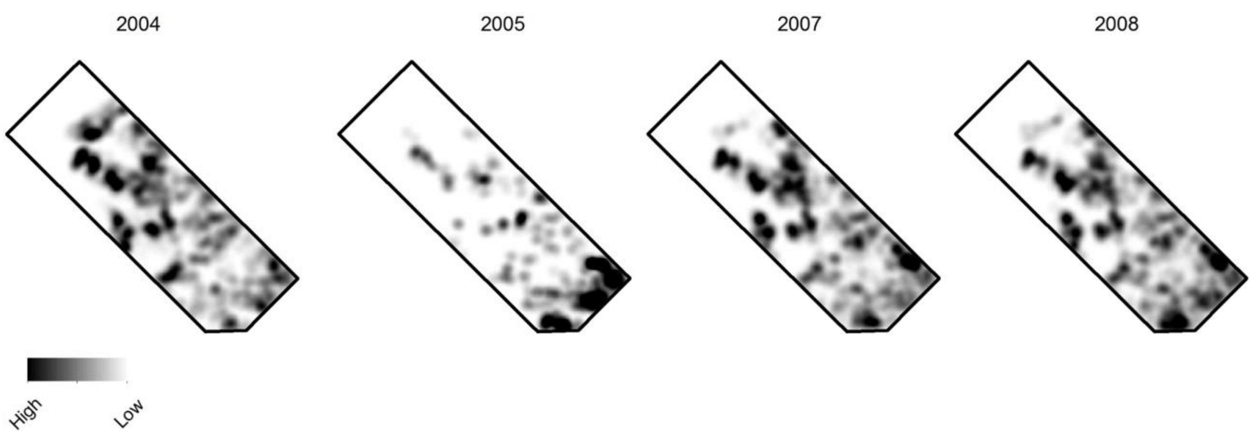
[25] Darker tones reflect lower NN values, and higher density; lighter tones reflect higher NN values, and lower density.

4. Kernel Density

a. Structure Count

Kernel density analysis provided an alternative in assessing change over time by creating a more precise surface for the entire region instead of yielding averages for the ROI or buffer zones[26]. In 2004, there was a high density of structures in the peninsulas and areas closest to the coast. By 2005, there was a dramatic decrease in the number of structures in all but the most inland areas, as seen by the very few dark areas on the map. Yet, by 2007 the coastal areas were again among the densest, and by 2008, the structure density closely resembled that of 2004, although with somewhat lower density along the coast but higher density in the areas farthest from the ocean.

Kernel Density by Structure Count: ROI South

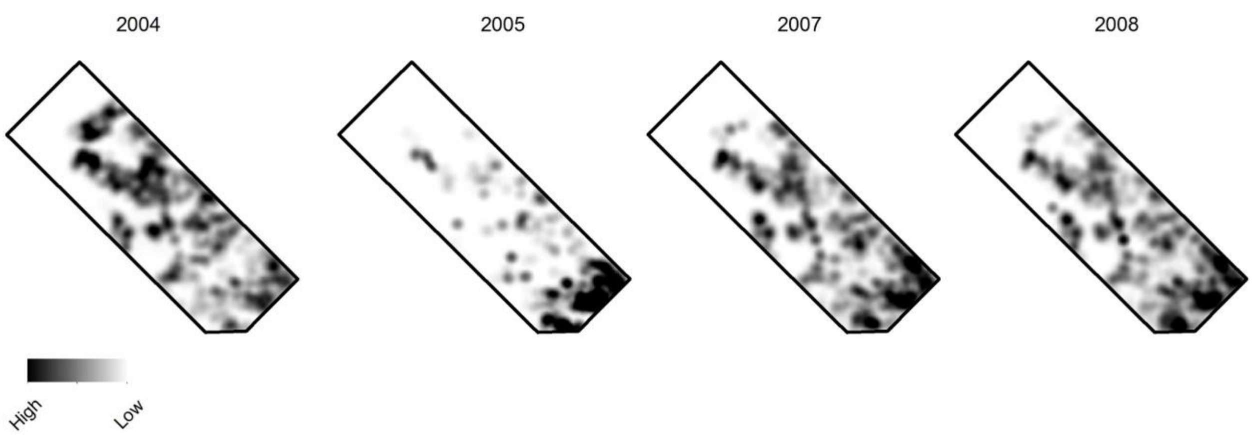


[26] This method combines discrete point data into a single surface showing a range of greater/lesser values, in this case the number of structures per unit area (square meters).

b. Structure Area

Using each structure's size to compute kernel density surfaces yielded very similar results as those for structure count. While the two sets of density distributions illustrated the same patterns on the whole, there were minor differences in the intensity of the kernel densities for structure area. Densities by area were higher between the coastline and 1.5km, as well as the southeastern portion of the ROI. These areas of increased kernel density indicated concentrations of structures that were larger in size, as opposed to being more numerous in quantity.

Kernel Density by Structure Area: ROI South



5. Clustering by Location

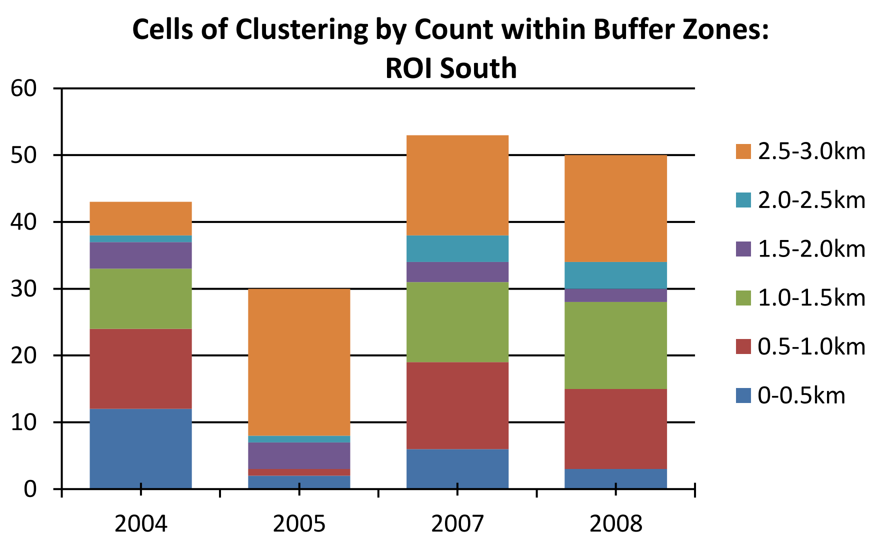
Clustering analysis was performed to detect statistically significant patterns in the locations of structures. Based on the global Moran's *I* statistic, there was less than a 1% probability (p-value = 0.000) that the clustered distribution of ROI South's structures was due to random chance. This held true for all time periods in the analysis. When the ROI was divided into the half-kilometer buffer zones, the structures remained significantly clustered for all years, with one exception. In 2005, there were only 33 structures between 0 and 0.5km of the coastline, with a dramatically different distribution from the year before, resulting in a "random" spatial distribution (i.e. neither clustered nor dispersed).

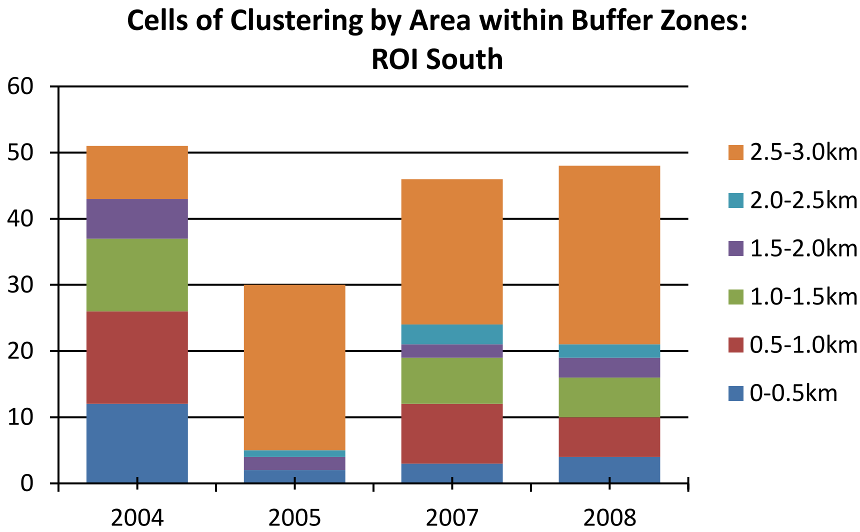
Spatial Distribution Types within Individual Buffer Zones: ROI South							
Year	**ROI**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**
2004	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2005	Clustered	*Random*	Clustered	Clustered	Clustered	Clustered	Clustered
2007	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2008	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered

6. CLUSTERING "HOT SPOTS" BY COUNT AND AREA

The Getis-Ord Gi* statistic was used to examine additional patterns in structures' locations, testing for hot spots, or "pockets of high spatial association" (Getis and Ord 1992). While the previous section evaluated each buffer zone as a whole, this hot spot analysis divided each zone into segments to test for clustering on a smaller scale through the use of a "fishnet" (a grid of uniform, square-shaped cells). Thus, the unit of analysis was an individual cell, each of which contained data for the count of structures *per cell* and the total land area of structures *per cell*. The Gi* statistic was used to test for *clusters of cells*, calculated individually for the two variables of interest (count and area). In other words, the value in each cell was compared with those of its neighboring cells, with the end result being a count of cells per buffer zone that were statistically significantly clustered by their values for structure count or structure area. In the table below, a value of "0" would indicate that there were no clustered cells in that buffer zone at a given time, while higher numerical values indicate greater numbers of clustered cells in a buffer zone at a given time. Simply put, this analysis allowed for an examination of whether or not certain buffer zones had more or less clustering than others.

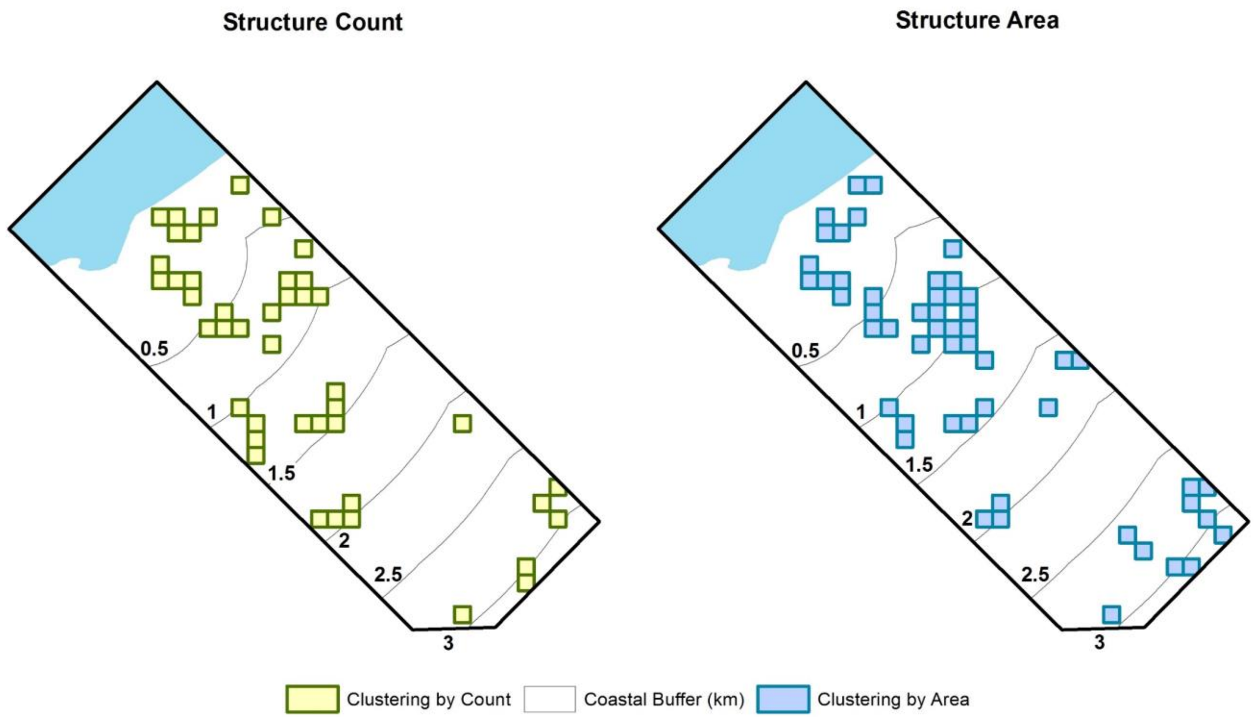
The Number of Cells per Buffer Zone with Clustering of Structures by Count and by Land Area: ROI South						
Clustering by Count						
Year	0-0.5km	0.5-1.0km	1.0-1.5km	1.5-2.0km	2.0-2.5km	2.5-3.0km
2004	12	12	9	4	1	5
2005	2	1	0	4	1	22
2007	6	13	12	3	4	15
2008	3	12	13	2	4	16
Clustering by Land Area						
Year	0-0.5km	0.5-1.0km	1.0-1.5km	1.5-2.0km	2.0-2.5km	2.5-3.0km
2004	12	14	11	6	0	8
2005	2	0	0	2	1	25
2007	3	9	7	2	3	22
2008	4	6	6	3	2	27





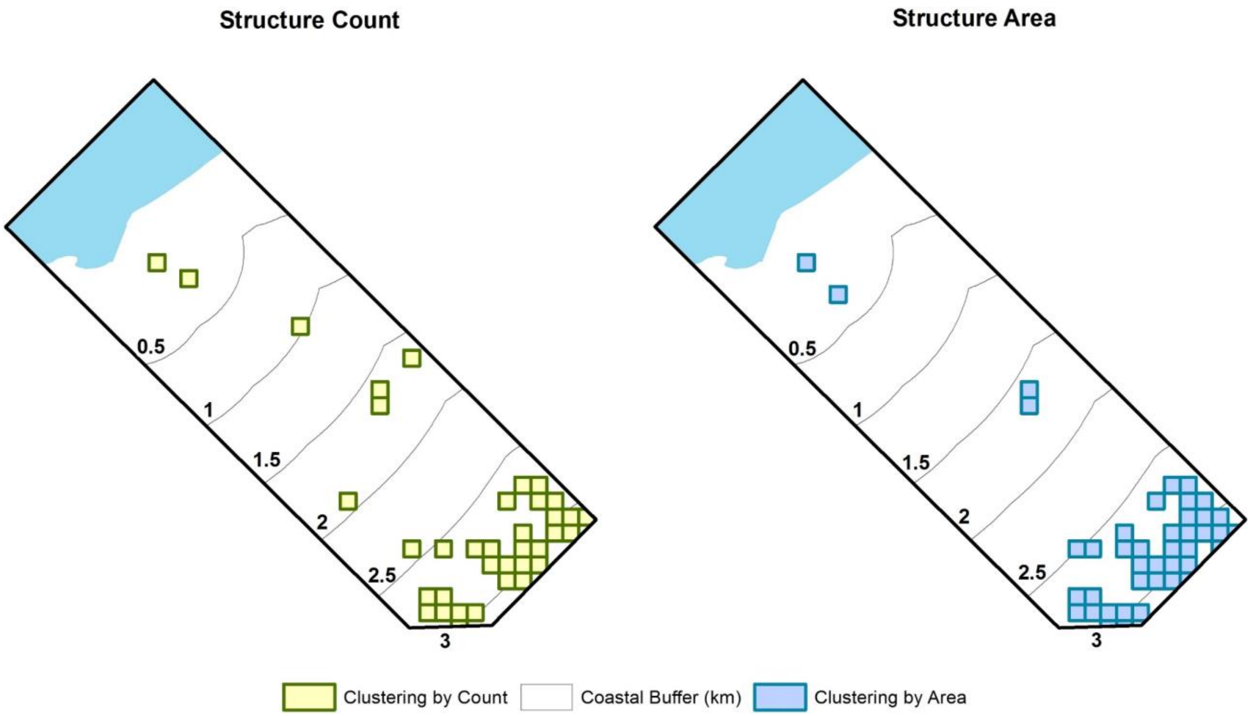
In 2004, ROI South exhibited more clustering by count in the buffer zones closest to the coastline relative to the rest of the ROI, specifically the zones between 0 and 0.5km (12 cells), 0.5 and 1.0km (12 cells), and 1.0 and 1.5km (9 cells). The inland zones had far less clustering, with only 1 cell between 2.0 and 2.5km, 4 cells between 1.5 and 2.0km, and 5 cells between 2.5 and 3.0km. Similar results can be seen for clustering by land area, with the three zones closest to the coast (ranging from 11 to 14 cells) having the far more than the four inland zones (ranging from 0 to 8 cells).

Structure Clustering by Count and Area: 2004



In 2005, following the tsunami, the locations of structures changed drastically, resulting in distinct clustering patterns. For the zones between the coastline and 2.5km, there was very little clustering by count (ranging from 0 to 4 cells), which was commensurate with the large losses of structures. Farther inland, however, there were 22 cells between 2.5 and 3.0km, which greatly exceeded the amount for that location in the previous year. A similar pattern was repeated for clustering by land area, with only 5 cells between 0 and 2.0km, but 25 cells between 2.5 and 3.0km. In comparison to baseline, there were relatively few cells of clustering in 2005 that coincided with those from 2004. There were only three zones where there was any overlap in clusters by structure count: 0 to 0.5km (2 cells), 1.5 to 2.0km (1 cell), and 2.5 to 3.0km (4 cells). For clustering by area, there was overlap in only two zones, the closest and farthest from the coast, but more cells in total (9 versus 7).

Structure Clustering by Count and Area: 2005



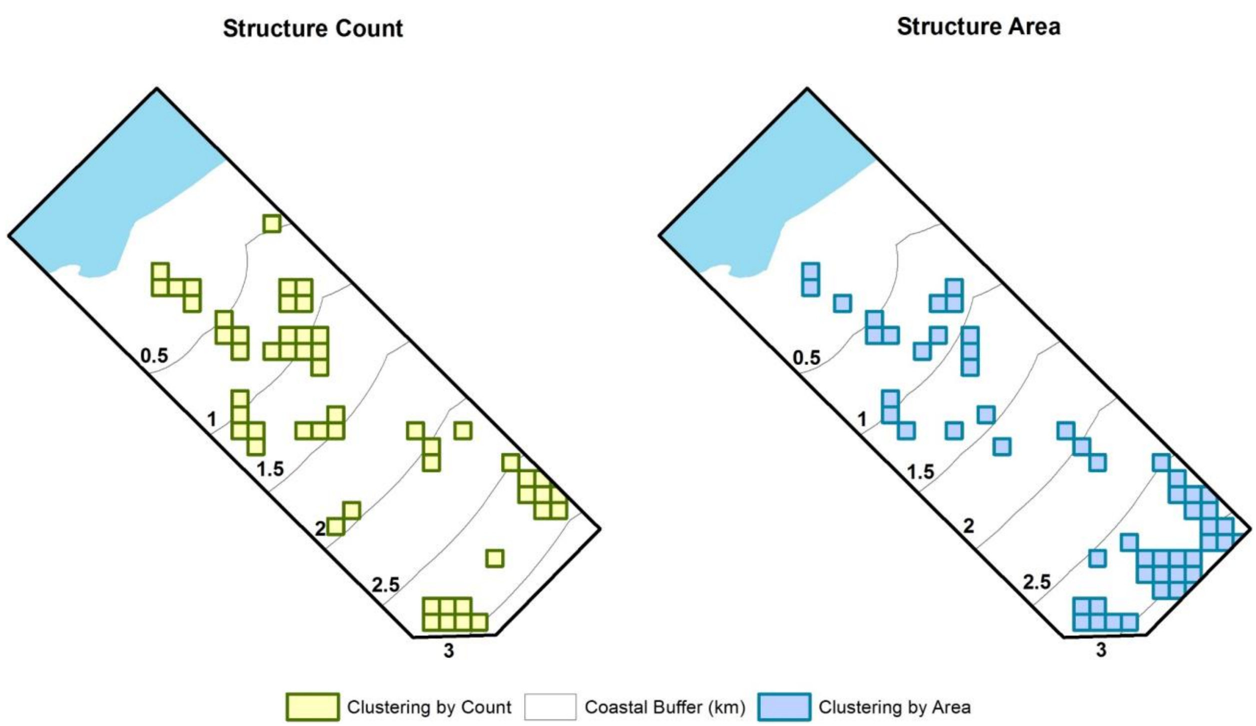
By 2007, the zonal clustering patterns began to resemble those from pre-tsunami 2004, running diagonally from the northwest to the southeast in the central portion of the ROI.[27] Two of the zones closest to the coast (between 0.5 and 1.0km, and 1.0 and 1.5km) and the inland zone between 2.0 and 2.5km exceeded the 2004 clustering values for the counts of structures, while the zone between 0 and 0.5km increased from its 2005 level (but not a full return to baseline). Between 2.5 and 3.0km, the amount of clustering by count decreased from 2005 (22 cells) to 2007 (15 cells), although it remained higher the 2004 total (5 cells).

[27] This spatial arrangement potentially indicates a return to pre-tsunami "normalcy," to be discussed later in the Discussion chapter.

Each of these patterns was mirrored in clustering by land area, particularly for the two coastal zones from 0.5km to 1.5km.

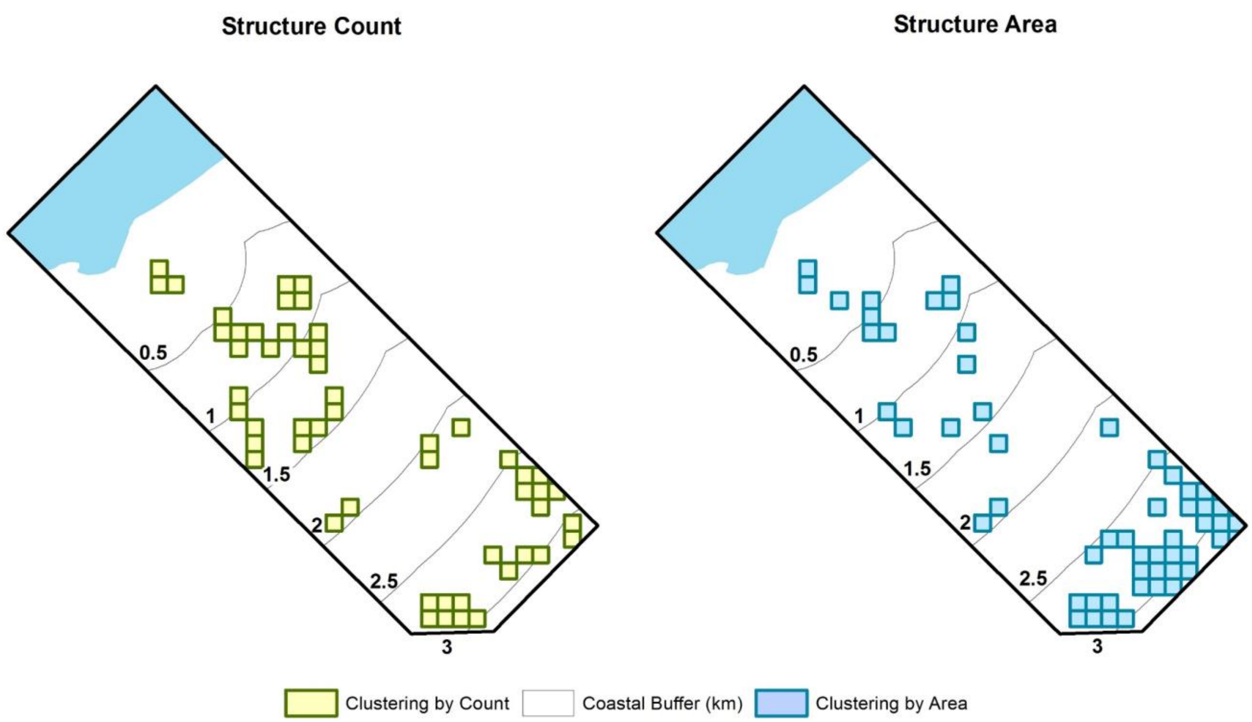
Unlike 2005, there were cells in common with baseline for clustering by count in all zones of the ROI. Notably, the largest number of common cells occurred in zones that had none in 2005 – there were 7 cells both zones from 0.5 to 1.0km and from 1.0 to 1.5km. There were also 5 common cells in the zone adjacent to the coast (0 to 0.5km), and up to 3 cells in each of the remaining zones. For clustering by area, there were no cells in common with baseline between 1.5 and 2.5km, but up to 8 cells in each of the remaining zones, including two zones that had no common cells in 2005.

Structure Clustering by Count and Area: 2007



Last, the clustering patterns in 2008 closely matched those of 2007 with only minor changes. Clustering by count changed by only one cell for all zones except for those nearest the coast (which decreased by 3), while the clustering between 2.0 and 2.5km was unchanged. Similarly, clustering by area increased or decreased by one cell for all zones, except for 0.5 to 1.0km (which decreased by 3) and 2.5 to 3.0km (which decreased by 5). As was the case in 2007, there were cells in common with 2004 of clustering by count in all zones, particularly the two between 0.5 and 1.5km (with 8 cells each). The largest number of shared cells for clustering by area, however, occurred in the most inland zone (also with 8 cells), followed by the zones from 0.5 to 1.5km (6 cells and 5 cells, respectively).

Structure Clustering by Count and Area: 2008

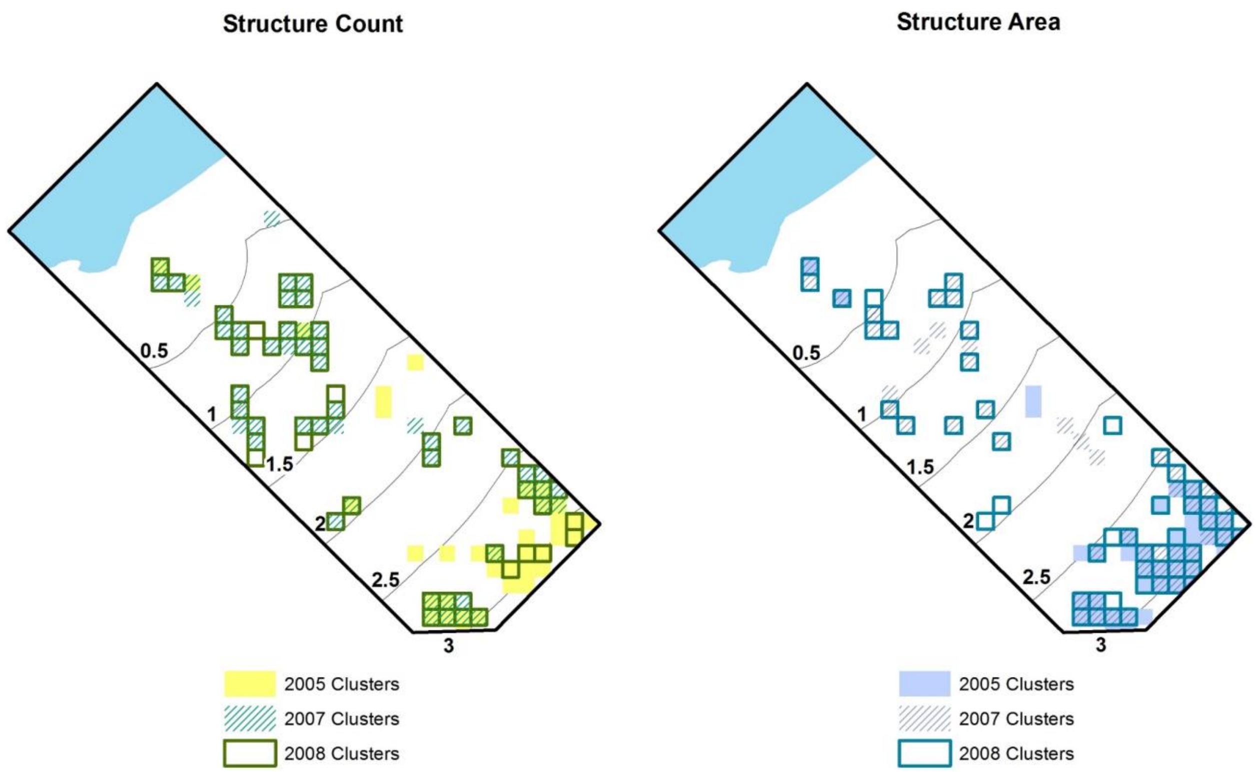


The Number of Cells per Buffer Zone with Clustering In Common with Cells from 2004: ROI South						
Clustering by Count						
Year	**0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**
2004	**	**	**	**	**	**
2005	2	0	0	1	0	4
2007	5	7	7	2	1	3
2008	3	8	8	2	1	3
Clustering by Land Area						
Year	**0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**
2004	**	**	**	**	**	**
2005	2	0	0	0	0	7
2007	2	8	6	0	0	8
2008	4	6	5	2	0	8

a. Post-Tsunami Clustering Comparison

The clustering patterns in the post-tsunami years were distinct from those in 2004, as demonstrated by the shift of clusters to the most inland areas of the ROI. During this period, it was rare for clustering hotspots to occur uniformly throughout a buffer zone, with the exception of the inland zone between 2.5 and 3.0km, which experienced the lion's share of clustering (for both count and area) from 2005 and onward. Although the hotspots by count varied across the ROI in the periods examined, there were specific locations where clusters existed for multiple years. Between 2.5 and 3.0km, there were 10 cells that coincided for 2005, 2007, and 2008. There was also a single cell between 0 and 0.5km, and another between 1.5 and 2.0km that were present in each of those years. Similar patterns were observed for clustering by structure area, with 19 cells between 2.5 and 3.0km, and 2 cells between 0 and 0.5km.

Post-Tsunami Structure Clustering, by Count and Area: 2005-2008



7. Proximity to Baseline Structure Locations

In order to gauge whether or not structures were built or rebuilt near the same locations as those in 2004, a tiered analysis was performed using several distances. In 2005, 80% of the structures partially or fully coincided with those that existed in 2004 (535 of 673); this rose to 88% (591 of 673) when the search radius was extended to the area within 5m of 2004 structures. When the distance was extended to the area within 10m of 2004 structures, the number increased to 631, 94% of that year's total. However, the proportion of structures that partially or fully coincide with 2004 structures was notably lower in 2007 and 2008 (69% and 65%, respectively). When the coverage areas were extended to 5m and 10m from

2004 structures, the percentages increased: in 2007, 82.4% fell within 5m, and 88.5% fell within 10m; in 2008, 79.7% fell within 5m, and 86.7% fell within 10m. In sum, while the majority of structures were still within 10m of their 2004 counterparts, as time progressed fewer structures fell within all three of the search distances. Though the percentage was relatively small (less than14% in 2008), more structures were beyond 10m of baseline structures with each additional year.

Count and Proportion of Structures in Proximity to 2004 Structure Locations: ROI South				
Year	**ROI Count**	**Fully/Partially Overlap**	**Within 5m**	**Within 10m**
2004	3085	**	**	**
2005	673	535 (79.5%)	591 (87.8%)	631 (93.8%)
2007	3242	2237 (69.0%)	2671 (82.4%)	2870 (88.5%)
2008	3812	2480 (65.1%)	3039 (79.7%)	3305 (86.7%)

8. Proximity to Roads

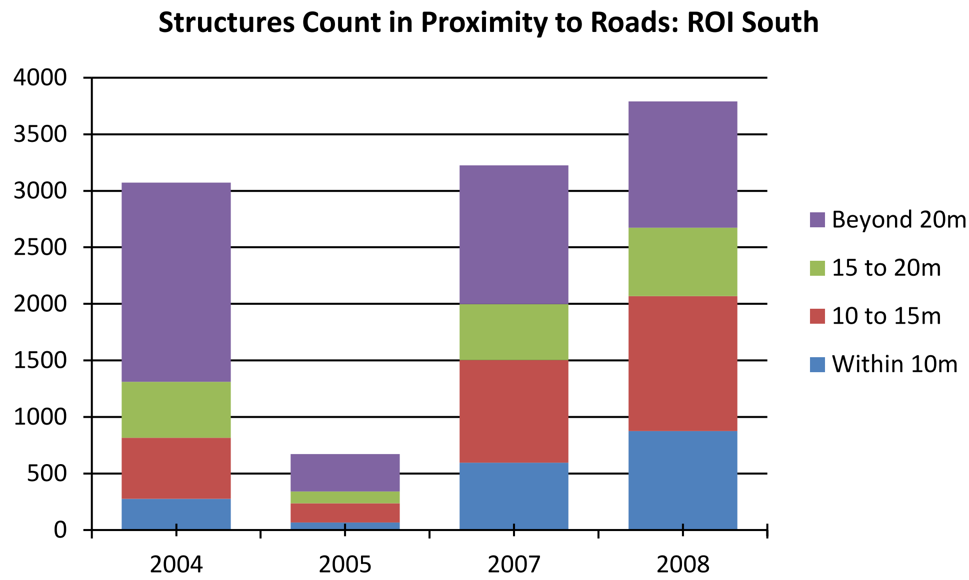
A similar proximity analysis was performed between each year's structures and roads[28]. In pre-tsunami 2004, less than half of the ROI's structures were within 20m of its roads, with the fewest falling within 10m (9% of the ROI's total). In post-tsunami 2005, though the total number of structures fell dramatically, similar proportions were within the respective

[28] The areas around the roads were mutually exclusive and not cumulative, representing a ring-like zone covering specific distances: 0 to 10m, 10 to 15m, 15 to 20m, and beyond 20m.

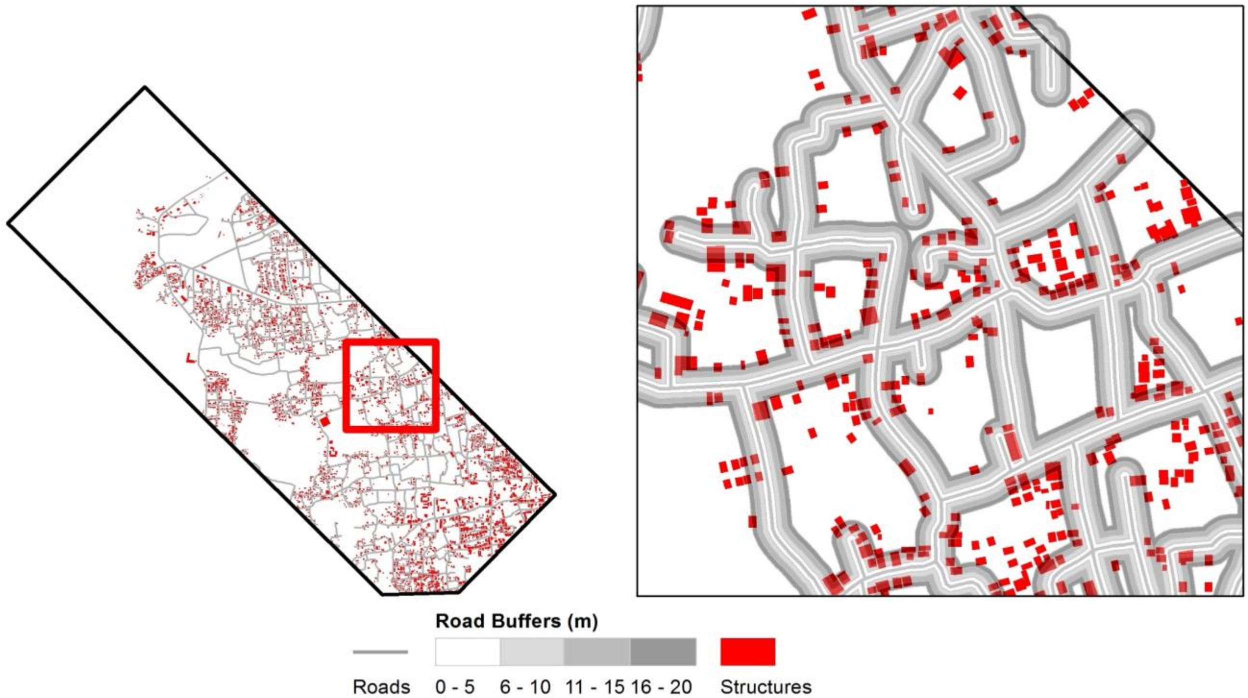
distance categories. There was an increase in the percent of structures within 15m, accompanied by a decrease of those beyond 20m. By 2007, there was a significant increase of structures falling within 10m, doubling in size and proportion from its total in 2004, while the percent of structures beyond 20m continued to fall. Last, in 2008, there were increases for the areas within 10m and 15m, a slight increase within 20m, and a further decrease beyond 20m. The overall trend indicated greater proportions of structures in closer proximity to roads, as well as a continued decline for structures farther away than 20m.

The Number and Proportion of Structures in Proximity to Roads: ROI South

Year	ROI Total	Within 10m	10 to 15m	15 to 20m	Beyond 20m
2004	3085	277 (9.0%)	539 (17.5%)	495 (16.0%)	1761 (57.1%)
2005	673	66 (9.8%)	170 (25.3%)	104 (15.5%)	332 (49.3%)
2007	3242	596 (18.4%)	906 (27.9%)	496 (15.3%)	1226 (37.8%)
2008	3812	875 (23.0%)	1194 (31.3%)	605 (15.9%)	1116 (29.3%)


Structures Count in Proximity to Roads: ROI South
4000
3500
3000
2500
2000
1500
1000
500
0
2004
2005
2007
2008
Beyond 20m
15 to 20m
10 to 15m
Within 10m

Structure Proximity to Roads: 2008



B. ROI NORTH

1. COUNTS & AREA

a. ROI Totals

As was the case in the southern ROI, there was a drastic decline in the total number of structures in ROI North, decreasing 37% from 2004 (5,738) to 2005 (3,643). This was accompanied by a 31% loss of structure area (from 945,509 sq. m to 657,344 sq. m). By 2007, the number of structures rebounded and exceeded the 2004 count by 6%, up to 6,103; structure area also increased from 2005, but was still 13% below baseline. Similarly, the number of structures in 2008 remained above the 2004 total,[29] and while the structure area rose to 901,096 sq. m, it was still 5% below the pre-tsunami levels.

<u>**Structures in ROI North: 2004-2008**</u>

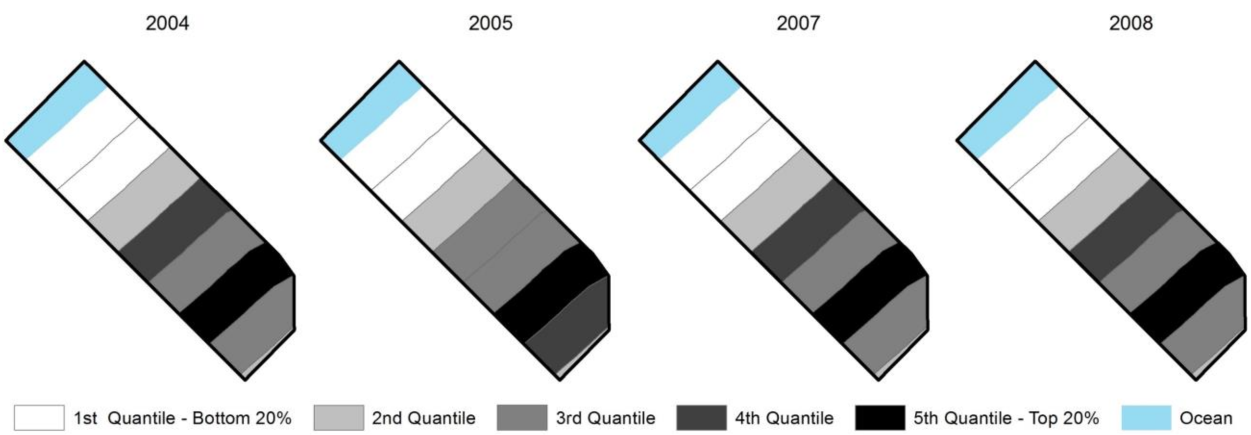
b. Buffer Zones

At baseline in 2004, the inland buffer zones in the middle of the ROI, from 1.5 to 3.0km, had the largest numbers of structures, ranging from 1,147 to 1,633 structures per zone. The neighboring zones (from 1.0 to 1.5km and 3.0 to 3.5km) contained roughly half as many structures, while the zone closest to the coast had extremely few (24). In 2005, the number of structures decreased in all buffer zones to varying degrees. The central zones between 1.5 and 2.0km, and 2.0 and 2.5km, had the greatest numerical losses, while the three zones closest to the coast had the highest proportional losses (-61% to -96%). Meanwhile, the inland areas beyond 2.5km from the coast had the least amount of loss (less than 5%). By

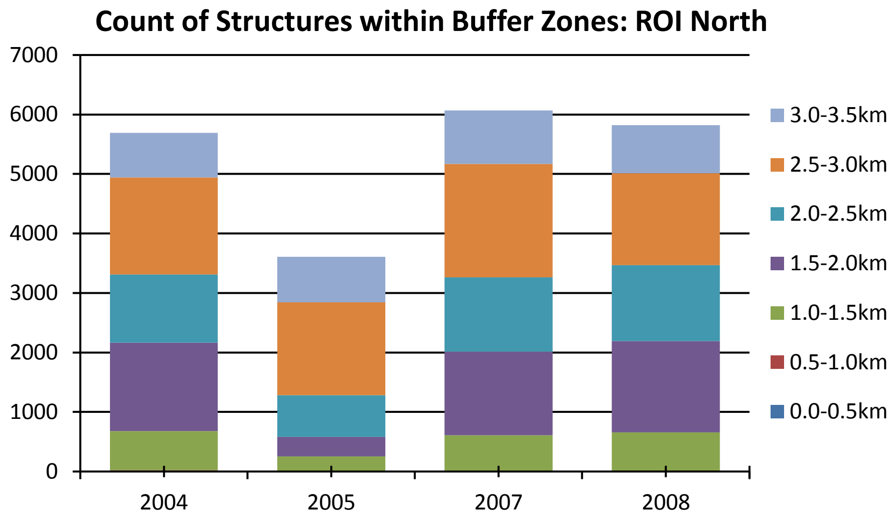
[29] The structure count for 2008 was actually below that of 2007, which was likely a result of the clarity in the original satellite imagery, as well as the digitization process, where subjective decisions can be made when creating individual features in shapefiles. (To be discussed in Limitations)

2007, all zones saw growth in the number of structures. Similar to 2004, the areas in the middle of the ROI (between 1.5 and 3.0km) had the largest counts. Although the three zones closest to the coast were still below the 2004 totals, the zones beyond 2.0km were all above baseline (having proportionally greater growth with increasing distance from the coast). As of 2008, the two zones closest to the coast and the zone from 2.5 to 3.0km were still below the 2004 totals, while the remaining zones ranged from 3.2% to 40.0% above baseline.

Structure Count by Quantile: 2004-2008

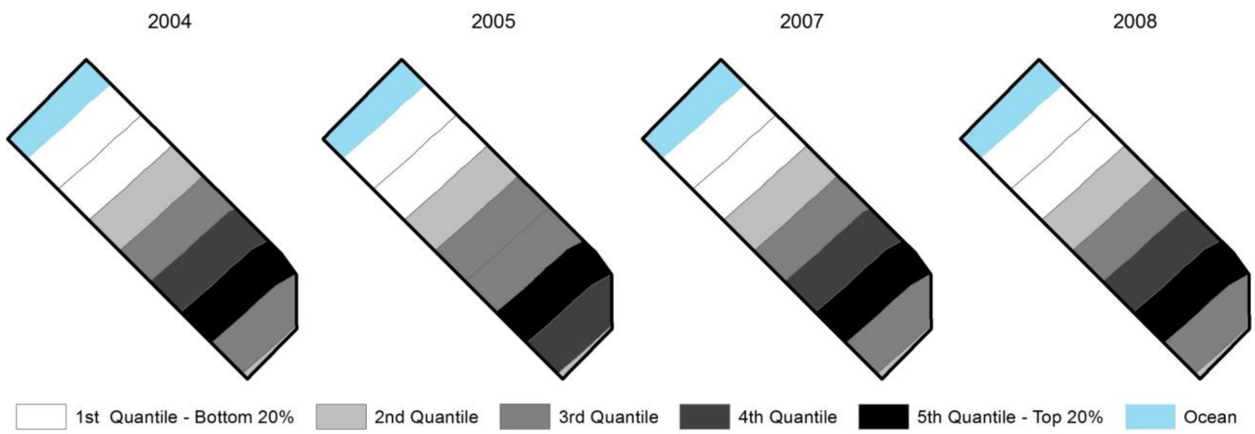


Count of Structures and Percent Change from 2004 Baseline within Individual Buffer Zones: ROI North								
Year	**ROI Total**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**	**3.0-3.5km**
2004	5738	**	24	653	1486	1147	1633	751
2005	3643 (-36.5%)	**	1 (-95.8%)	254 (-61.1%)	329 (-77.9%)	698 (-39.1%)	1559 (-4.5%)	768 (2.3%)
2007	6103 (6.4%)	**	14 (-41.7%)	597 (-8.6%)	1401 (-5.7%)	1251 (9.1%)	1905 (16.7%)	902 (20.1%)
2008	5858 (2.1%)	**	15 (-37.5%)	644 (-1.4%)	1534 (3.2%)	1276 (11.2%)	1546 (-5.3%)	808 (7.6%)

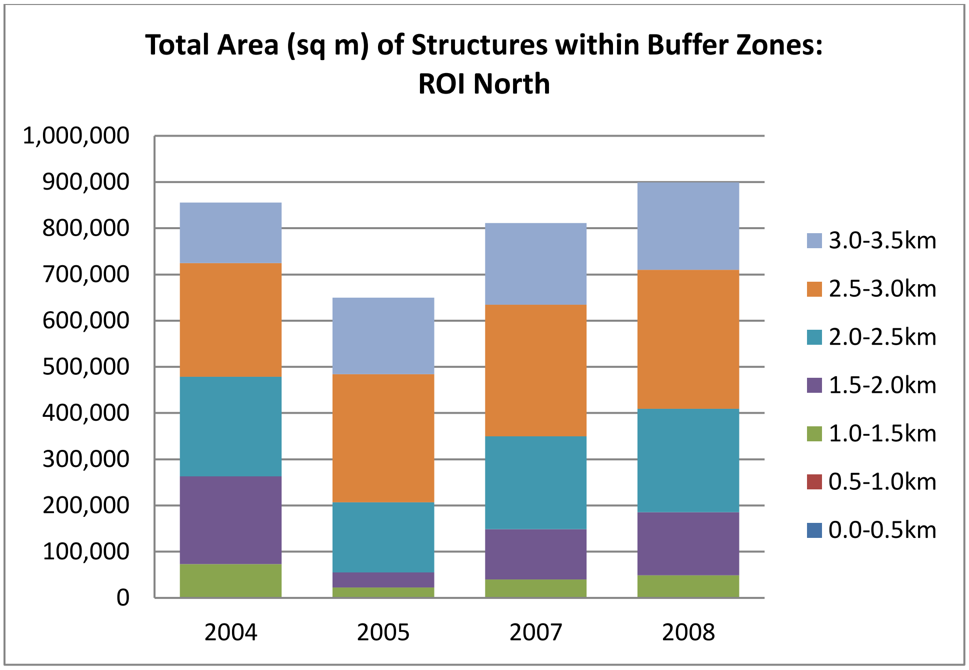


In 2004, the largest amounts of structure area were found in the zones between 2.0 and 3.0km, while the two the two zones closest to the coast (0.5 to 1.5km) held the least amount. Following the tsunami, the zones between 0.5 and 2.5km all experienced losses in structure area, ranging from 89% below baseline (0.5 to 1.0km) to 29.6% below baseline (2.0 to 2.5km). Meanwhile, structure areas in the two zones beyond 2.5km had risen above their 2004 totals, increasing with greater distance from the coast (13% and 26%, respectively). By 2007, all buffer zones experienced increases in structure area. However, as in 2005, the zones from 0.5 to 2.5km remained below baseline, while those beyond 2.5km were higher than baseline. In 2008, a similar pattern remained: the zones from 0.5 to 2.0km were below their respective baselines (-50% to -28%), and those beyond 2.0km ranged from 4% to 44% above baseline.

Structure Area by Quantile: 2004-2008



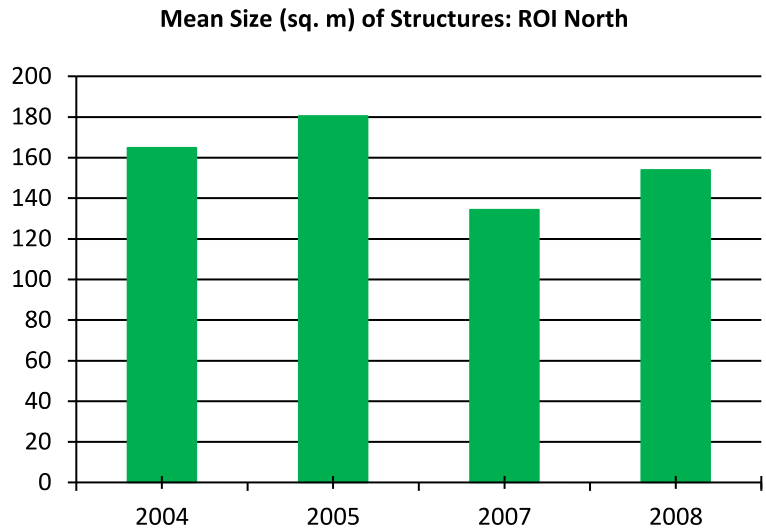
Area (sq. m) of Structures and Percent Change from 2004 Baseline within Individual Buffer Zones: ROI North								
Year	**ROI Total**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**	**3.0-3.5km**
2004	945,508.5	**	1,846.4	71,360.5	189,998.7	215,266.5	245,856.4	131,475.0
2005	657,343.9 (-30.5%)	**	198.6 (-89.2%)	22,682.2 (-68.2%)	32,571.4 (-82.9%)	151,477.5 (-29.6%)	277,332.4 (12.8%)	165,749.6 (26.1%)
2007	819,380.7 (-13.3%)	**	677.6 (-63.3%)	39,399.4 (-44.8%)	108,771.7 (-42.8%)	200,715.7 (-6.8%)	284,662.9 (15.8%)	176,758.6 (34.4%)
2008	901,095.8 (-4.7%)	**	919.3 (-50.2%)	48,066.4 (-32.6%)	136,321.3 (-28.3%)	224,012.9 (4.1%)	301,103.3 (22.5%)	188,933.8 (43.7%)



2. Mean Structure Size

a. ROI Totals

While both the count of structures and their total land area both fell in excess of 30% from 2004 to 2005 in the ROI, mean structure size rose 9.5% above baseline in the same time period (from 165 sq. m to 180 sq. m). As the number of structures increased in the succeeding years, mean size fell to 18.5% below baseline in 2007 (134 sq. m), and 6.6% below baseline in 2008 (154 sq. m). In sum, while there were more structures in 2007 and 2008 than in 2004, structures were both smaller in size on average and in total than in the pre-event period.



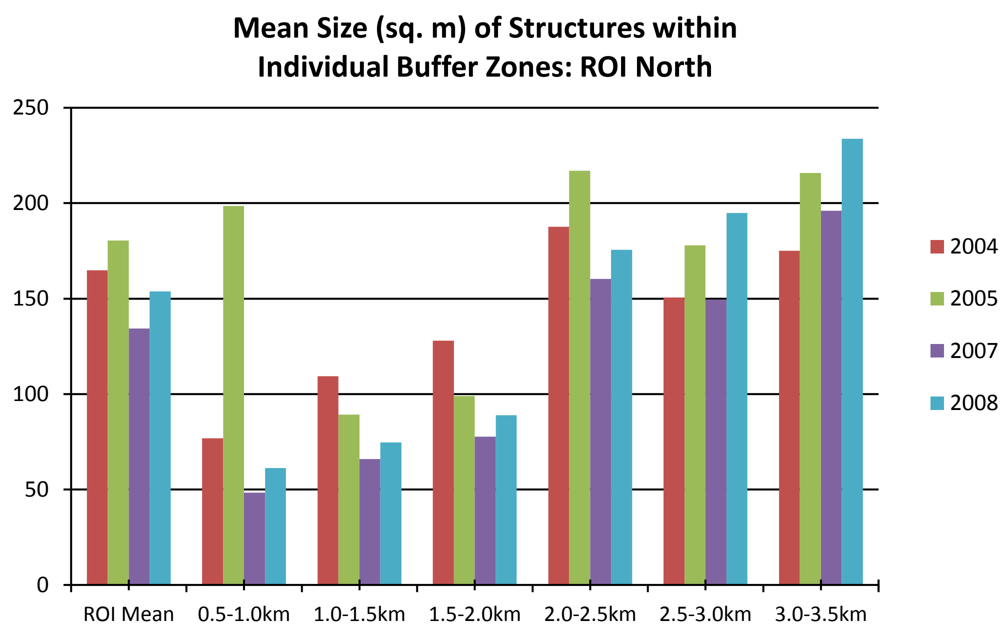
b. Buffer Zones

Some geographically-specific trends emerged when examining the individual buffer zones compared to the ROI as a whole. Although the average structure size across the ROI rose from 2004 to 2005, the mean sizes in the zones between 1.0 and 2.0km fell roughly 20%. This was offset by moderate increases in mean size ranging from 15.6% to 23.2% between 2.0 and 3.5km[30]. In 2007, structure sizes decreased further, nearly 40% below baseline in the three zones between 0.5 and 1.5km, and 15% between 2.0 and 2.5km. There was, however, an 11.9% rise from the 2004 average in the inland zone from 3.0 to 3.5km. By 2008, the zones between 0.5 and 2.5km were all below baseline, though to a lesser degree, while those beyond 2.5km exceeded baseline by roughly 30%. As seen in the figure below, although there was variation in the mean sizes of structures throughout the years

[30] The effect of the large increase in mean structure size from 0.5 to 1.0km was diminished by the fact that there was only one structure present in 2005.

examined, the pattern of relative size per zone was the same in 2008 as it was in 2004: the smallest structures were in the three zones nearest the coast (increasing in size with increased distance), and much larger structures were found in the zones from 2.0km and beyond.

Mean Size (sq. m) of Structures within Individual Buffer Zones: ROI North								
Year	**ROI Mean**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**	**3.0-3.5km**
2004	164.8	**	76.9	109.3	127.9	187.7	150.6	175.1
2005	180.4 (9.5%)	**	198.6 (158.3%)	89.3 (-18.3%)	99.0 (-22.6%)	217.0 (15.6%)	177.9 (18.1%)	215.8 (23.2%)
2007	134.3 (-18.5%)	**	48.4 (37.1%)	66.0 (-39.6%)	77.6 (-39.3%)	160.4 (-14.5%)	149.4 (-0.8%)	196.0 (11.9%)
2008	153.8 (-6.7%)	**	61.3 (-20.3%)	74.6 (-31.7%)	88.9 (-30.5%)	175.6 (-6.4%)	194.8 (29.3%)	233.8 (33.5%)



3. Density

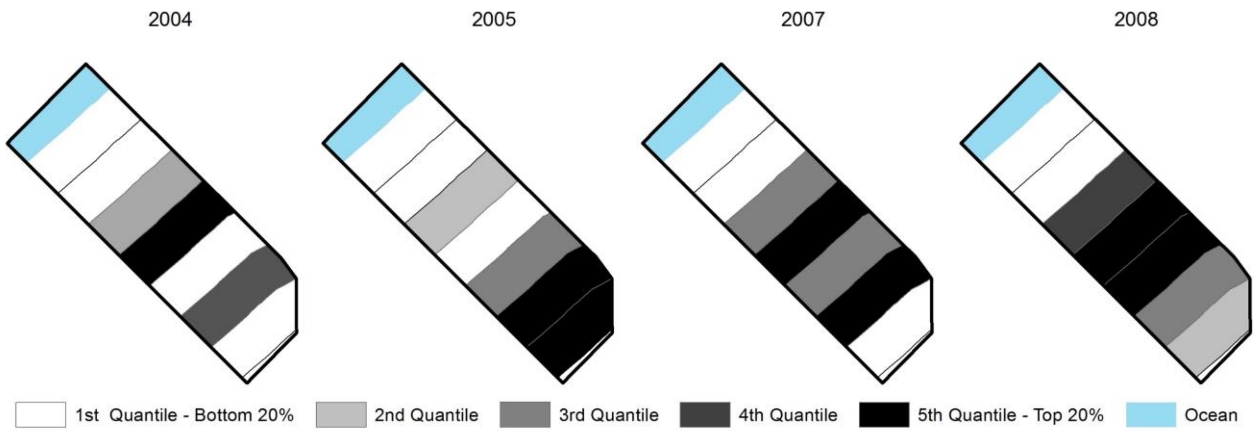
a. ROI Totals

According to a nearest neighbor analysis, the centroids of structures were 12.3m apart on average in 2004. This distance between structure centroids increased to 13.7m following the tsunami, equating to lower density. However, as structures were built or rebuilt in the succeeding years, the nearest neighbor distance fell below the 2004 baseline to 12.1 m and 11.9 m in 2007 and 2008, respectively. As the number of structures increased in the post-tsunami years, their distances apart shrunk at the same time, indicating greater density across space.

b. Buffer Zones

In 2004, the zones with the highest densities (i.e. low NN distances) were in the middle of the ROI, while the zone closest to the coast had the lowest density (18.1m), followed by the farthest-inland zone (14.1m). From 2004 to 2005, structure density in the buffer zones decreased as nearest neighbor distances increased in all but the most inland area (where the distance fell 3.5% from baseline). By 2007, density patterns shifted to begin to resemble those from before the tsunami: the zone closest to the coast became less dense, exceeding its baseline NN distance; the zone between 1.0 and 1.5km greatly increased in density, returning to its baseline distance; and structure density increased between 1.5 and 3.5km, where NN distances fell 8% to 11% from baseline. In 2008, although structure distances fluctuated slightly, the zones resembled the trend from 2004: the ROI's middle zones had the highest densities, particularly between 1.5 and 2.0km, while the zones to either side had lower densities.

Structure Density by NN Distance (m) by Quantile: 2004-2008[31]



Nearest Neighbor Distances (m) and Percent Change from Baseline for Individual Buffer Zones: ROI North								
Year	**ROI Mean**	**0.0-0.5km**	**0.5-1.0km**	**1.0-1.5km**	**1.5-2.0km**	**2.0-2.5km**	**2.5-3.0km**	**3.0-3.5km**
2004	12.3	**	18.1	11.9	11.6	13.2	11.7	14.1
2005	13.7 (11.4%)	** **	n/a*	17.7 (48.7%)	18.1 (56.0%)	14.5 (9.8%)	11.9 (1.7%)	13.6 (-3.5%)
2007	12.1 (-1.6%)	** **	19.1 (5.5%)	11.9 (0.0%)	10.7 (-7.8%)	11.9 (-9.8%)	10.7 (-8.5%)	12.6 (-10.6%)
2008	11.9 (-3.3%)	** **	18.8 (3.9%)	12.1 (1.7%)	10.7 (-7.8%)	11.9 (-9.8%)	12.3 (5.1%)	13.6 (-3.5%)
* There was only 1 structure in 2005 in this zone, preventing a nearest neighbor calculation.								

[31] Darker tones reflect lower NN values, and higher density; lighter tones reflect higher NN values, and lower density

4. Kernel Density

a. Structure Count

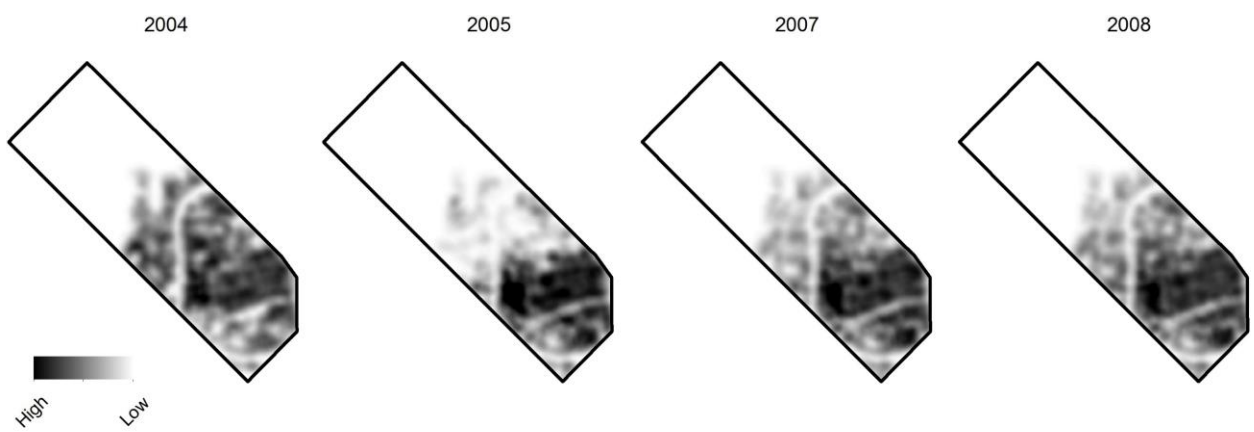
Visualizing the count of structures via kernel density yielded similar results as the nearest neighbor analysis, while allowing for greater geographic precision of the locations higher and lower densities. In 2004, there were several areas of relatively high structure density in the zones from 1.0 to 2.0km, as well as a very heavy concentration of structures between 2.5 and 3.0km. Following the tsunami, structure density dropped significantly in the areas closest to the coast, while the high density area between 2.5 and 3.0km was relatively unaffected. By 2007, pockets of higher density reappeared in the zones between 1.0 and 2.0km, in roughly the same locations as 2004. Structure density in 2008 closely resembled the pre-tsunami distribution, although there was relatively lower density near the coast, and slightly higher density approximately 1.5km from the coast.

Kernel Density by Structure Count: ROI South

b. Structure Area

Kernel density using structure area heavily declined from 2004 to 2005 in the coastal areas of ROI North, although there was an increase in density in the portion of the ROI farthest from the coast. Unlike structure count, however, structure area density did not return to 2004 levels in the portion of the ROI closest to the coast in either 2007 or 2008. Instead, the density appeared to become more dispersed in the coastal areas, while the high density areas inland remained in both years.

Kernel Density by Structure Area: ROI North



5. Clustering by Location

As in the southern region, there was statistically significant clustering of structures for ROI North as a whole from 2004 to 2008. However, when the ROI was broken into the half-kilometer buffer zones, a different pattern emerged. Unlike those of ROI South, the northern zones were not universally clustered. Instead, there were zones that were significantly dispersed and those that were randomly distributed. In 2004, structures were randomly distributed in two of the seven zones: between 0.5 and 1.0km; 3.0 and 3.5km. Meanwhile, structures were significantly dispersed in another three zones: between 1.5km and 2.0km; 2.0km and 2.5km; and 2.5km and 3.0km. Only one zone was significantly clustered – the area between 1.0 and 1.5km.

Due to the drastic change to the landscape following the tsunami, there were several changes in the clustering results for 2005. Between 0.5km and 1.0km from the coastline, only a single structure remained, and thus no clustering was possible. However, there was significant clustering in three zones: between 1.0 and 1.5km; 1.5 and 2.0km, and 2.0 and 2.5km. In contrast, there was significant dispersal farther inland, between 2.5 and 3.0km, and 3.0 and 3.5km.

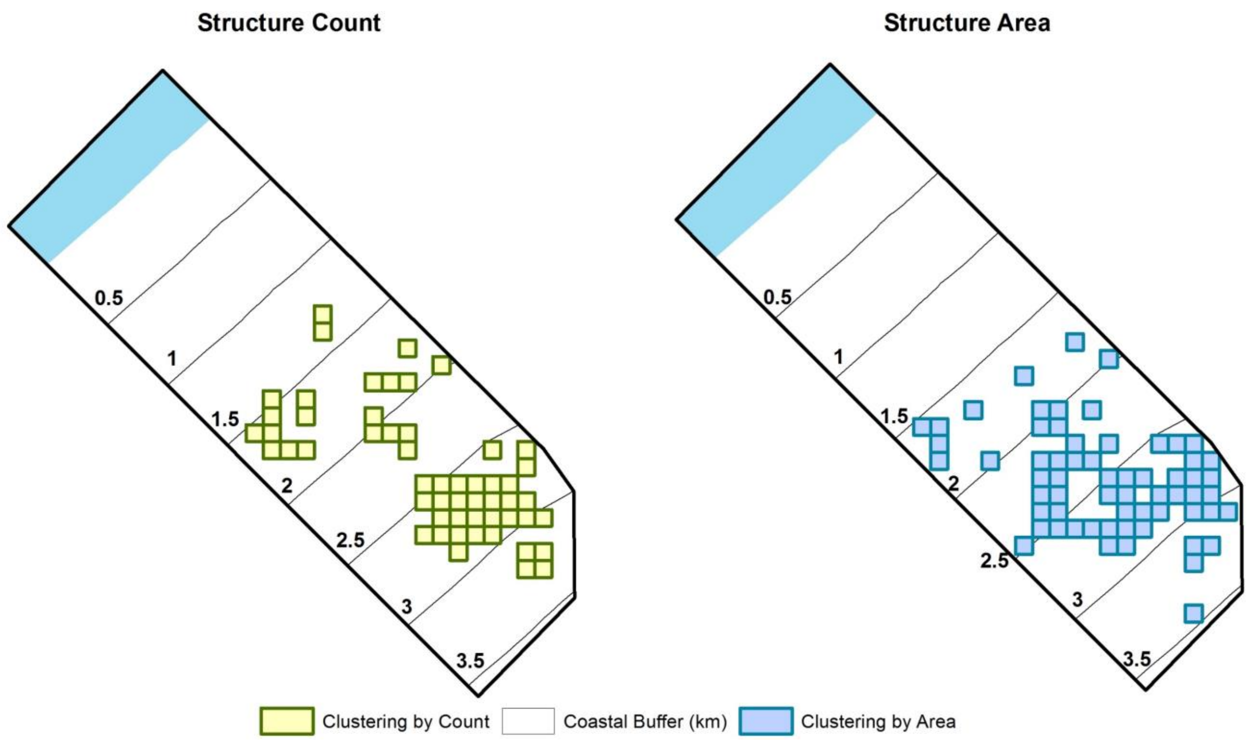
By 2007, further changes occurred, with four zones being significantly clustered (versus three in 2005): between 0.5 to 1.0km; 1.0 and 1.5km; 1.5 and 2.0km; and 2.5 to 3.0km. Unlike the two prior time periods, however, none of the buffer zones exhibited dispersed distributions. Instead, the two most-inland zones had random distributions (increasing from only one zone in 2005): between 2.0 and 2.5km, 3.0 and 3.5km. Last, more changes occurred by 2008, as only one zone (between 1.0 and 1.5km) remain clustered, two zones were randomly distributed (0.5 to 1.0km, and 1.5 to 2.0km), and one was dispersed (2.5 to 3.0km). Compared with previous years, 2008 was predominantly characterized by randomly distributed structures (five of the seven zones), while the preceding years were primarily clustered or dispersed. Overall, only one zone had a clustered distribution for all time periods (between 1.0 and 1.5km), while no zone was consistently dispersed from 2004 to 2008.

Spatial Distribution Types within Individual Buffer Zones: ROI North							
Year	**ROI Total**	**0.5 – 1.0km**	**1.0 – 1.5km**	**1.5 – 2.0km**	**2.0 – 2.5km**	**2.5 – 3.0km**	**3.0 – 3.5km**
2004	Clustered	Random	Clustered	Dispersed	Dispersed	Dispersed	Random
2005	Clustered	n/a	Clustered	Clustered	Clustered	Dispersed	Dispersed
2007	Clustered	Clustered	Clustered	Clustered	Random	Clustered	Random
2008	Clustered	Random	Clustered	Random	Random	Dispersed	Random

6. Clustering "Hot Spots" by Count and Area

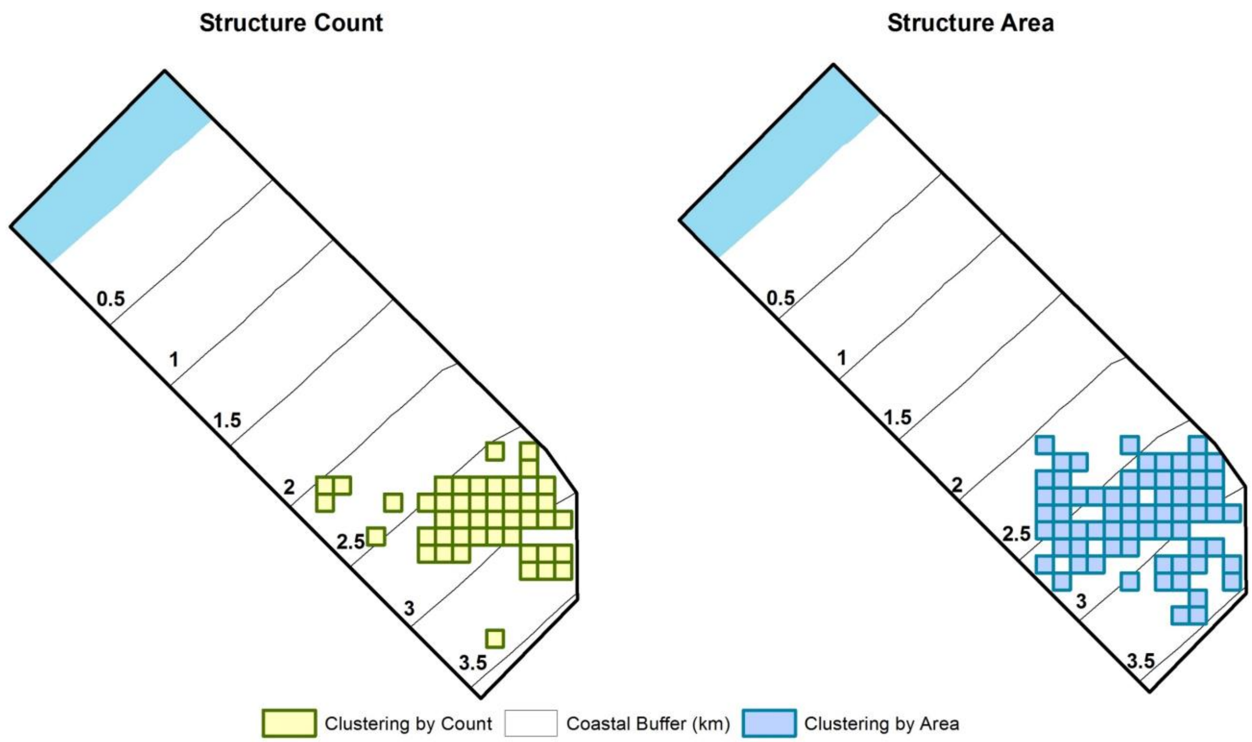
To assess more specific locations of clusters of structures within the buffer zones, a "hotspot" analysis was performed using the same fishnet approach as with ROI South. At the 2004 baseline, the zones between 1.5 and 2.0km (14 cells), and 2.5 and 3.0km (27 cells), exhibited the most clustering *by the count of structures*. There was also minor clustering in the following zones: 1.0 to 1.5km (3 cells); 2.0 to 2.5km (5 cells); and 3.0 to 3.5km (5 cells). Clustering *by the land area of structures* occurred slightly further inland, in the following areas: 1.5 to 2.0km (10 cells); 2.0 to 2.5km (18 cells); 2.5 to 3.0km (30 cells); and 3.0 to 3.5km (6 cells). The inland zone from 2.5 to 3.0km demonstrated the highest amount of clustering hotspots for both methods *despite* the zone as a whole being categorized as dispersed using the previous nearest neighbor analysis.

Structure Clustering by Count and Area: 2004



In 2005, structure hotspots by both count and area were found further inland than in 2004, specifically in the areas beyond 2.0km from the coastline. As with the year prior, the largest amount of clustering was found between 2.5 and 3.0km, with 31 cells of clustering by count, and 41 cells of clustering by area. Additional clustering of both types can be seen between 2.0 and 2.5km (5 cells for count and 12 cells for area), and 3.0 and 3.5km (9 cells for count and 15 cells for area). Clustering common to both 2004 and 2005 was restricted to the most-inland portions of the ROI: for clustering by count, there were 27 cells in common between 2.5 and 3.0km, and 5 cells between 3.0 and 3.5km. Likewise, for clustering by area, there were 9 common cells between 2.0 and 2.5km, 26 cells between 2.5 and 3.0km, and 6 cells between 3.0 and 3.5km.

Structure Clustering by Count and Area: 2005



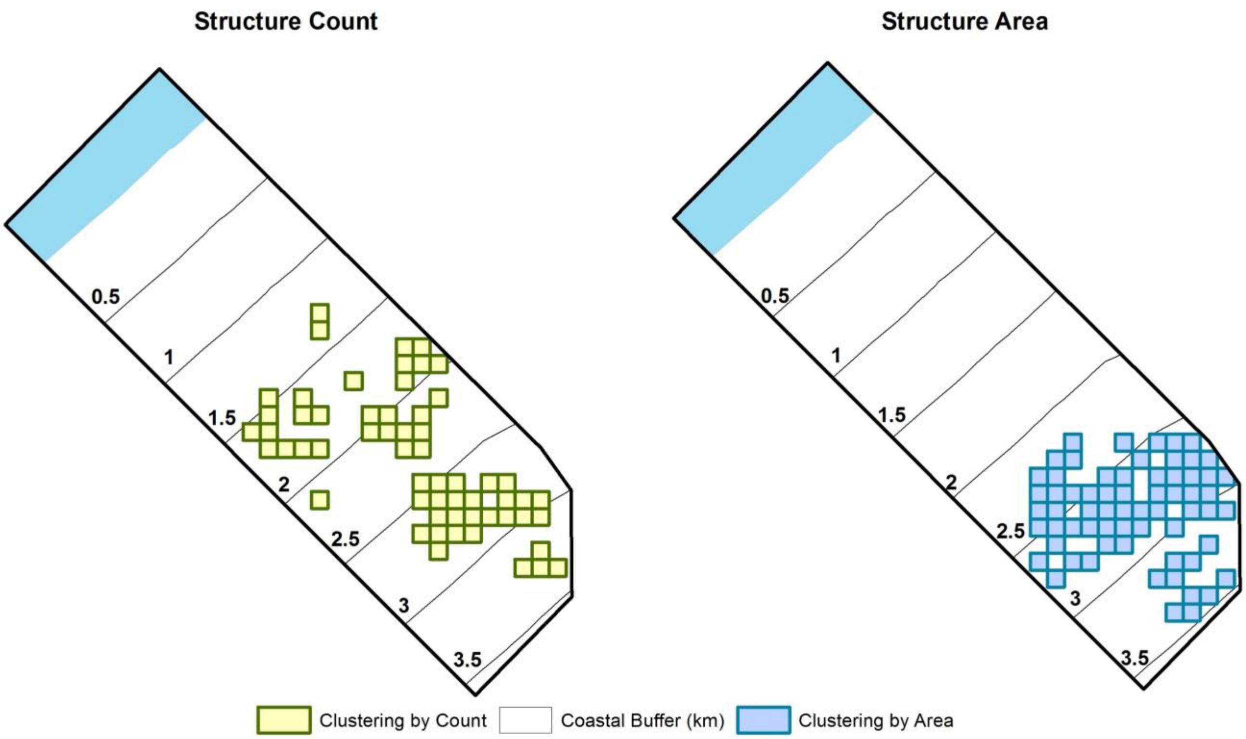
In 2007, there were five zones with hot spots of clustering by count, with the largest amount again appearing between 2.5 and 3.0km (30 cells). However, the remaining zones had far fewer hotspots: 1.0 and 1.5km (3 cells); 1.5 and 2.0km (10 cells); 2.0 and 2.5km (8 cells); and 3.0 and 3.5km (6 cells). That same year, only three zones exhibited clustering by area, with the zone between 2.5 and 3.0km (39 cells) far exceeding those between 2.0 and 2.5km (13 cells), and 3.0 and 3.5km (14 cells). When compared to baseline, there were areas of clustering count common both to 2007 and 2004, primarily between 2.5 and 3.0km (27 cells by count, 28 cells by area). As with 2005, there were more hotspots of structures by count (5 zones) than by area (3 zones)

Structure Clustering by Count and Area: 2007

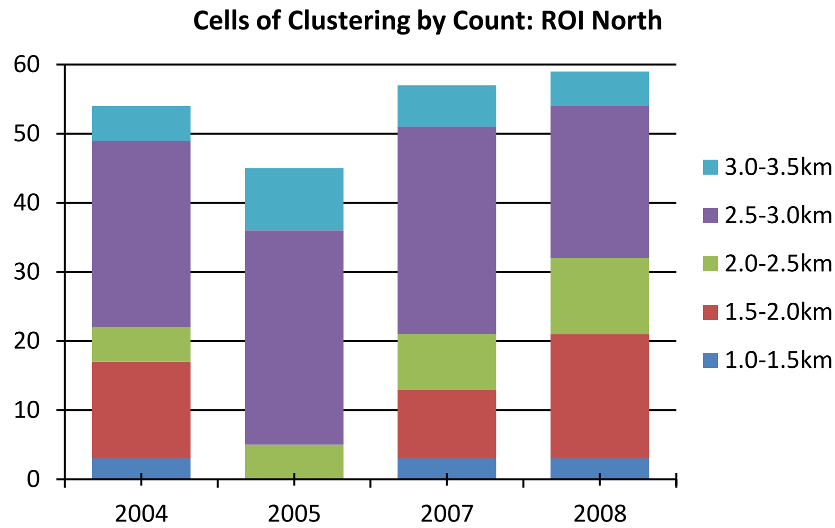
In 2008, there were very similar patterns as the year prior, with clustering hot spots by both count and area in the same zones as in 2007. However, there was a decrease in the number of hotspots by count from 2.5 to 3.0km (down to 22 cells), but increased clustering between 1.5 and 2.0km (18 cells versus 10), and 2.0 and 2.5km (11 versus 8). There was also increased clustering by area between 2.5 and 3.0km (41 cells versus 39), but minor declines in the zones from 2.0 to 2.5km and 3.0 to 3.5km.

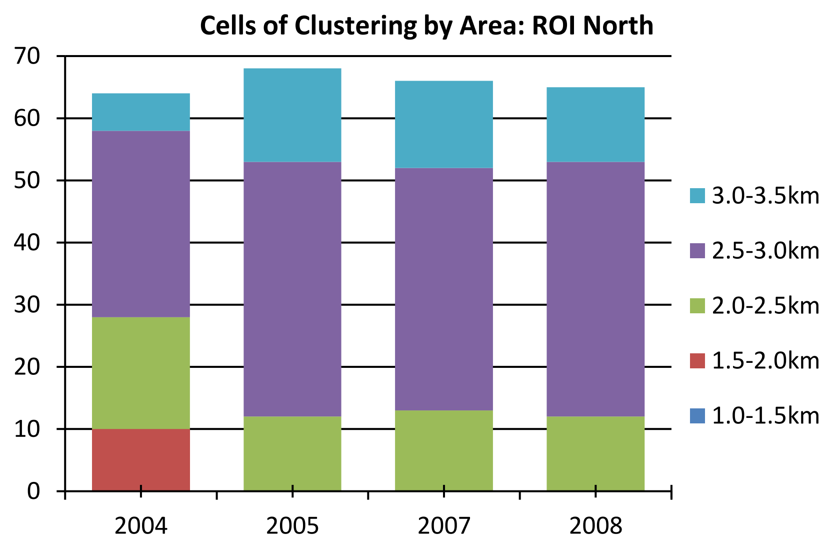
Cells of clustering were common to both 2008 and 2004, and were nearly identical in number and location as in 2007. The greatest amount in common clusters occurred between 2.5 and 3.0km, followed by the zones from 1.5 to 2.0km, 3.0 to 3.5km, and 1.0 to 1.5km. While there was a decrease in the number of common cells between 2.5 and 3.0km (from 27 to 20), there was an increase in number between 1.5 and 2.0km (from 8 to 12). Hotspots of clustering by area common to 2008 and 2004 were primarily located between 2.5 and 3.0km, but were also found from 2.0 to 2.5km, and 3.0 to 3.5km.

Structure Clustering by Count and Area: 2008



The Number of Cells per Buffer Zone with Clustering of Structures by Count and Land Area: ROI North							
Clustering by Count							
Year	0 – 0.5km	0.5 – 1.0km	1.0 – 1.5km	1.5 – 2.0km	2.0 – 2.5km	2.5 – 3.0km	3.0 – 3.5km
2004	0	0	3	14	5	27	5
2005	0	0	0	0	5	31	9
2007	0	0	3	10	8	30	6
2008	0	0	3	18	11	22	5
Clustering by Land Area							
2004	0	0	0	10	18	30	6
2005	0	0	0	0	12	41	15
2007	0	0	0	0	13	39	14
2008	0	0	0	0	12	41	12


Cells of Clustering by Count: ROI North
60
50
40
30
20
10
0
2004
2005
2007
2008
3.0-3.5km
2.5-3.0km
2.0-2.5km
1.5-2.0km
1.0-1.5km

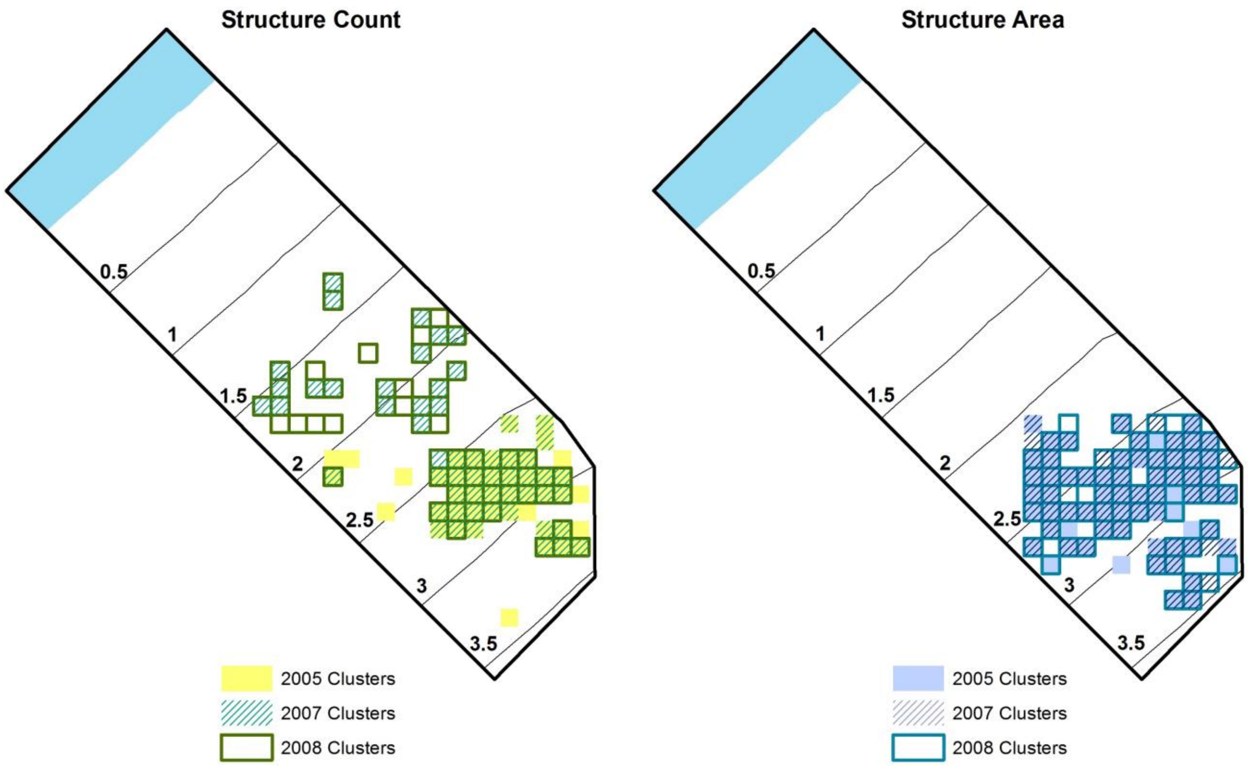

Cells of Clustering by Area: ROI North
70
60
50
40
30
20
10
0
2004
2005
2007
2008
3.0-3.5km
2.5-3.0km
2.0-2.5km
1.5-2.0km
1.0-1.5km

The Number of Cells of Clustering per Buffer Zone in Common with those in 2004: ROI North							
Clustering by Count							
Year	0-0.5km	0.5-1.0km	1.0-1.5km	1.5-2.0km	2.0-2.5km	2.5-3.0km	3.0-3.5km
2004	**	**	**	**	**	**	**
2005	**	**	**	**	**	27	5
2007	**	**	3	8	4	27	5
2008	**	**	3	12	5	20	4
Clustering by Land Area							
2004	**	**	**	**	**	**	**
2005	**	**	**	**	9	26	6
2007	**	**	**	**	11	28	5
2008	**	**	**	**	10	29	5

a. Post-Tsunami Clustering Comparison

While the amount and locations of structure hotspots varied in the years examined above, there were instances of significant clustering occurring in the same cells for *all* three of the post-tsunami periods (2005, 2007, and 2008). As seen in the previous section, these clusters occurred in the zones farthest from the coast, predominantly between 2.5 and 3.0km, where there were 23 cells in common across the post-tsunami periods. In addition, there were four cells between 3.0 and 3.5km, and a single cell between 2.0 and 2.5km existing in all three years. This finding also corroborates the previous evidence of consistently high density in the same zones across multiple years.

Structure Clustering by Count and Area: 2005-2008



7. Proximity to Baseline Structure Locations

ROI North appears have a greater proportion of its structures intersecting/coinciding with those of 2004 compared to ROI South for all years. In 2005, despite the impacts of the tsunami, 94.1% of that year's structures partially or fully overlapped those from 2004. When the search radius around the 2005 structures was expanded, this figure increased to 98.4% for an additional 5m around each structure polygon, and 99.2% for an additional 10m. In 2007, 90.3% of structures directly coincided with those of 2004, and increased to 97.7% and 98.8% for 5m and 10m, respectively. The following year, each of these proportions dropped a fractional amount, but maintained the same trend with 89.3%

partially/fully overlapping, 97.4% falling within an additional 5m, and 98.7% within an additional 10m.

Count and Proportion of Structures in Proximity to 2004 Structure Locations: ROI North				
Year	ROI Total	Fully/Partially Overlap	Within 5m	Within 10m
2004	5738	**	**	**
2005	3643	3429 (94.1%)	3586 (98.4%)	3612 (99.1%)
2007	6103	5508 (90.3%)	5960 (97.7%)	6031 (98.8%)
2008	5858	5231 (89.3%)	5703 (97.4%)	5779 (98.7%)

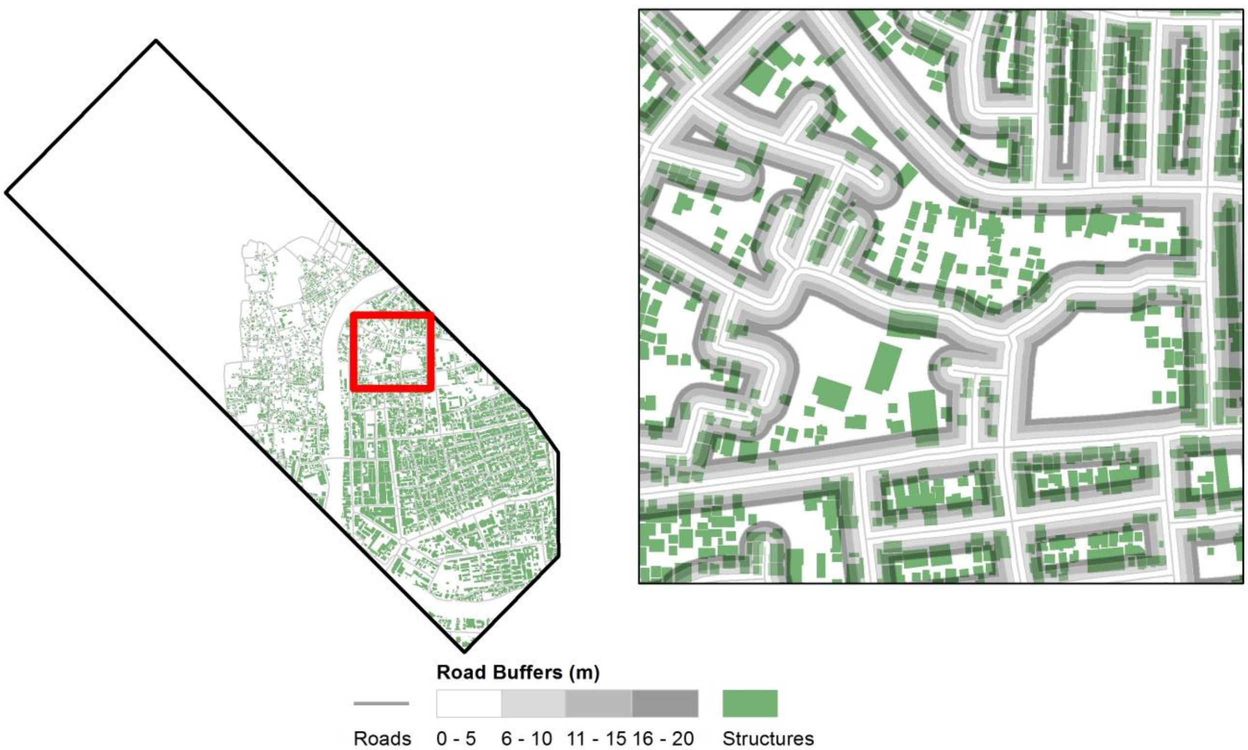
8. PROXIMITY TO ROADS

A proximity analysis was also performed for the structures and roads of ROI North[32]. At baseline in 2004, more than 60% of the ROI's structures were within 20m of roads, compared to less than half of structures in ROI South. While the general distribution of structures was similar following the tsunami, the structures beyond 20m increased in proportion in 2005, while the other three groups decreased to total just over 50%. By 2007, a shift occurred, as the structures within 10m increased from 12% to 21%. Meanwhile, there was similarly-sized decrease in the number structures beyond 20m (down to 37% of all structures), resulting in a similar distribution as baseline. The trends from 2007 continued into 2008, as the proportion of those beyond 20m continued to decrease slightly,

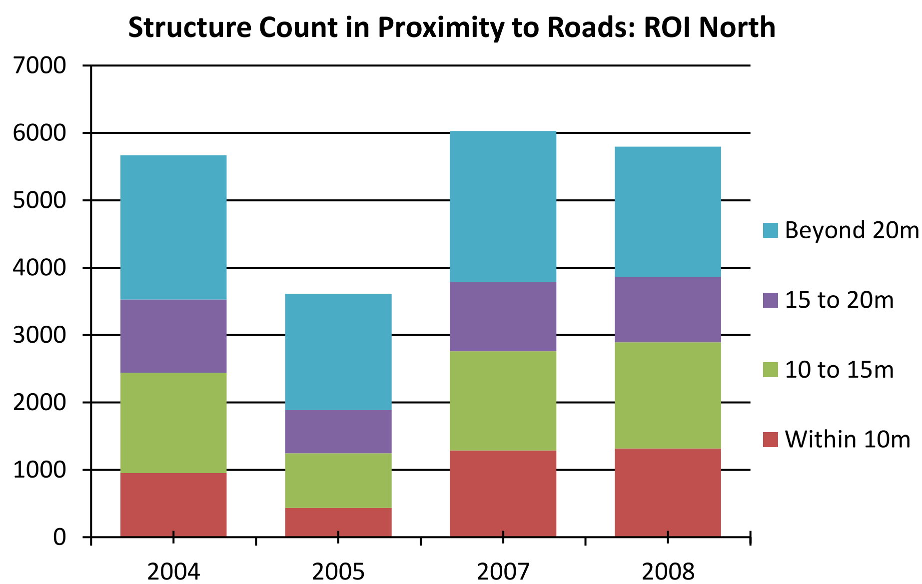
[32] The proximity analysis for structures and roads differs from the proximity to baseline structure analysis in that it uses separate, non-cumulative distance groups, versus the cumulative categories used for the baseline structures.

paired with minor growth in the structures between 10 and 15m, and 15 to 20m. Compared to 2004, there were more structures in 2008 that were in close proximity to roads (within 10m), and fewer at distances farther than 15m.

Structure Proximity to Roads: 2008



The Number and Annual Proportion* of Structures in Proximity to Roads: ROI North					
Year	ROI Count	Within 10m	10 to 15m	15 to 20m	Beyond 20m
2004	5738	949 (16.5%)	1493 (26.0%)	1085 (18.9%)	2143 (37.4%)
2005	3643	436 (12.0%)	811 (22.3%)	641 (17.6%)	1723 (47.3%)
2007	6103	1290 (21.1%)	1467 (24.0%)	1030 (16.9%)	2243 (36.8%)
2008	5858	1318 (22.5%)	1572 (26.9%)	976 (16.7%)	1931 (33.0%)
*Proportion denotes number of structures out of that year's total					



II. ROADS

A. ROI SOUTH

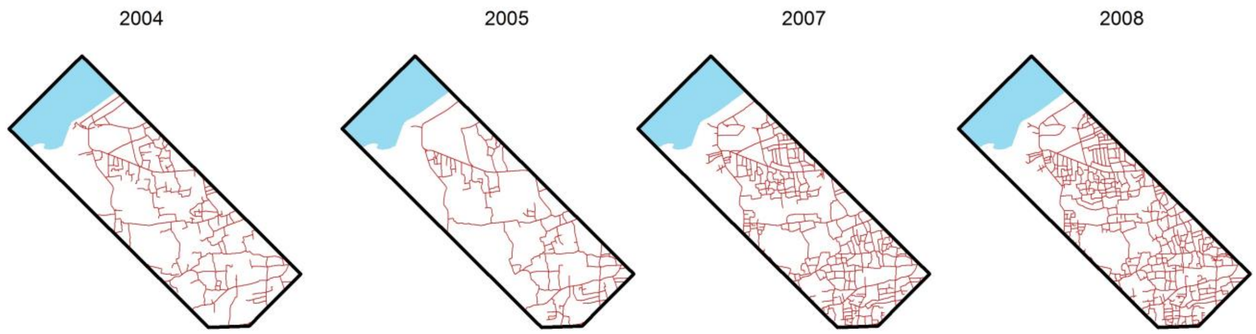
1. TOTAL ROAD LENGTH

Roads play a crucial role in the health wellbeing of communities, facilitating access to economic markets and the movement of people and goods across space (Hugo 1981; Jacoby 2000). They are similarly critical in the reconstruction process, for without materials and labor, rehabilitation and rebuilding may not be possible. While not a perfect measure, roads were quantified in this study via their lengths in meters to provide a single outcome that could be readily-understood and easily-replicated in other studies and locations.

a. ROI Totals

As with structures, there was a decrease in the total amount of roads following the tsunami, falling nearly 20% from 33,871m in 2004 to 27,506m in 2005. Although the overall distribution of the roads in 2005 resembled that of the previous year, many of the smaller roads ceased to exist, leaving large gaps in network coverage. By 2007, however, the total length of roads in the ROI substantially surpassed the 2004 amount by 56%, up to 52,716m. Many areas that previously lacked roads at baseline were connected to the road network, and there was a noticeable rise in the amount of connector and informal roads throughout the study area. This trend continued into 2008, as the total road length further increased to 61,315m (81% above baseline) and further gaps were filled and connected to the road network.

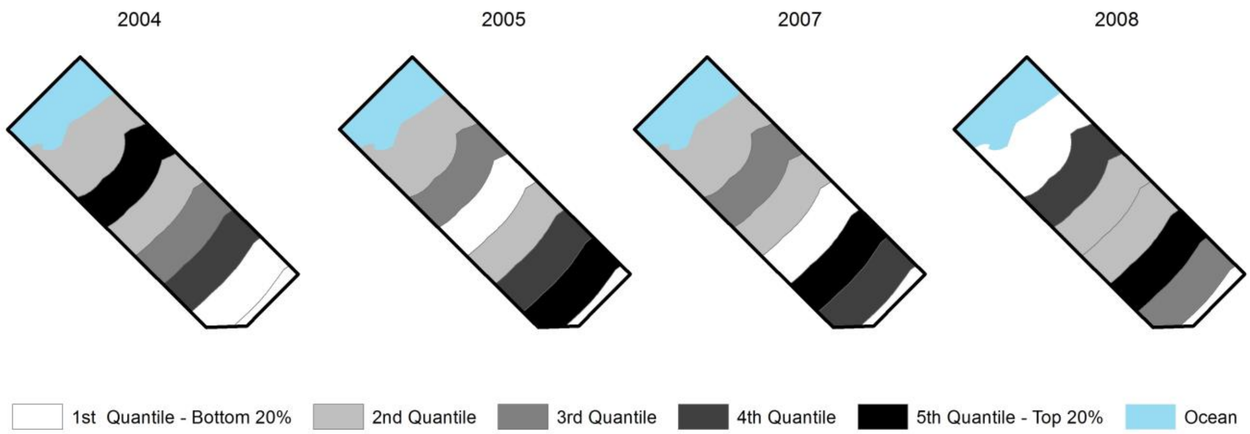
Roads in ROI South: 2004-2008



b. Buffer Zones

Within the individual coastal buffer zones, different patterns emerged depending on the location within the ROI. At baseline in 2004, roads stretched across the various buffer zones in a fairly even manner. The coastal zone between 0.5 and 1.0km, and the inland zone between 2.0 and 2.5km, had the largest amounts of roads, with 6,428m and 6,024m, respectively, while the remaining zones ranged from 4,745m to 5,471m. Following the tsunami, total road lengths declined most notably in the four zones closest to the coastline, falling 24% to 43% from baseline. The inland area between 2.0 and 2.5km decreased only 11.5% in the same period, while the zone from 2.5 to 3.0km actually increased 36% above baseline. By 2007, all but one zone rebounded and exceeded their 2004 totals. The zones farthest inland (2.0 to 2.5km and 2.5 to 3.0km), which lost the least in 2005, increased the most by 2007, rising 81% to 117% above baseline. The road lengths in the two zones between 0.5 and 1.5km rose somewhat less (55% and 67%), while the coastal zone from 0 to 0.5km increased the least (11%). The central portion of the ROI between 1.5 and 2.0km was the only exception to the growth patterns and remained 3% below baseline. By 2008, all zones had more roads than at baseline, with the largest total lengths in the two most-inland zones (2.0 to 2.0km), followed closely by the zone from 0.5 to 1.0km.

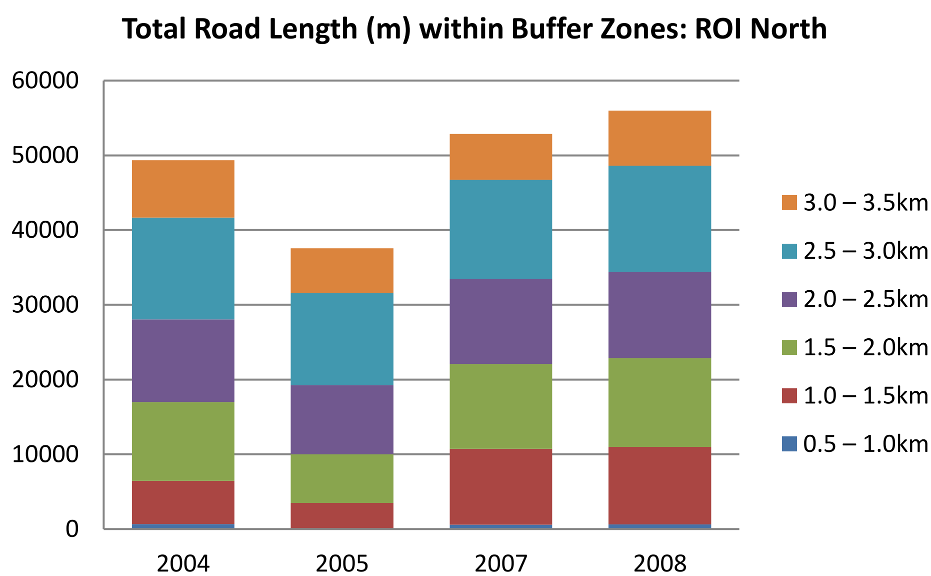
Total Road Lengths per Buffer Zone: 2004-2008



Total Road Length (m) and Percent Change from 2004 Baseline: ROI South							
Year	**ROI Total**	**0.0 – 0.5km**	**0.5 – 1.0km**	**1.0 – 1.5km**	**1.5 – 2.0km**	**2.0 – 2.5km**	**2.5 – 3.0km**
2004	33,870.7	5,395.6	6,428.0	4,978.1	5,471.0	6,023.8	4,745.0
2005	27,505.5 (-18.8%)	3,257.5 (-39.6%)	4,897.3 (-23.8%)	3,037.8 (-39.0%)	3,119.6 (-43.0%)	5,330.1 (-11.5%)	6,436.2 (35.6%)
2007	52,715.6 (55.6%)	5,979.4 (10.8%)	9,936.8 (54.6%)	8,300.4 (66.7%)	5,325.5 (-2.7%)	10,913.7 (81.2%)	10,271.9 (116.5%)
2008	61,315.0 (81.0%)	6,790.2 (25.8%)	11,606.6 (80.6%)	10,412.1 (109.2%)	7,266.5 (32.8%)	11,671.4 (93.8%)	11,562.9 (143.7%)

Next, the zones were categorized by percentile for total road lengths in order to illustrate changes in road distribution over time. In 2004, the zone from 0.5 to 1.0km from the coast held the top 20% for the total amount of roads, followed by the zone much farther inland from 2.0 to 2.5km. After the tsunami, the road distribution appeared quite different from baseline. In both 2005 and 2007, the largest amounts of roads shifted inland, the two zones between 2.5 and 3.5km contained over 40% of that year's total road length. However, in 2008, the distribution resembled a hybrid of the pre- and post- tsunami periods: the top 20th percentile was from 2.0 to 2.5km, followed by 0.5 to 1.0km and 2.5 to 3.0km.

Total Road Length and Percent of Annual Total: ROI South							
Year	**ROI Total**	**0.0 – 0.5km**	**0.5 – 1.0km**	**1.0 – 1.5km**	**1.5 – 2.0km**	**2.0 – 2.5km**	**2.5 – 3.0km**
2004	33,870.7	5,395.6 (15.9%)	6,428.0 (19.0%)	4,978.1 (14.7%)	5,471.0 (16.2%)	6,023.8 (17.8%)	4,745.0 (14.0%)
2005	27,505.5	3,257.5 (11.8%)	4,897.3 (17.8%)	3,037.8 (11.0%)	3,119.6 (11.3%)	5,330.1 (19.4%)	6,436.2 (23.4%)
2007	52,715.6	5,979.4 (11.3%)	9,936.8 (18.8%)	8,300.4 (15.7%)	5,325.5 (10.1%)	10,913.7 (20.7%)	10,271.9 (19.5%)
2008	61,315.0	6,790.2 (11.1%)	11,606.6 (18.9%)	10,412.1 (17.0%)	7,266.5 (11.9%)	11,671.4 (19.0%)	11,562.9 (18.9%)

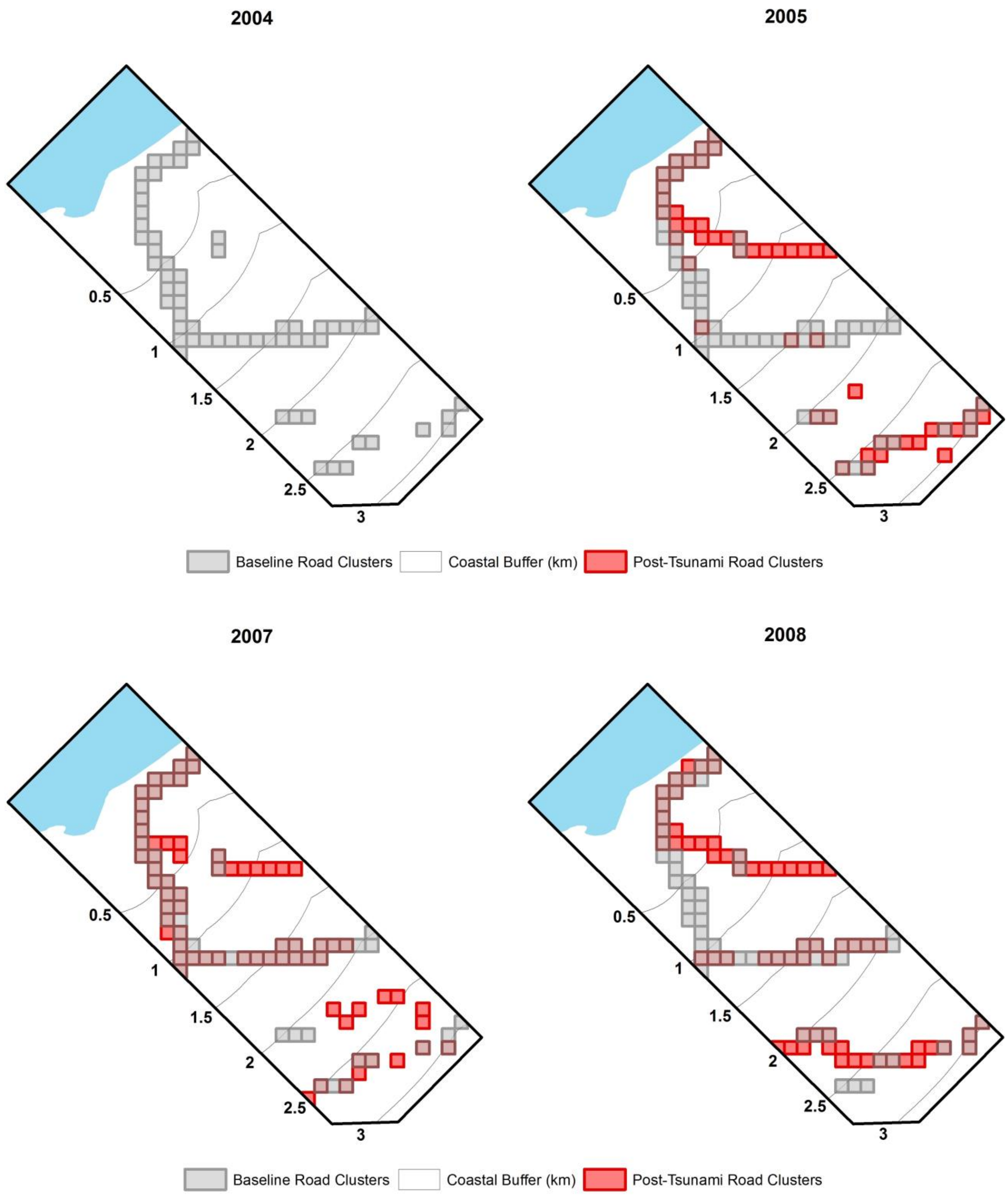


2. Road Network Hotspots

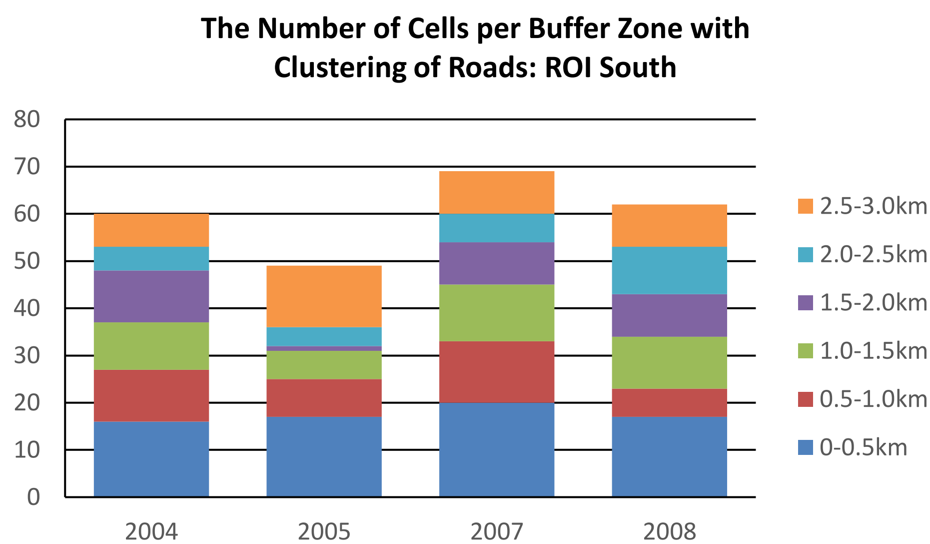
In order to examine statistically significant changes in the road network over time, hotspot analysis was performed using road lengths per fishnet cell. At baseline, the road clustering patterns resemble the major roads of the ROI, and were located primarily in the more coastal half of the region. The clusters stretched from the northeastern portion of the zone from 0 to 0.5km, down to the southwest through the next two zones, and then back to the east through the zones from 1.0 to 1.5km and 1.5 to 2.0km. Following the tsunami, the road clusters closest to the coast are similar to those from the year before. However, there are additional clusters that connect to the coastal road hotspots and extend east through the neighboring zones (from 0.5 to 1.5km). There were also clusters in 2005 in the inland zones from 2.5 to 3.0km, both adjacent to and overlapping with those from 2004.

By 2007, the trends from 2005 continued, and were bolstered by considerable overlap with baseline clusters, as seen between 0.5 and 2.0km. Although most of the clusters in 2007 occurred on or near those from baseline, there were some unique hotspots between 2.0 and 2.5km where none existed previously. Last, in 2008, road clustering patterns reverted back to resemble those from 2005, while preserving some of the clusters that appeared in 2007. For the most part, the hotspots in 2008 match those of baseline, while adding two lengthy clusters reaching from east to west (from 0.5 to 1.5km, and 2.5 to 3.0km).

<u>Road Clustering by Total Length in ROI South: 2004-2008</u>



The Number of Cells per Buffer Zone that Cluster by Road Length: ROI South						
Year	0-0.5km	0.5-1.0km	1.0-1.5km	1.5-2.0km	2.0-2.5km	2.5-3.0km
2004	16	11	10	11	5	7
2005	17	8	6	1	4	13
2007	20	13	12	9	6	9
2008	17	6	11	9	10	9



3. Road Network Expansion – "New Roads"

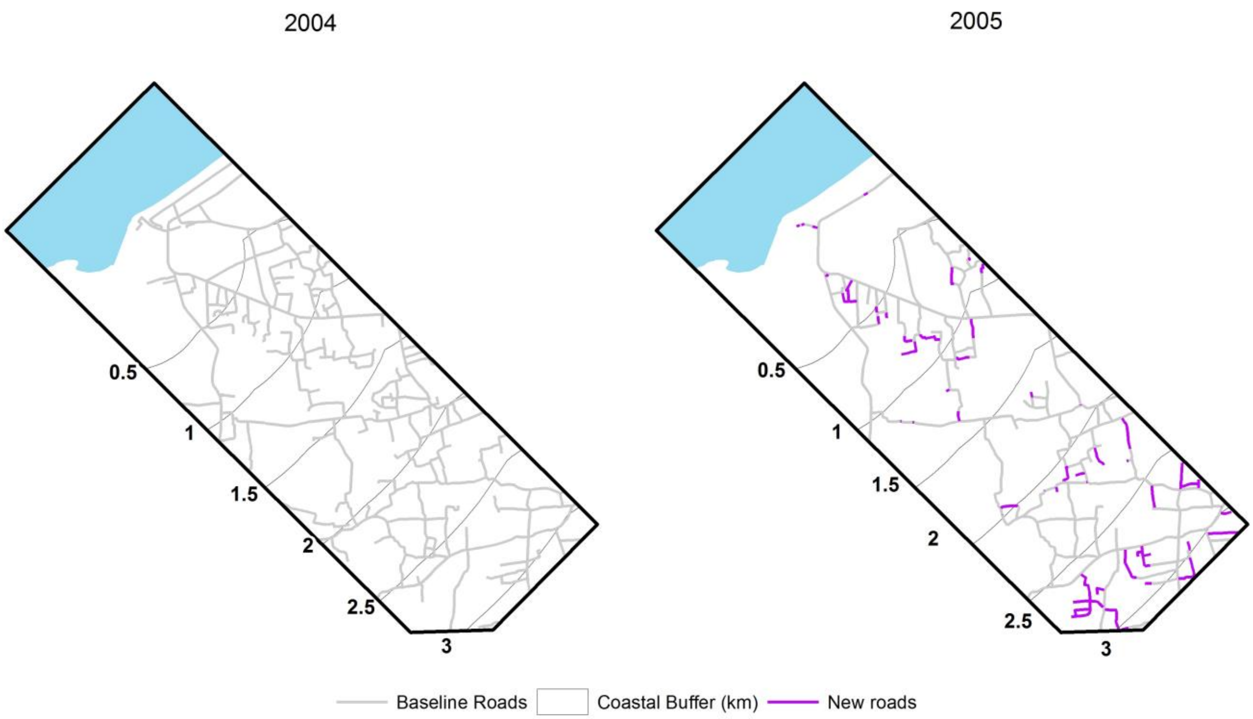
By overlaying one year's road data over that of 2004, it was possible to isolate and examine the amount of expansion of the road network from baseline[33]. The data for each year are the segments of roads that did not exist in 2004, i.e. "new roads." These extensions of the baseline network are shown in red in the figures below, while the roads shared with the 2004 network are shown in gray.

In 2005, 17% of all roads in ROI South were additions that did not exist at baseline, though the proportion varied from 4% to 32% within the individual zones. There were small but visible extensions to the network in the zones between 0 and 2.5km, ranging from 315m and 709m. The largest expansion of the network occurred throughout the zone from 2.5 to 3.0km, adding 2,057m of new roads (comprising 32% of that zone's road stock). In 2007, there were extensive additions to the 2004 network, equating to 44.9% of all roads that year, filling in many gaps in each of the zones. In particular, there were substantial expansions in the northeastern portions of the zones from 0.5 to 1.0km, and 1.0 to 1.5km (ranging from 1,981m to 4,939m), as well as the across the entirety of the zones from 2.0 to 2.5km and 2.5 to 3.0km (5,197m and 5,523m, respectively). The network expansion in each of the zones represented a considerable portion of all roads that year, with three zones exceeding 40% and two zones exceeding 50%. By 2008, there was continued growth of the network, more than half the roads in the ROI did not exist at baseline. The largest

[33] The road data here provide snapshots of each year versus baseline. These data are cumulative in nature – the new roads in 2008 include any new roads from 2008, 2007, and 2005 (minus any that ceased to exist in later periods), and the 2007 include any additions to the network in 2007 and 2005.

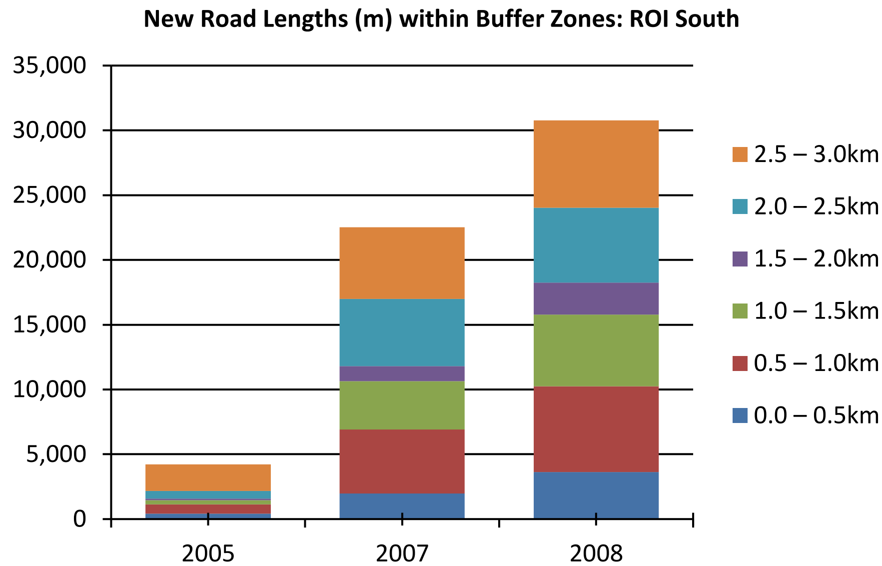
cumulative increases were those between 0.5 and 1.0km (6,635m, 58.2% of all roads in that zone), and 2.5 and 3.0km (6,729m, or 57%). This was followed by increases in the remaining zones, ranging from nearly 2,500m to 5,800m (or 34% to 50% of roads in their respective zones).

<u>"New Roads" vs Baseline Roads in ROI South: 2004-2008</u>



New Road Lengths (m) and their Percent of All Roads[34] within Buffer Zones: ROI South							
Year	**ROI Total**	**0.0 – 0.5km**	**0.5 – 1.0km**	**1.0 – 1.5km**	**1.5 – 2.0km**	**2.0 – 2.5km**	**2.5 – 3.0km**
2004	**	**	**	**	**	**	**
2005	4,798.9 (17.4%)	422.9 (13.0%)	708.5 (14.5%)	314.7 (10.4%)	131.2 (4.2%)	583.4 (10.9%)	2,056.9 (32.0%)
2007	23,648.0 (44.9%)	1,981.0 (33.1%)	4,939.1 (49.7%)	3,714.0 (44.7%)	1,165.2 (21.9%)	5,197.1 (47.6%)	5,522.6 (53.8%)
2008	31,898.1 (52.0%)	3,620.6 (53.3%)	6,634.6 (57.2%)	5,526.8 (53.1%)	2,462.9 (33.9%)	5,789.6 (49.6%)	6,729.0 (58.2%)

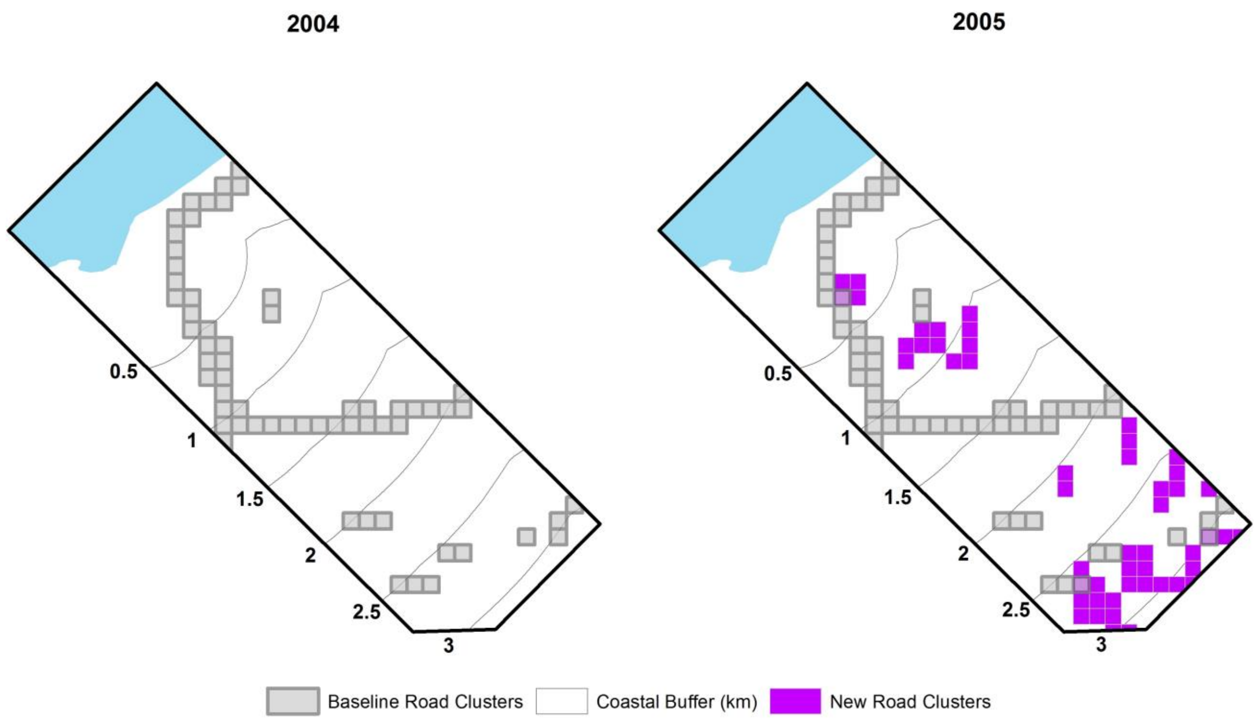
[34] The percent here is derived from the total length of “new roads” in a zone out of all roads for a given zone in a given year.

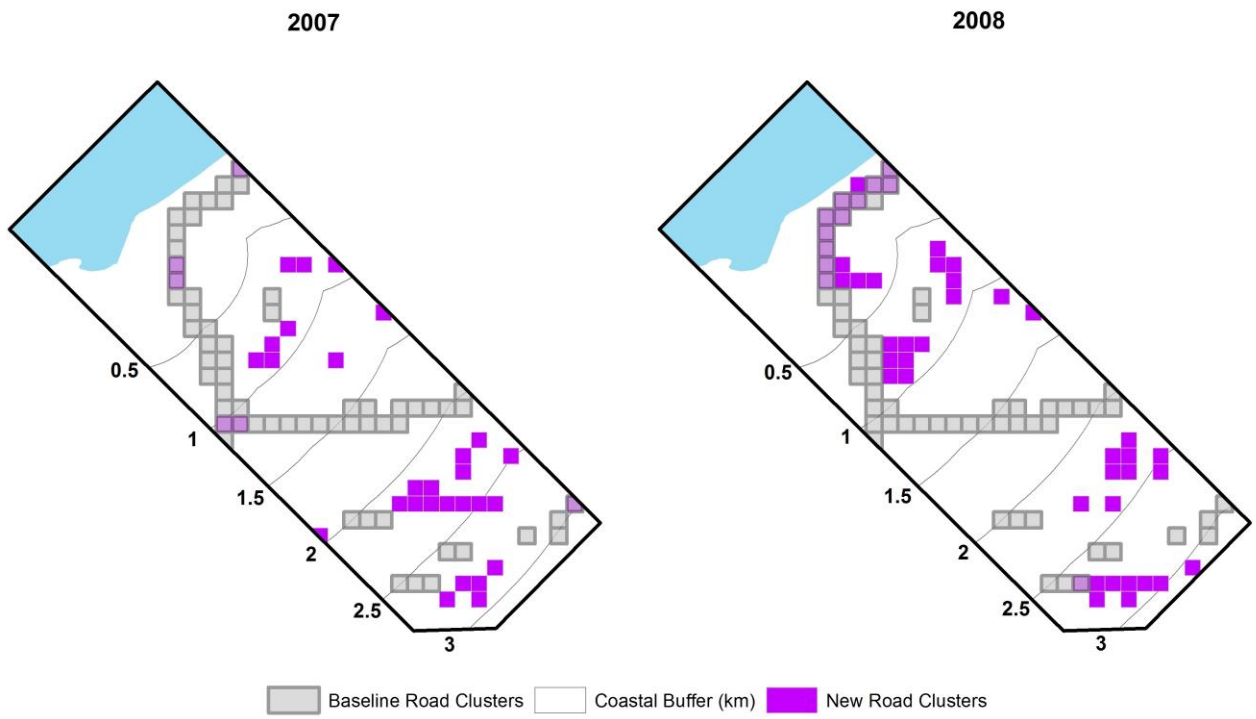


4. New Road Clustering Hotspots

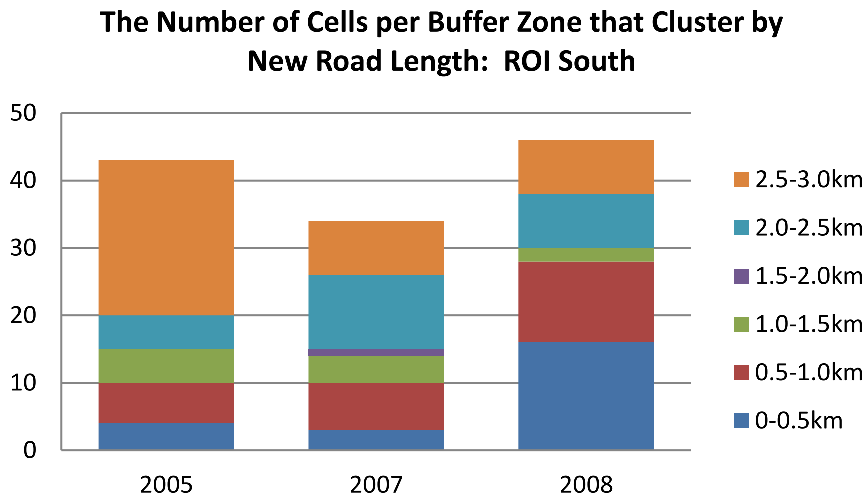
At baseline in 2004, the highest number of "new road" clusters (by road length) occurred in in the four zones closest to the coast (ranging from 10 to 16 cells), in an arrangement closely resembling several of the major roads in the region. However, in 2005, new roads in the network were the most heavily-clustered in the inland zone between 2.5 and 3.0km (23 cells), with far fewer hotspots in the other zones (ranging from 0 to 6 cells per zone). Although there was little overlap with the clusters from 2004, those of 2005 complemented and expanded upon those of the baseline network. By 2007, the clustering of new roads appeared to be more dispersed across the ROI and far less concentrated in any one area. The largest amount of clustering occurred in the inland zone between 2.0 and 2.5km (11 cells), followed by its neighboring zone from 2.5 to 3.0km, and then the three zones closest to the coast. As in 2005, these hotspots appeared to further extend the pre-tsunami network, with very little overlap with either the 2004 or 2005 clusters. Last, by 2008, network expansion resembled a mix of the previous years. Similar to pre-tsunami 2004, far more clustering occurred in the zones closest to the ocean, with 16 cells between 0 and 0.5km, and 12 cells between 0.5 and 1.0km. The remaining clustering follows the example of 2007, with the next highest amounts of clustering occurring farther inland, from 2.0 to 2.5km (8 cells), and 2.5 to 3.0km (8 cells). These additional clusters were located where there were large gaps in at baseline, expanding the pre-tsunami network, as seen below.

New Road Hotspots in ROI South: 2004-2008





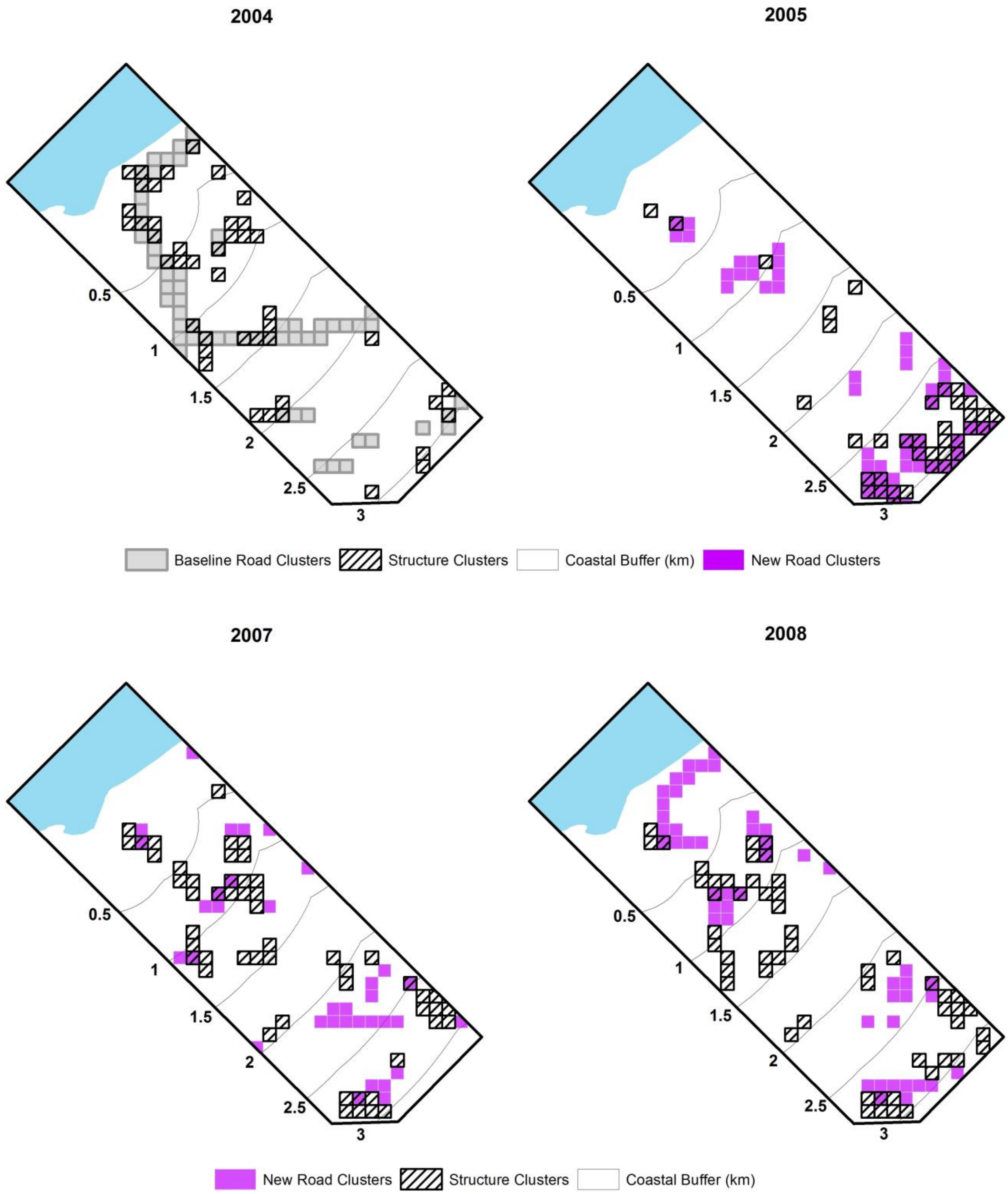
The Number of Cells per Buffer Zone that Cluster by New Road Length: ROI South						
Year	0-0.5km	0.5-1.0km	1.0-1.5km	1.5-2.0km	2.0-2.5km	2.5-3.0km
2004	**	**	**	**	**	**
2005	4	6	5	0	5	23
2007	3	7	4	1	11	8
2008	16	12	2	0	8	8



a. New Road Clustering versus Structure Clustering (by Count)

To compare the reconstruction of roads with the presence of structures (either old or new) in the post-tsunami years, a similar overlay technique was performed. In 2005, there were many instances of overlap (16 cells) between new roads and structures (by count) in the zone between 2.5 and 3.0km, where the majority of road and structure clustering occurred. In addition, where they two types of hotspot did not directly overlap, new roads clusters were adjacent to those of the structures. Yet, in 2007, clustering for both new roads and structures were more widely dispersed across the ROI and there were far few cases where the hotspots overlapped. There were only six common cells throughout the ROI, although hotspots of both types were located adjacent to or near one another. Even in the instances where new road clusters were not immediately next to those of structures, they appeared to bridge the gap between structure clusters. Similarly, by 2008, although there were only seven cases of overlapping clusters throughout the ROI, hotspots for both new roads and structures were again located adjacent to or near to each other. New road hotspots occurred primarily along the coast and most-inland areas, while structures tended to cluster in the middle of the ROI and different portions of the inland zone from 2.5 to 3.0km.

Structures and New Roads Hotspots: 2005-2008



5. Structure and Road Correlation

In addition to the proximity and clustering analyses above, tests of correlation were performed between the existence of structures and roads for each cell in the ROI fishnet[35]. In the post-disaster years, there was a rise from somewhat weak (r=0.2) to moderate (r=0.3) correlation between the structure and road variables (both structure count and area and total length of all roads). While the correlation coefficients for structure area were slightly lower than those for structure count, the same overall trend existed for both. By 2008, increases in structure count or area were moderately correlated with increased total road length.

However, when the analysis was limited to the roads that did not exist in 2004 (i.e. "new roads"), there was a decrease from moderate (0.4) to somewhat weak (0.1 to 0.2) correlation between structures (by both count and area) and roads across the study period. As above, the correlation coefficients were slightly lower for structure area than for structure count. Overall, increases structure count or area were weakly correlated with increased lengths of new roads in a given cell.

In sum, there was a weak to moderate correlation between structures and roads in ROI South. Although increases in structure count or structure area were correlated with increases in road lengths, the correlation was stronger for all roads in a given cell than for the "new roads."

[35] Structures were measured by the count per fishnet cell, and total structure area per cell; roads were measured by the total length in meters per cell, for both all roads and the "new roads" (i.e. post-2004 additions).

Correlation Coefficients for Structures (by Count, Area) and Roads (by Length), ROI South				
Year	All Roads		New Roads	
	Structure Count	Structure Area (sq.m)	Structure Count	Structure Area (sq.m)
2004	0.31	0.35	**	**
2005	0.19	0.16	0.41	0.40
2007	0.24	0.23	0.21	0.16
2008	0.32	0.31	0.19	0.15

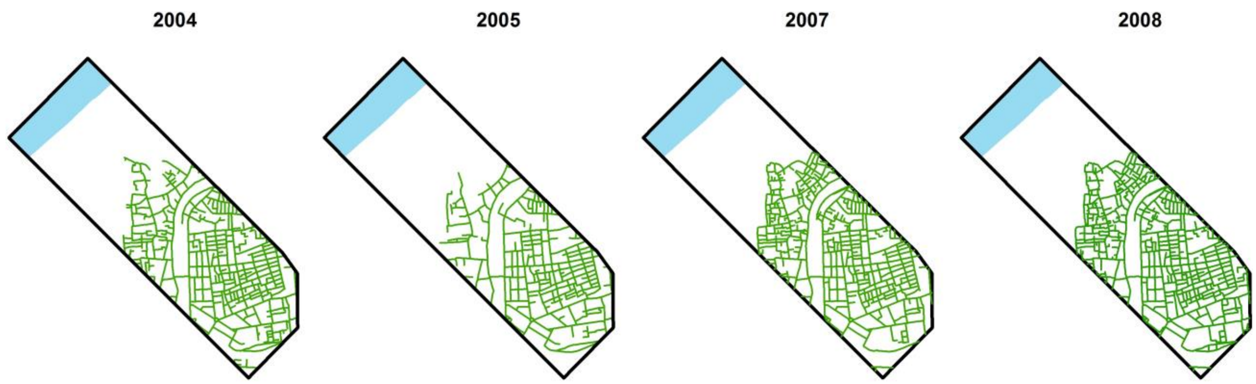
B. ROI NORTH

1. TOTAL ROAD LENGTH

a. ROI Total

Similar to the southern region of interest, there was nearly a 25% decrease in the total length of roads in ROI North from 49,689m 2004 to 37,851m in 2005. Although the general configuration of the road network remained the same, large losses were visible in the areas closest to the coastline. However, by 2007, this situation had reversed with an increase in total road length up to 53,147m (7.0% above baseline), reestablishing lost portions of the network, as well as extending it further. By 2008, the road stock rose to 56,429m (13.6% above baseline) through continued expansion and additional connections to the network.

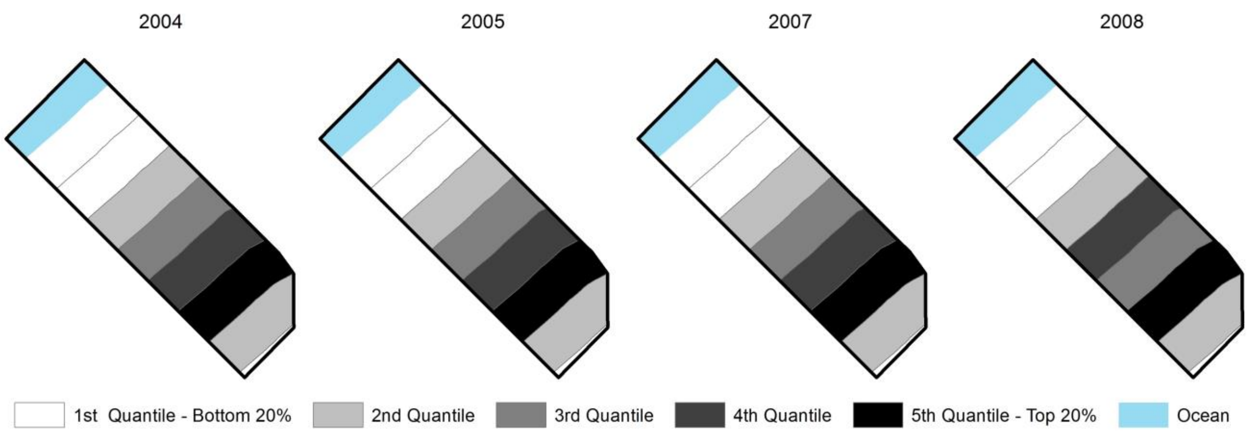
Roads in ROI North: 2004-2008



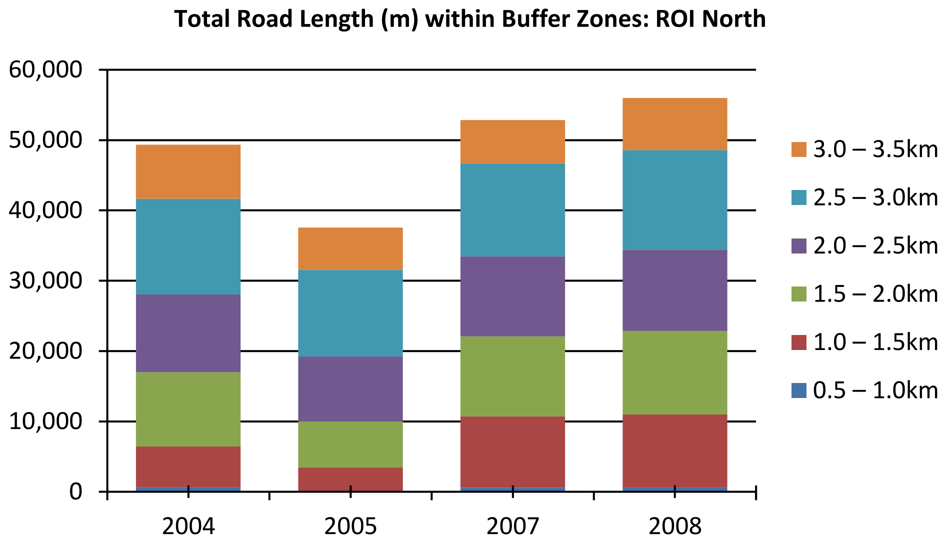
b. Buffer Zones

When the ROI was broken into the individual buffer zones, specific patterns emerged. At baseline in 2004, the largest amounts of roads were found in the inland portions of the ROI beyond 1.5km from the coastline, particularly the zone between 2.5 and 3.0km with over 13,000m. Following the tsunami, the zone closest to the coast (0.5 and 1.0km) lost all 673m of its roads. The neighboring zones from 1.0 to 2.0km lost almost 40% of their total road lengths, while the zones farther inland faced much lower losses. By 2007, all zones in the ROI experienced growth in their road stock from 2005. These gains were led by the zone from 1.0 to 1.5km, which increased to over 10,000m, 75% above baseline, while the zone from 3.0 to 3.5km gained only 100m and remained nearly 20% below baseline. As with the previous years, the largest total road length was in the zone from 2.5 to 3.0km (13,244m), and the coastal zone from 0.5 to 1.0km held the least amount (582m). Road coverage continued to increase in all zones in 2008, and only the zones closest to the coast (0.5 to 1.0km) and the farthest inland (3.0 to 3.5km) remained below baseline (-8.1% and -3.7%, respectively). In comparison to ROI South, the northern region appeared to have fared worse, with slower rebuilding rates (e.g., between 2.5 and 3.0km, and beyond 3.5km) and two zones that were still below baseline in 2008 (between 0.5 and 1.0km, and 3.0 and 3.5km). Of ROI North's zones, the greatest amount reconstruction was completed between 1.0 and 1.5km (up 79.8% from 2004), and the inland zone from 2.5 to 3.0km held the largest total road lengths for all periods.

Total Road Lengths per Buffer Zone: 2004-2008



Total Road Length (m) and Percent Change from 2004 Baseline within Buffer Zones: ROI North								
Year	**ROI Total**	**0.0 – 0.5km**	**0.5 – 1.0km**	**1.0 – 1.5km**	**1.5 – 2.0km**	**2.0 – 2.5km**	**2.5 – 3.0km**	**3.0 – 3.5km**
2004	49,689.50	**	672.6	5,774.8	10,561.3	11,047.5	13,623.6	7,664.9
2005	37,845.90 -23.8%	** **	0.0 (-100.0%)	3,477.0 (-39.8%)	6,531.9 (-38.2%)	9,238.2 (-16.4%)	12,292.8 (-9.8%)	6,025.3 (-21.4%)
2007	53,147.40 7.0%	** **	582.0 (-13.5%)	10,131.6 (75.4%)	11,364.9 (7.6%)	11,388.8 (3.1%)	13,243.9 (-2.8%)	6,157.4 (-19.7%)
2008	56,428.60 13.6%	** **	618.2 (-8.1%)	10,383.3 (79.8%)	11,867.1 (12.4%)	11,531.9 (4.4%)	14,189.0 (4.2%)	7,378.9 (-3.7%)

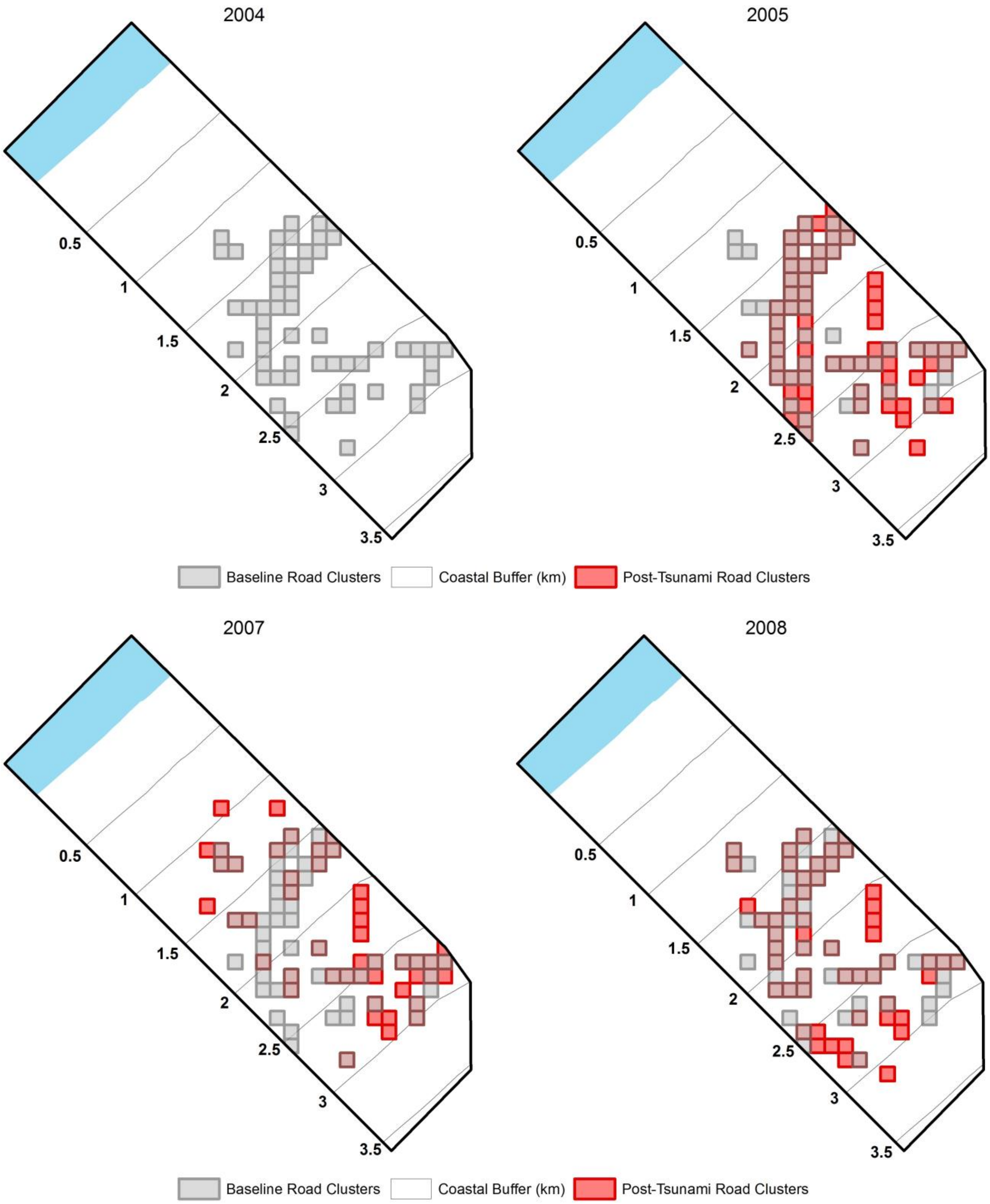


2. Road Network Hotspots

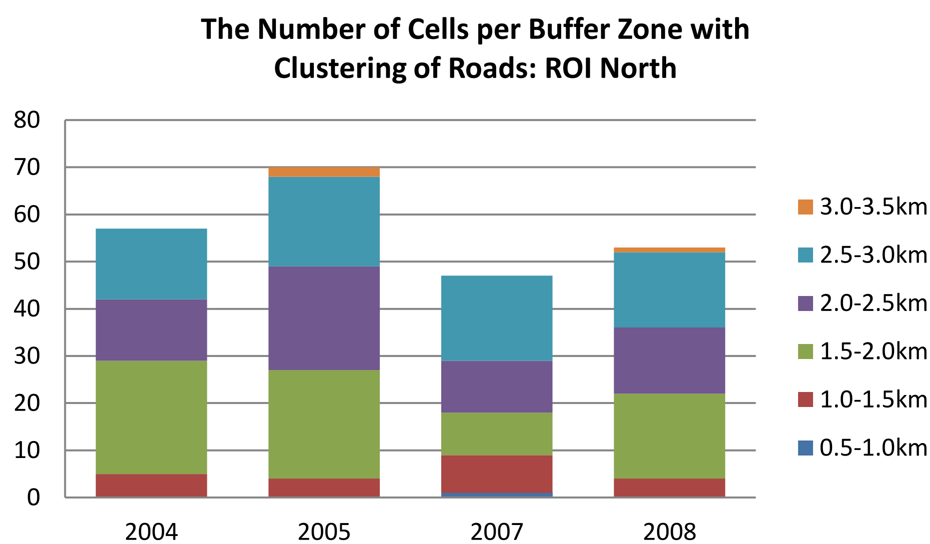
In 2004, clustering in the road network[36] was concentrated in the middle of ROI North, most heavily in the zone from 1.5 to 2.0km, followed by the two neighboring zones from 2.0 to 3.0km. After the tsunami, several of the clusters from 2004 closest to the coast ceased to exist. Otherwise, the road clusters in 2005 closely resembled those from the year before, with numerous additional hotspots running north/south between 2.0 and 3.0km. By 2007, however, the significantly clustered portions of the road network slightly diverged from 2004 and 2005. Road hotspots reappeared in the zone between 1.0 and 1.5km, including the same three cells that existed at baseline, while others between 1.5 and 2.0km were no longer present. Road clustering in 2008, however, more closely resembled that of baseline, while also including some of the later additions (such as those between 2.0 and 3.0km).

[36] Road clustering was measured via total road length per fishnet cell.

Road Clustering by Total Length in ROI North: 2004-2008



The Number of Cells per Buffer Zone that Cluster by Road Length: ROI North							
Year	0-0.5km	0.5-1.0km	1.0-1.5km	1.5-2.0km	2.0-2.5km	2.5-3.0km	3.0-3.5km
2004	0	0	5	24	13	15	0
2004	0	0	4	23	22	19	2
2007	0	1	8	9	11	18	0
2008	0	0	4	18	14	16	1

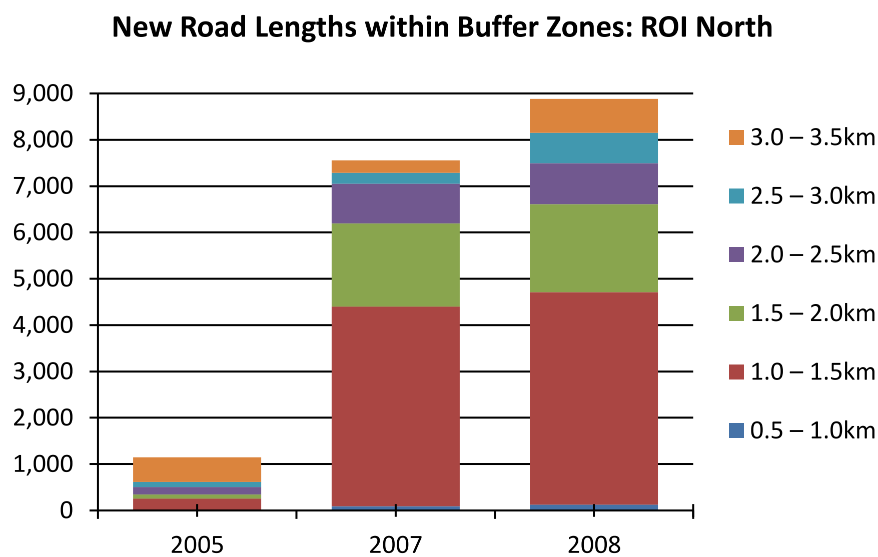


3. Road Network Expansion – "New Roads"

In 2005, there were relatively small additions made to the baseline road network in ROI North. There were no new roads in the two zones closest to the coast (0 to 1.0km), and between 86m and 258m of network expansion per zone between 1.0 and 3.0km. The largest addition of new roads occurred in the zone farthest from the coast (3.0 to 3.5km), totaling 530m. The proportions of new roads to total road lengths were also quite small, ranging from 1% to 9% of all roads in a given zone. By 2007, a substantial amount of growth had taken place between 1.0 and 1.5km, with over 4,300m of new roads (representing 43% of all roads for that zone). The neighboring zone (1.5 to 2.0km) added nearly 1,800m of roads, as well as over 850m of new roads between 2.0 and 2.5km. There was relatively little expansion in the two most-inland zones, each adding less than 300m, which represented a mere 2% to 4% of those zones' respective totals. While there was only 92m of new roads were added between 0.5 and 1.0km, there had been no existing road stock in that zone in 2005, and the growth represented 16% of the zone's total amount of roads. As a result of the cumulative nature of this analysis, very similar trends followed in 2008, as the zone from 1.0 to 1.5km had the largest amount of expansion to the 2004 network (4,585m, or 44%), and the remaining zones followed the same patterns as 2007.

"New Roads" vs Baseline Roads in ROI North: 2005-2008

New Road Lengths (m) and their Percent of All Roads within Buffer Zones: ROI North								
Year	ROI Total	0.0 – 0.5km	0.5 – 1.0km	1.0 – 1.5km	1.5 – 2.0km	2.0 – 2.5km	2.5 – 3.0km	3.0 – 3.5km
2004	**	**	**	**	**	**	**	**
2005	1,217.85 3.2%	0.0 **	0.0 **	258.4 7.4%	86.3 1.3%	160.6 1.7%	110.7 0.9%	530.0 8.8%
2007	7,568.50 14.2%	0.0 **	92.4 15.9%	4,308.0 42.5%	1,794.2 15.8%	857.1 7.5%	232.6 1.8%	273.4 4.4%
2008	9,017.82 16.0%	0.0 **	127.1 20.6%	4,585.2 44.2%	1,897.4 16.0%	886.7 7.7%	655.7 4.6%	728.7 9.9%

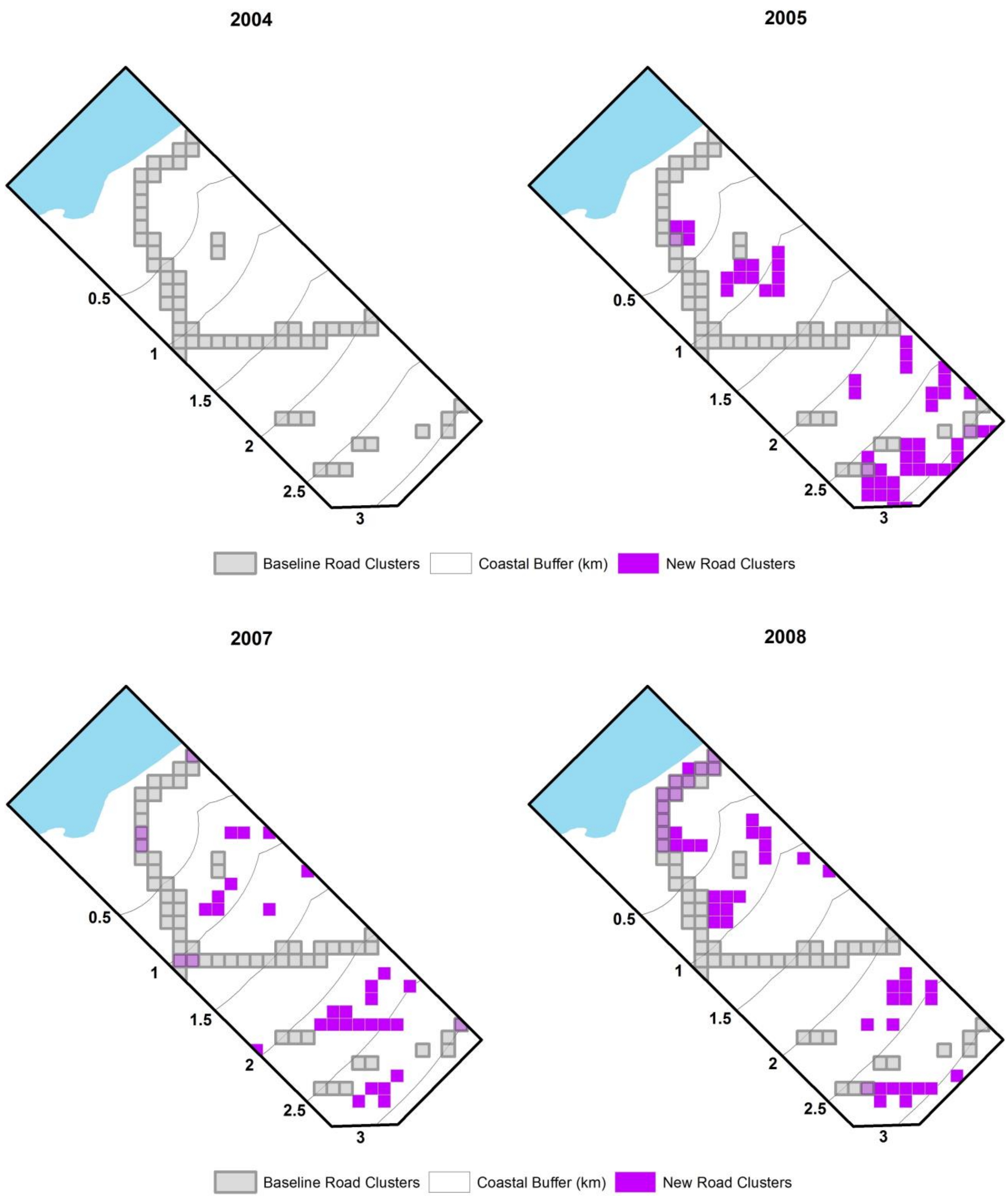


4. NEW ROAD HOTSPOTS

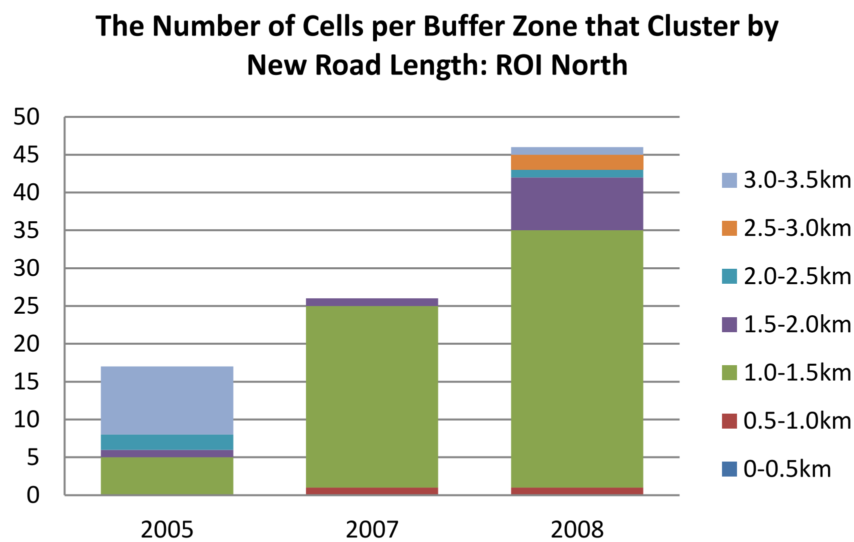
Clustering analysis was also performed for the post-tsunami additions to the road network. In 2005, there were few hotspots in the ROI as a result of the small amount of network expansion that year. The area between 3.0 and 3.5km had the largest number of new roads hotspots (9 cells), which was an area where no baseline clusters existed. There were five clusters in the zone from 1.0 to 1.5km, either overlapping or adjacent to baseline hotspots, and two clusters between 2.0 and 2.5km, which were in a large gap between baseline clusters. Hotspots were visible in even fewer zones by 2007, and far more concentrated between 1.0 and 1.5km (24 cells). These coastal hotspots appeared to expand the baseline network, filling in gaps in the baseline network throughout the buffer zone. There were also minor clusters between 0.5 and 1.0km (2 cells), and 1.5 to 2.0km (1 cell), adjacent to either 2005 or baseline hotspots.

Building upon the two previous periods, new road hotspots in 2008 were arranged in a similar fashion in the ROI. The new roads clusters were primarily located from 1.0 to 1.5km, extending closer to the coast than the baseline clusters had. There were also seven hotspots in the neighboring zone from 1.5 to 2.0km, either overlapping or in close proximity to baseline clusters. Minor clustering also occurred in the inland half of the ROI, adjacent to baseline clusters near the 3.0km zone boundary. Of the 46 hotspots in 2008, six overlapped with clusters from 2004, seeming to indicate that the 2008 “new” roads hotspots complemented and expanded the baseline network.

New Road Hotspots in ROI North: 2004-2008



The Number of Cells per Buffer Zone that Cluster by New Road Length: ROI North							
Year	0-0.5km	0.5-1.0km	1.0-1.5km	1.5-2.0km	2.0-2.5km	2.5-3.0km	3.0-3.5km
2005	0	0	5	1	2	0	9
2007	0	1	24	1	0	0	0
2008	0	1	34	7	1	2	1



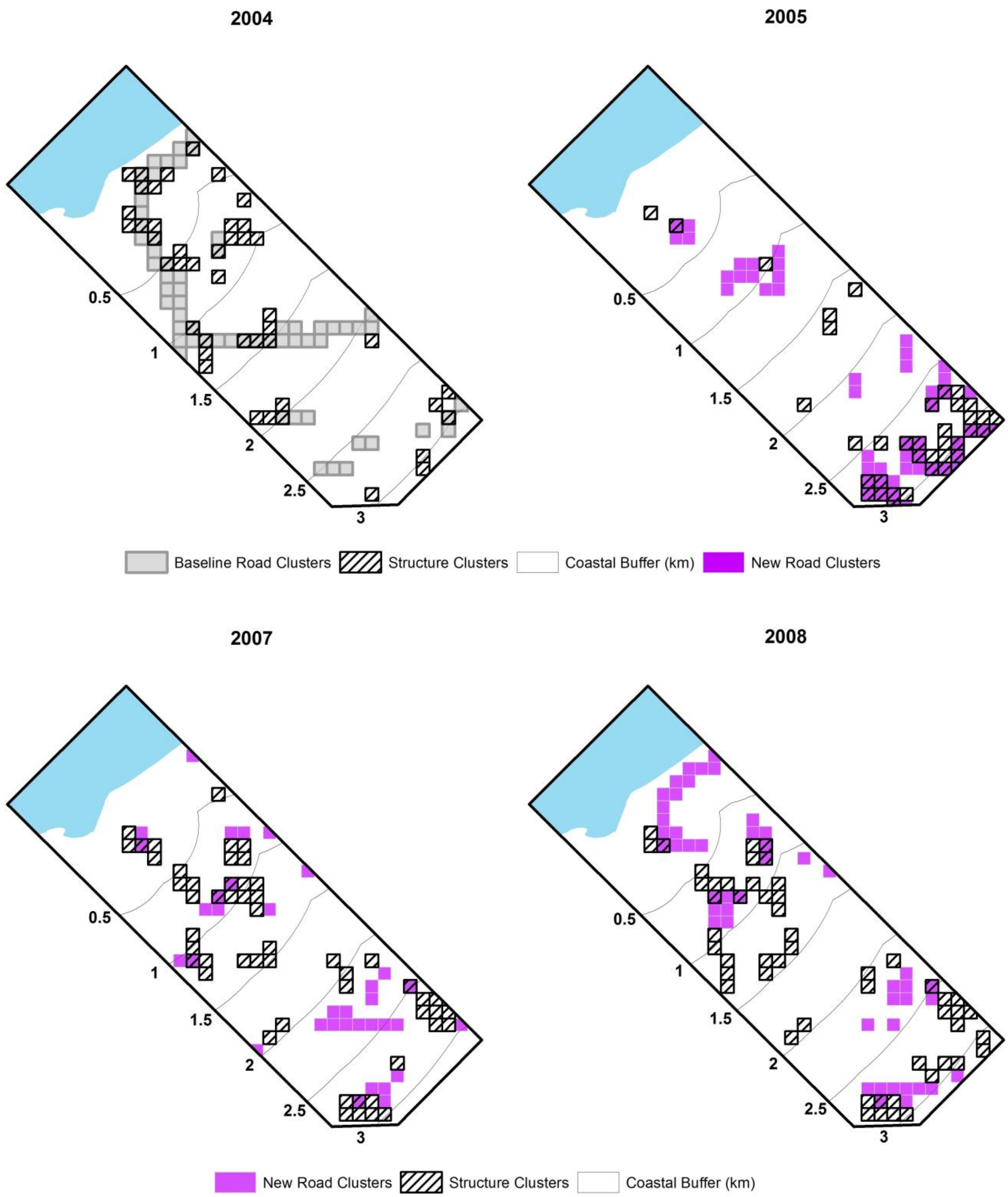
a. New Road Clustering versus Structure Clustering (by Count)

In 2005, structures were significantly clustered in the inland portions of ROI North (from 2.0 to 3.5km), and most of the new roads hotspots that year were in close proximity (aside from those between 1.0 and 1.5km). There were only two instances of overlap, while the remaining new roads clusters were to the north and south of the concentrated structure clusters. By 2007, the clustering patterns for roads and structures changed, with both types of hotspots occurring much closer to the coast. New roads clusters were concentrated in the two zones between 0.5 and 1.5km, while structure hotspots were dispersed between

1.5 and 2.5km, as well as a heavy concentration between 2.5 and 3.0km. There was minimal overlap between the two types of hotspots, although they were found in close proximity between 1.0 and 2.0km.

As the built environment changed further by 2008, there were more instances of overlap and adjacency between the two cluster types, again primarily between 1.0 and 2.0km. Structure hotspots were found in greater numbers in the middle of the ROI instead of solely in the most-inland portions. New roads clusters, though concentrated near the coastal areas, could also be found inland near the structure clusters between 1.5 and 3.0km. In sum, there were significant clusters of both new roads and structures closer to the coast compared to post-tsunami 2005, indicating reconstruction in areas that faced the greatest disaster impacts.

Structures and New Roads Hotspots: 2004-2008



5. Structure and Road Correlation

Pearson correlation coefficients were calculated for the structures (by count and by area) and roads (by length) of ROI North. Structure count was consistently moderately correlated with the total lengths of roads ("all roads") per fishnet cell in all periods. Structure area, however, slightly decreased in correlation with road length in the years examined (r = 0.3 in 2004, r=0.24 in 2008). However, in both cases, increases in structure count or area were correlated with increases in total road length from 2004 to 2008. Very different results were seen when only "new roads" (those that did not exist in 2004) were used in the analysis. There was almost no correlation between structure count and new road length in 2005 and 2008, except for a weak negative correlation in 2007 (r=-0.1). Structure area was moderately negatively correlated with new road lengths in 2007 and 2008. In these cases, increases in structure count or area were weakly to moderately correlated with decreases in new road lengths per cell. Therefore, although the presence of structures was correlated with that of all roads in a given fishnet cell, the same was not true for the newer, post-2004 road segments, where the relationship was reversed.

Correlation Coefficients for Structures (by Count, Area) and Roads (by Length): ROI North

Year	All Roads		New Roads	
	Structure Count	Structure Area (sq.m)	Structure Count	Structure Area (sq.m)
2004	0.33	0.31	**	**
2005	0.32	0.29	0.01	-0.03
2007	0.31	0.22	-0.13	-0.28
2008	0.30	0.24	-0.02	-0.24

III. *TAMBAKS*

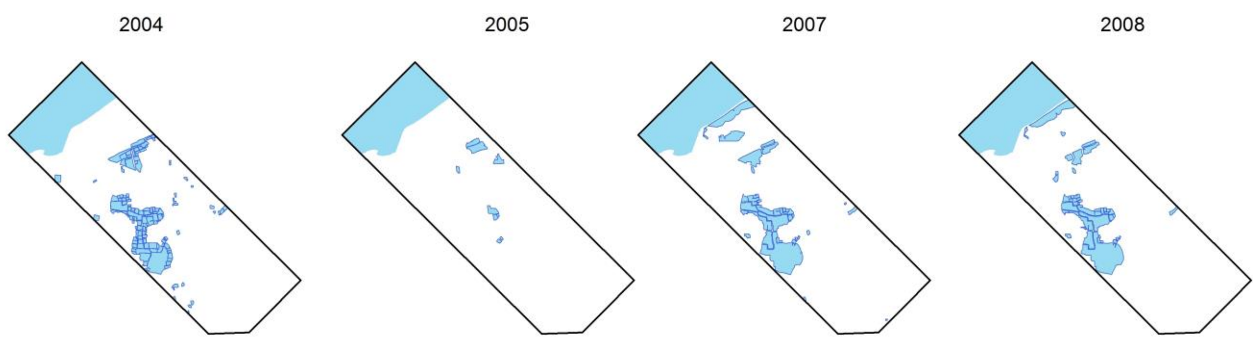
A. ROI SOUTH

1. COUNT AND AREA

a. ROI Totals

At baseline, there were 138 *tambaks* in ROI South, covering over 400,000 sq m. The tsunami had severe impacts on the aquaculture ponds, leading to a 93.5% drop in number and 86.2% decrease in total area for 2005. By 2007, while the number of *tambaks* was still well below the 2004 figure (down 70.3%), their total area was 10.5% greater than baseline. In 2008, there were two additional *tambaks* from the previous year, up to 43 in total; yet, due to changes in land uses, the total area fell 2008 to 415,892 sq. m, just 0.9% above baseline.

<u>*Tambaks* in ROI South: 2004-2008</u>



Tambak Count, Land Area, and Percent Change from Baseline: ROI South		
Year	**Count**	**Area (sq. m)**
2004	138	412,182.8
2005	9 (-93.5%)	56,827.3 (-86.2%)
2007	41 (-70.3%)	455,276.5 (10.5%)
2008	43 (-68.8%)	415,892.3 (0.9%)

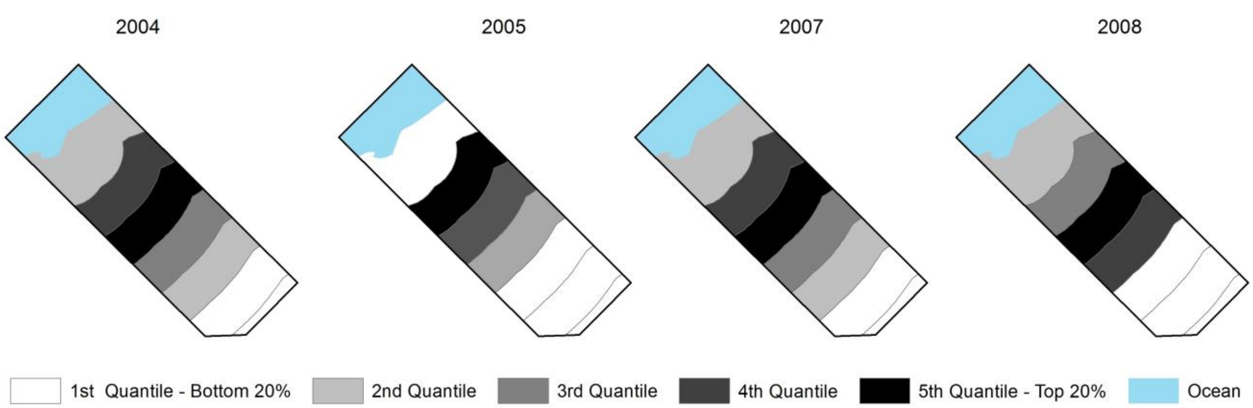
b. Buffer Zones

In order to examine the aquaculture ponds for the individual buffer zones, only *tambak* land area was used, as it could be more easily divided across zones than could their count[37]. In 2004, the zones with the largest areas of *tambaks* were between 0.5 and 1.0km, 1.0 and 1.5km, and 1.5 and 2.0km, while smaller *tambak* areas were found immediately adjacent to the coast (between 0 and 0.5km) and farther inland (2.0 and 2.5km). There were no tambaks within the inland zone from 2.5 to 3.0km for any time period. In 2005, following the impacts of the tsunami, *tambaks* were found in only three zones, each of which experienced large decreases in area: between 0.5 and 1.0km (down 68.0% from baseline), 1.0 and 1.5km (-90.1%), and 1.5 and 2.0km (-97.4%).

[37] For the buffer zones, *tambaks* are measured by area, and not count, for the ROI buffer zones, since some ponds would be arbitrarily divided between the zones due to their large size. For this analysis, the number of ponds is less important than the amount of land being used for the ponds, since it is the amount of productive land, and not the number of crop types that is being considered.

By 2007, much of the *tambak* land area in the coastal half of the ROI had been reclaimed. In particular, after lacking any of the ponds in 2005, the coastal zone between 0 and 0.5km increased 261.3% from baseline, to total more than 100,000 sq. m. However, while *tambaks* in the zone between 0.5 and 1.0km more than doubled in area since 2005, they were still 28.9% below the 2004 total. The next two zones grew substantially from the prior period, and each exceeded baseline by a small margin (6.4% and 3.3%, respectively). Although ponds in the inland zone from 2.0 to 2.5km recovered over 1,000 sq. m since 2005, the total area was significantly below baseline (-87.4%). These general trends continued into 2008, with relatively minor change between 0.5 and 2.0km. Despite the relative lack of change in those zones, the coastal zone between 0 and 0.5km lost over 30,000 sq. m from 2007 (down to 71,474 sq. m), yet was still 153% greater than its baseline total. In a reversal from 2007, the zone beyond 2.0km lost its pond area, representing a loss of 1,003 sq. m.

***Tambak* Area (sq. m) by Quantile: 2004-2008**

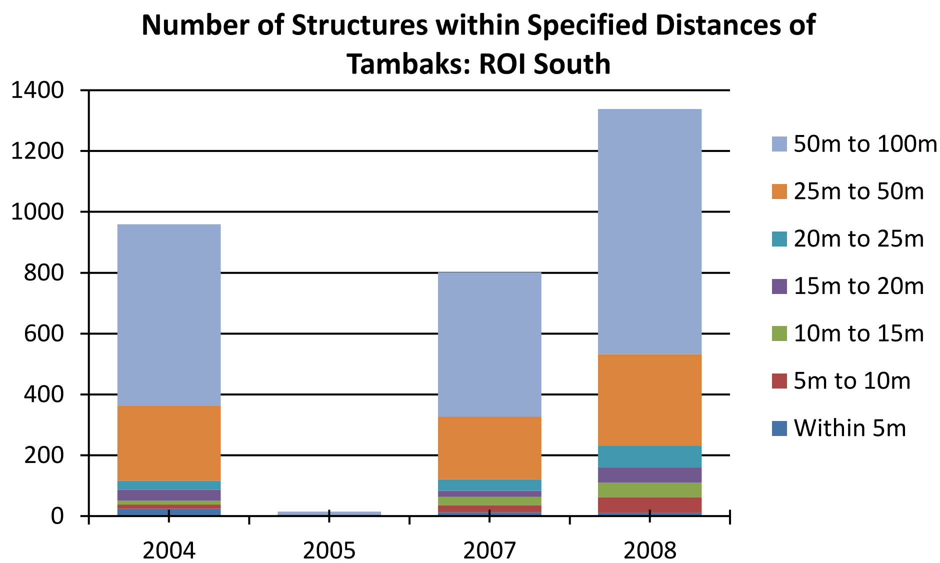


Tambak Area (sq. m) and Percent Change from Baseline within Individual Buffer Zones: ROI South							
Year	**ROI Total**	**0.0 – 0.5km**	**0.5 – 1.0km**	**1.0 – 1.5km**	**1.5 – 2.0km**	**2.0 – 2.5km**	**2.5 – 3.0km**
2004	412,182.8	28,258.9	125,847.8	138,223.9	111,582.8	7,975.6	**
2005	56,827.3 (-86.2%)	0.0 (-100.0%)	40,263.2 (-68.0%)	13,679.2 (-90.1%)	2,884.8 (-94.7%)	0.0 (-100.0%)	**
2007	455,276.5 (10.5%)	102,092.9 (261.3%)	89,477.7 (-28.9%)	147,024.0 (6.4%)	115,272.6 (3.3%)	1,003.0 (-87.4%)	**
2008	415,892.3 (0.9%)	71,473.6 (152.9%)	85,360.8 (-32.2%)	146,386.4 (5.9%)	112,671.5 (1.0%)	0.0 (-100.0%)	**

2. *Tambak* and Structure Proximity

The proximity of structures to the *tambaks* was also evaluated for each period. In 2004, relatively few structures fell within 25m of the ponds, totaling only 116, or 4% of that year's total. More than twice that amount fell between 25 and 50m (8%), and nearly 20% of that year's structures were between 50 and 100m of the *tambaks*. In 2005, due to widespread damage to the built environment, only 15 structures were within 100m of the ponds. Less than two years later, structure counts in 2007 resembled those of the pre-tsunami baseline, with 10% of the year's structures between 0 and 50m, and another 15% between 50 and 100m. By 2008, there were increases both in the number and proportion of structures near *tambaks* for nearly all distances (the exception being the area within 5m), and as a whole, over 35% of all structures were within 100m of the aquaculture ponds, versus 31% at baseline.

Number and Percent of Structures[38] within Specified Distances of *Tambaks*: ROI South								
Year	**Count**	**Within 5m**	**5m to 10m**	**10m to 15m**	**15m to 20m**	**20m to 25m**	**25m to 50m**	**50m to 100m**
2004	3085	24 (0.8%)	14 (0.5%)	13 (0.4%)	35 (1.1%)	30 (1.0%)	246 (8.0%)	597 (19.4%)
2005	673	1 (0.1%)	2 (0.3%)	1 (0.1%)	1 (0.1%)	0 (0.0%)	0 (0.0%)	10 (1.5%)
2007	3242	13 (0.4%)	23 (0.7%)	27 (0.8%)	20 (0.6%)	38 (1.2%)	206 (6.4%)	475 (14.7%)
2008	3812	11 (0.3%)	51 (1.3%)	49 (1.3%)	49 (1.3%)	70 (1.8%)	302 (7.9%)	806 (21.1%)

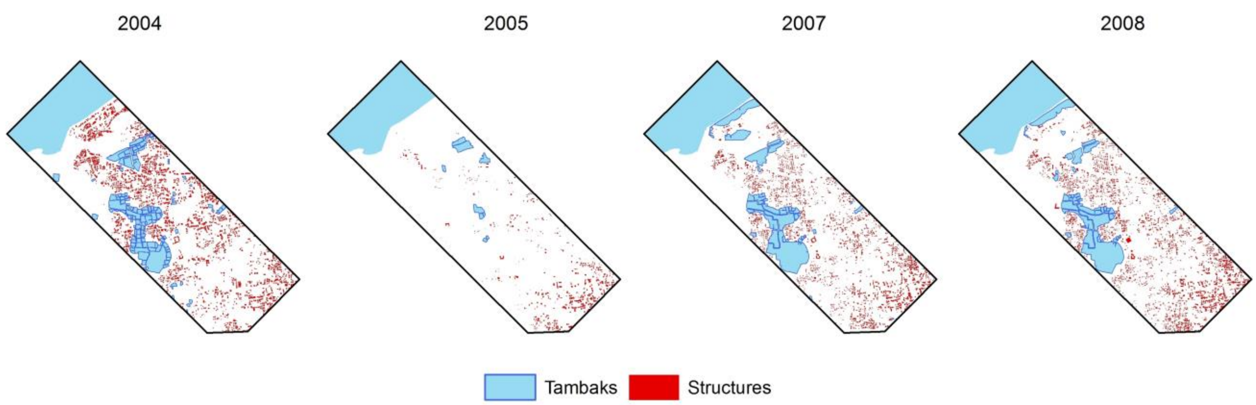


[38] The percentage represents the number of structures within a specified distance of *tambaks* out of all structures for that year.

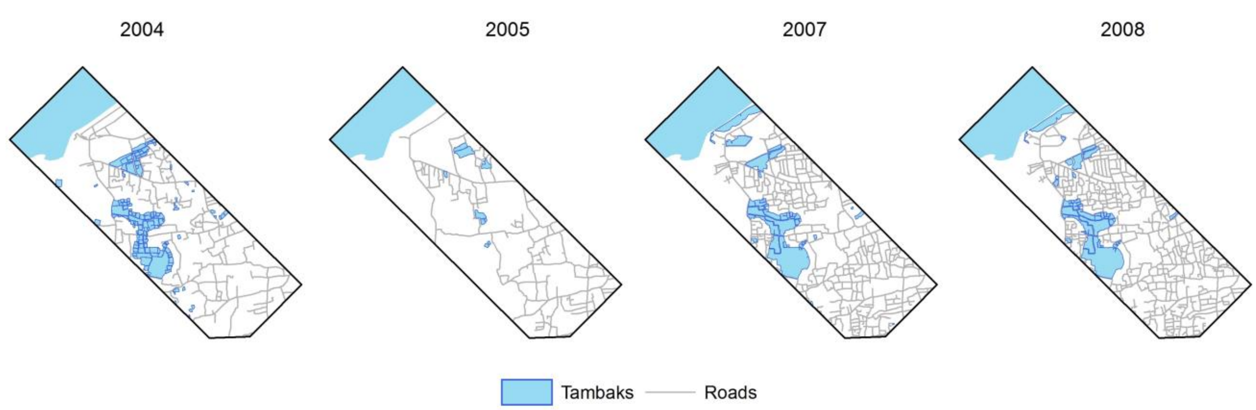
3. Geographic Distribution of *Tambaks*, Structures, and Roads

Tambaks were the most prevalent in the zones between 1.0 and 2.0km both at baseline in 2004, and in post-tsunami 2007 and 2008. The zone between 1.0 and 1.5km was also consistently among the highest for the count and area of structures in the same periods. Roads, however, were found in their greatest quantities in different zones, namely the neighboring areas from 0.5 to 1.0km, and 2.0 to 3.0km.

***Tambaks* and Structures in ROI South: 2004-2008**

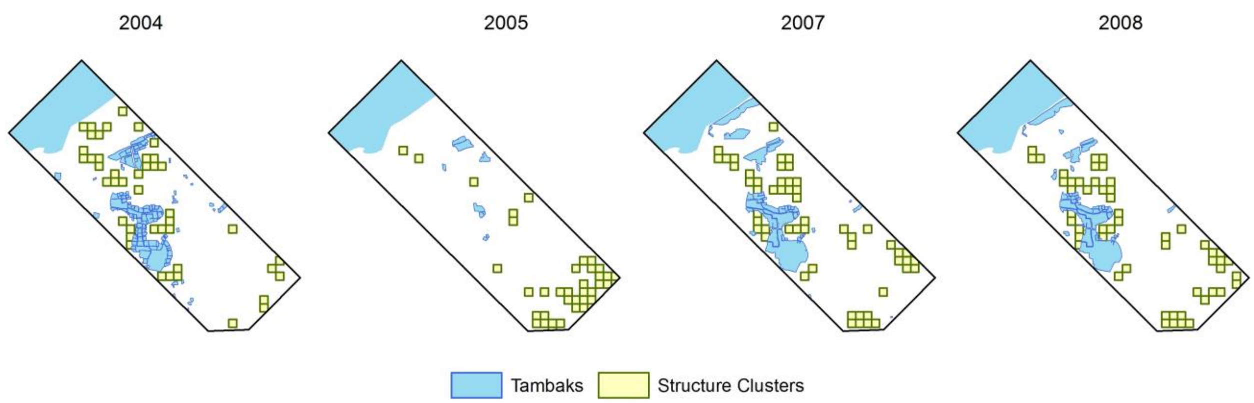


***Tambaks* and Roads in ROI South: 2004-2008**

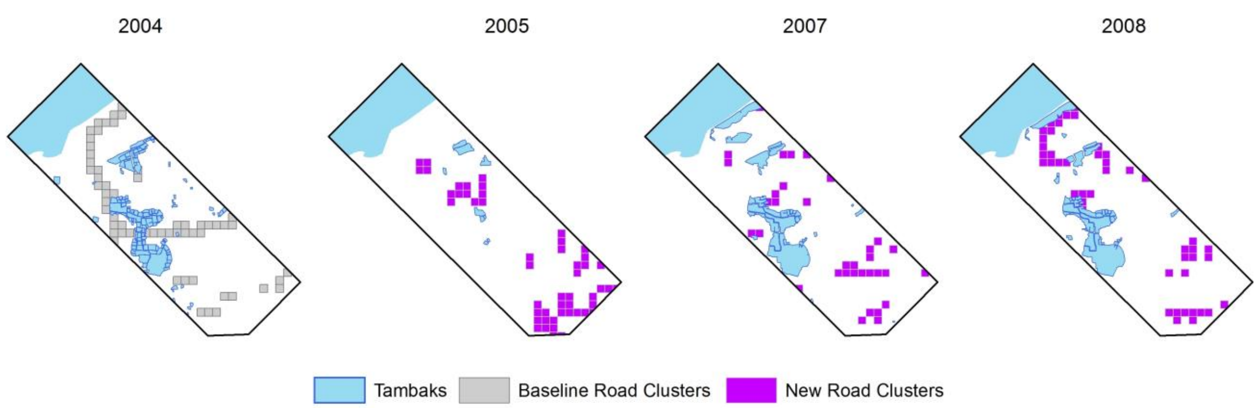


In terms of significant clustering, there were hotspots for both structures (by count) and roads (by length) around and between the *tambaks* at baseline. However, following the tsunami, there were no clusters of structures near the few remaining *tambaks*, and only a few hotspots of new roads in proximity to them (approximately 1.0km from the coast). Yet, by 2007 and 2008, although the spatial configurations of the *tambaks*, structures, and roads changed significantly since baseline in some locations, there were numerous clusters of both structures and new roads in close proximity to the rebuilt *tambaks*, as seen below.

Tambaks & Structure Clusters: 2004-2008



Tambaks & Baseline/New Road Clusters: 2004-2008



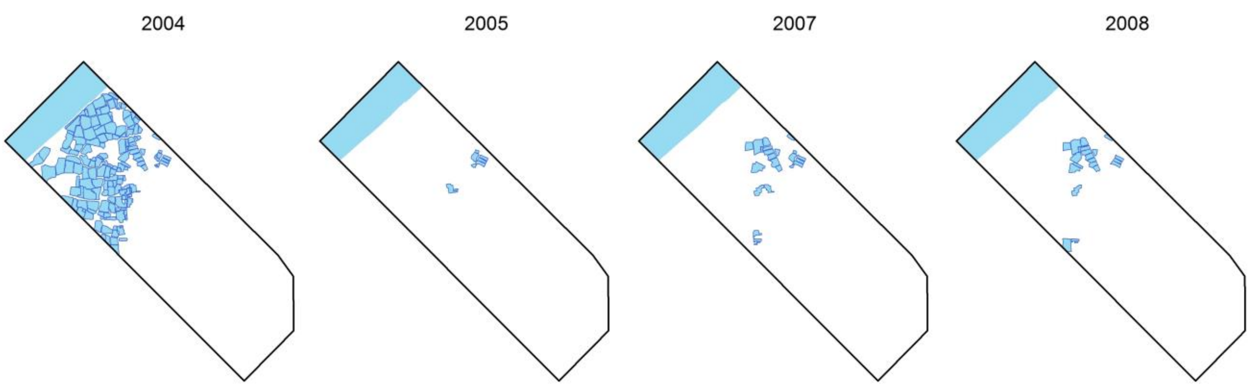
B. ROI NORTH

1. COUNT AND AREA

a. ROI Totals

The number and total land area of *tambaks* also decreased dramatically for ROI North following the tsunami. Between 2004 and 2005, the *tambaks* fell by 96% in number and 97.1% in area. There was little improvement over the succeeding years. Although the area of the *tambaks* had increased by nearly 100,000 sq. m in 2007, the total was still 87.5% below baseline. By 2008, there were still only 19 distinct ponds (down 87.2% from baseline), which covered nearly 120,000 sq. m (down 86.8%). Unlike in ROI South, the total area of the ponds did not recover and remained well below baseline by the end of the study period.

***Tambaks* in ROI North: 2004-2008**

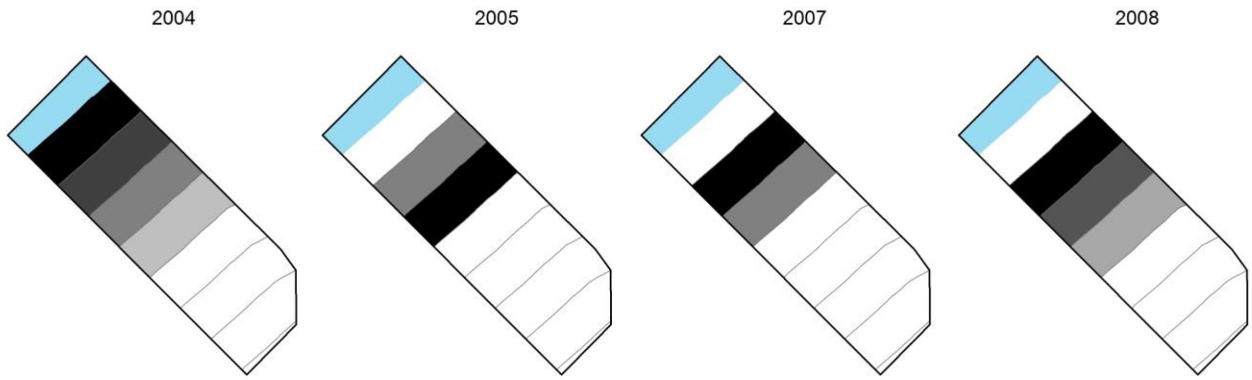


Tambak Count, Land Area, and Percent Change from Baseline: ROI North		
Year	**Count**	**Area (sq. m)**
2004	149	904,925.6
2005	6 (-96.0%)	26,333.1 (-97.1%)
2007	21 (-85.9%)	113,104.4 (-87.5%)
2008	19 (-87.2%)	119,867.2 (-86.8%)

b. Buffer Zones

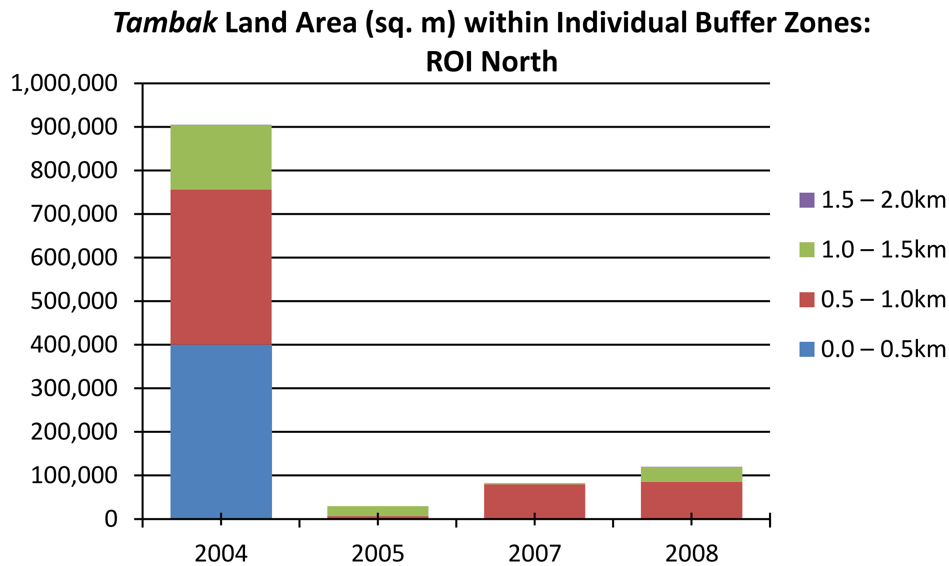
The *tambaks* in ROI North were confined to the areas closest to the coast, and none were found beyond 2.0km from the coast for any time period. In 2004, the largest amount of *tambak* area was between 0 and 0.5km (over 400,000 sq. m), and decreased with each zone moving inland. Following the tsunami, there were no *tambaks* between 0 and 0.5km, with just a fraction of the previous totals remaining between 0.5 and 1.0km (down 77.7% from baseline), and 1.0 and 1.5km (down 97.9%). In 2007, *tambaks* were still only present in those two zones, and although the total area between 0.5 and 1.0km increased by over 70,000 sq. m, pond area shrunk by more than 19,000 sq. m between 1.0 and 1.5km. By 2008, the *tambaks* in both zones increased in size, although they were still well below their baseline totals. This was accompanied by minimal expansion into the neighboring zone from 1.5 to 2.0km, as a small portion of one pond extended into the next buffer zone.

Tambak Area (sq. m) by Quantile: 2004-2008[39]



Tambak Land Area (sq. m) and Percentage Change from Baseline within Individual Buffer Zones: ROI North							
Year	**ROI Total**	**0.0 – 0.5km**	**0.5 – 1.0km**	**1.0 – 1.5km**	**1.5 – 2.0km**	**2.0 – 2.5km**	**2.5 – 3.0km**
2004	904,925.60	400,428.10	356,625.20	147,369.00	500.1	0	0
2005	26,333.10 (-97.1%)	0 (-100.0%)	6,907.30 (-98.1%)	22,557.50 (-84.7%)	0 (-100.0%)	0 **	0 **
2007	113,104.40 (-87.5%)	0 (-100.0%)	79,381.80 (-77.7%)	3,065.70 (-97.9%)	(-100.0%)	0 **	0 **
2008	119,867.20 (-86.8%)	0 (-100.0%)	85,894.30 (-75.9%	33,767.70 (-77.1%)	205.2 (-59.0%)	0 **	0 **

[39] This map layout is for illustrative purposes and not direct comparison. The data for 2005 and 2007 include only three values in each year (i.e., forming three quantiles), and could not be compared with 2004 (5 values) or 2008 (4 values). However, these maps are able to indicate where high/low values of *tambak* area were located within the ROI for each year.



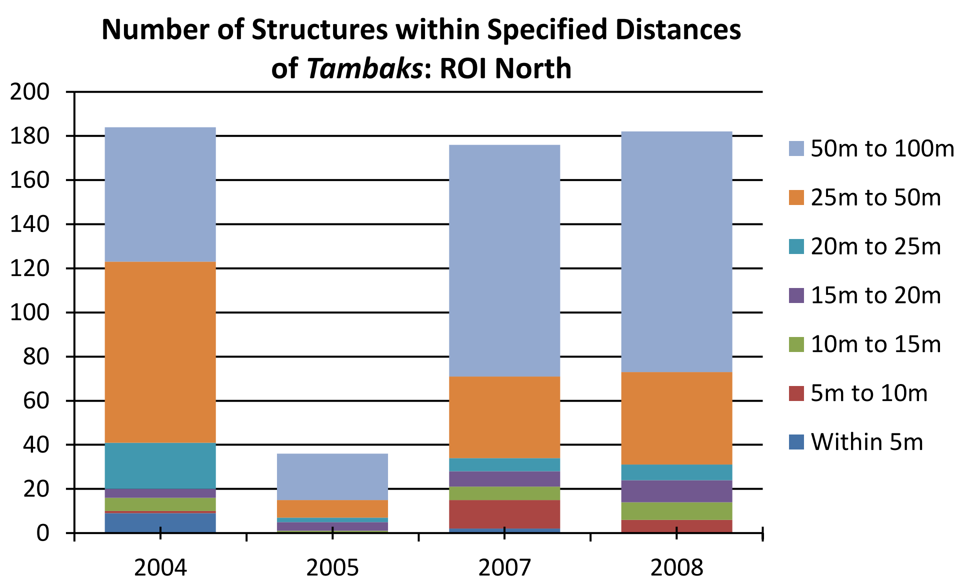
2. *Tambak* and Structure Proximity

For all time periods, few structures fell within 25m of the aquaculture ponds, although the greatest number in this range occurred at baseline (41 structures)[40]. There were also more structures between 0 and 50m of *tambaks* at baseline (123) than in the later periods (versus 71 in 2007, and 73 in 2008). Conversely, there were more structures between 50 and 100m in 2007 and 2008 (105 and 109, respectively) than at baseline (61). Yet, on the whole, the total number of structures within 100m of *tambaks* was similar at baseline (184, 3.2% of all structures) and in 2008 (182, 3.1%). Thus, while the total numbers and proportions of structures within 100m of the ponds were similar in the pre- and post-tsunami periods,

[40] In 2005, there were extremely few structures within the entire 100m range, particularly the distances less than 25m from the ponds (7 in total), causing it to be an outlier from the other three years.

more structures were farther away in the later periods than at baseline within that 100m distance.

Number and Percent of Structures[41] within Specified Distances of *Tambaks*: ROI North								
Year	**Count**	**Within 5m**	**5m to 10m**	**10m to 15m**	**15m to 20m**	**20m to 25m**	**25m to 50m**	**50m to 100m**
2004	5738	9 (0.2%)	1 (0.0%)	6 (0.1%)	4 (0.1%)	21 (0.4%)	82 (1.4%)	61 (1.1%)
2005	3643	0 (0.0%)	0 (0.0%)	1 (0.0%)	4 (0.1%)	2 (0.1%)	8 (0.2%)	21 (0.6%)
2007	6103	2 (0.0%)	13 (0.2%)	6 (0.1%)	7 (0.1%)	6 (0.1%)	37 (0.6%)	105 (1.7%)
2008	5858	0 (0.0%)	6 (0.1%)	8 (0.1%)	10 (0.2%)	7 (0.1%)	42 (0.7%)	109 (1.9%)



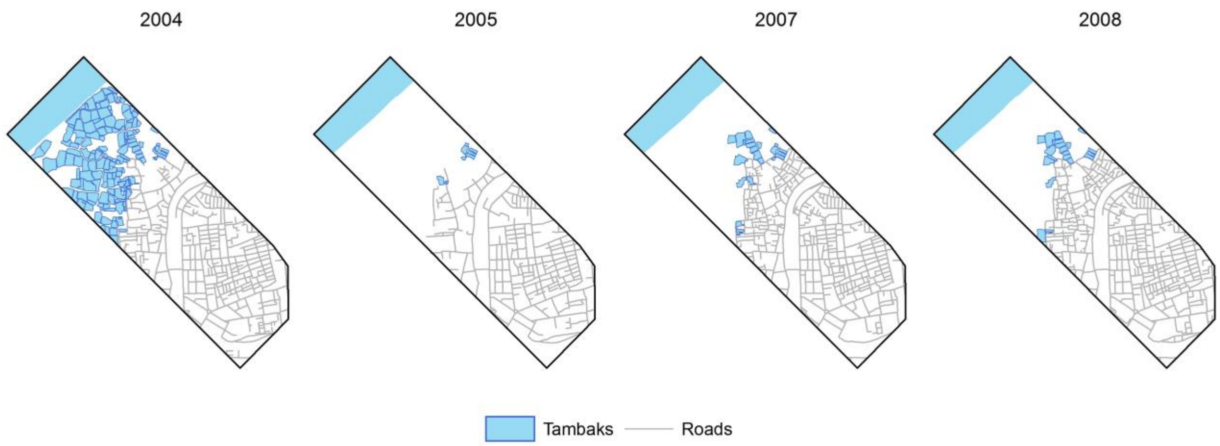
[41] The percentage represents the number of structures within a specified distance of *tambaks* out of all structures for that year.

3. Geographic Distribution of *Tambak*s, Structures, and Roads

ROI North differed substantially from ROI South in that its *tambaks* were located only in the portions closest to the coast. As a result, the ponds provide a similar geographic barrier as the ocean does, bounding the built environment at its northernmost limits. Although a small number structures and roads in each time period were located next to or between some of the *tambaks*, it was a rarity compared to the southern ROI, where roads would run between ponds or structures would be located to all sides.

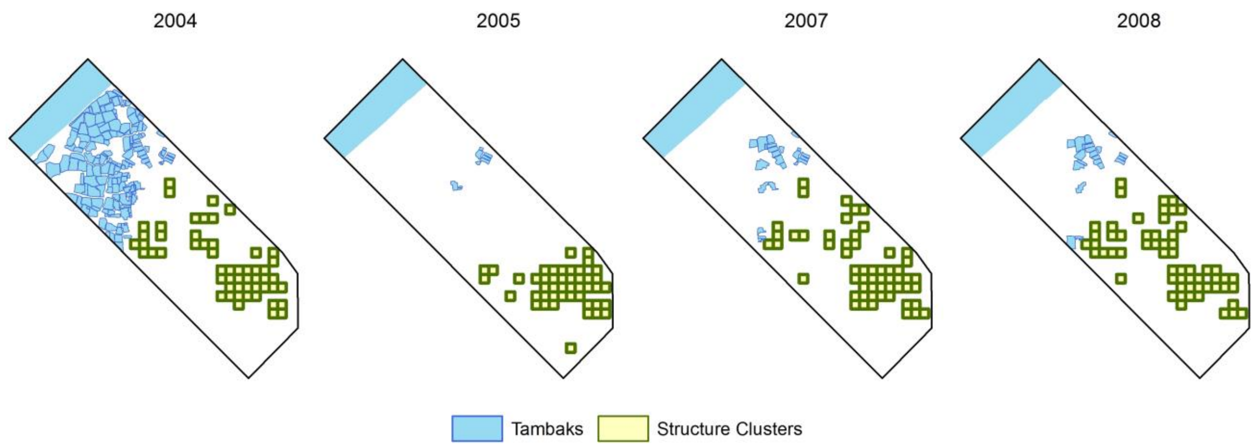
***Tambaks* & Structures in ROI North: 2004-2008**

<u>*Tambaks* & Roads in ROI North: 2004-2008</u>

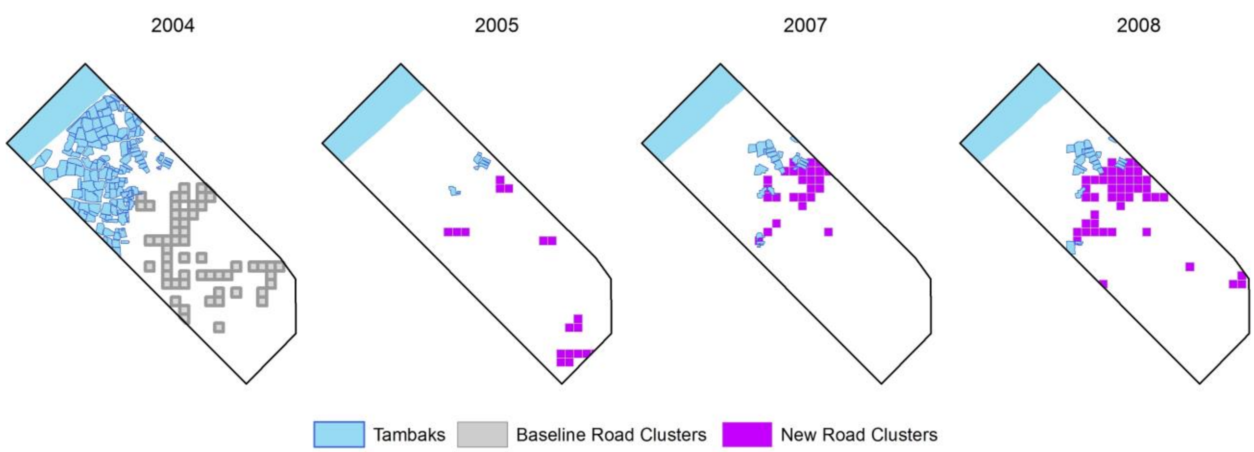


Very little clustering of structures (by count) occurred in close proximity to the *tambaks* of ROI North. In 2004, 2007, and 2008, there was only one structure hotspot immediately adjacent to a *tambak*, with several others adjoining that cell. As noted, structures were predominantly clustered much farther inland in each of the time periods. This finding matched those from the structure proximity analysis, where most individual structures were located more than 100m from a *tambak*. However, in 2007 and 2008 there were numerous clusters of new roads were adjoining the *tambaks*.

Tambaks & Structure Clusters: 2004-2008



Tambaks & Baseline/New Road Clusters: 2004-2008



IV. SUMMARY AND CONCLUSION

Using satellite imagery, GIS data, and spatial analyses, it was possible to assess the reconstruction of structures, roads, and aquacultural ponds in Banda Aceh. Multiple types of measurement were used, ranging from quantification by count/area/length, to feature proximity, to spatial statistics. Overall, while there were gains, there were also substantial losses. The sections below summarize the major findings and provide several conclusions based upon them.

ROI SOUTH

Several years after the tsunami's devastating impacts, the southern study area (ROI) in Banda Aceh exceeded its pre-disaster totals for both structures and roads. By 2008, the number of structures increased nearly 25% above the pre-disaster baseline, and nearly 90% were within 10m of their pre-tsunami counterparts. However, while the total count of structures was greater in 2008 than in 2004, buildings were more than one-third smaller on average. This change in mean area may have allowed more structures to be built on the same pieces on land; however, such decreases in size may have impacted the maximum number of users, or limited a buildings' utility.

In addition to the increase in structures, the total length of roads more than doubled in the same period. A higher proportion of structures were also in closer proximity to roads, which in combination with the increase in road lengths, may have enhanced personal mobility and access throughout the ROI. Extension of the road network in the post-disaster periods may have also enabled further reconstruction by allowing for greater transportation of people and materials. Similarly, the ROI's *tambaks* rebounded in total land area following the huge losses from the tsunami's impacts, despite a large change in their total count. Proportionally more structures were within 100m of *tambaks* as well, potentially resulting in greater convenience or access to the ponds.

Zonal Differences

Reconstruction was not uniformly distributed throughout the region, despite the overall trends for the ROI. The portion of the ROI closest to the ocean faced the highest tsunami-related losses in the number and area of structures, and by 2008, the zone adjacent to the coast still remained below its pre-disaster total. Conversely, in the same periods, the zone farthest inland grew the most in structure count and was the only zone to increase in total structure area. This pattern was mirrored in changes in structure density across the zones, with increased density occurring at greater distances from the ocean. Significant clustering of structures also increased over time, particularly in the most-inland zone, while clustering decreased in the coastal zones. These patterns were non-random events, indicating that the patterns in reconstruction occurring inland weres not merely by chance. These findings contribute to the conclusion that there was a clear shift within the ROI for development and reconstruction in the areas farthest from the coast in ROI South.

Changes in the ROI's roads were unevenly distributed. Although there was substantial growth of roads overall, the greatest increases occurred in the middle of the ROI and those areas farthest from the coast. The distribution of roads changed from the pre-disaster period as a result, with proportionally fewer roads near the coast, and more roads farther inland. While the decrease in roads along the coast may have hindered mobility and access in the area to a degree, the impacts may have been somewhat offset by the sharp decline in the number of structures in the same part of the ROI, potentially reducing the demand for their use. Conversely, the increase of inland roads accompanied the growth in structures and rise in density, likely improving mobility in the areas with the greatest amount of reconstruction, and potentially greater demand for road travel.

Last, despite the drastic impacts of the tsunami, the *tambak* aquacultural ponds were reconstructed to resemble their pre-disaster distribution by the end of the study period. The overall arrangement of the ponds in 2008 was very similar to that at baseline. Contrary to the reconstruction trends of the structures and roads, which fared poorly close to the ocean, the *tambaks* nearest the coast more than doubled their baseline total area. This large increase was able to offset the decrease in tambak area in the neighboring zone, and the complete loss of ponds in the zone farthest inland. In addition, by 2008, there was also a greater proportion of structures within 100m of *tambaks* than at baseline, and this improvement in proximity may have enhanced the population's access to the ponds.

In sum, post-tsunami ROI South was essential "built back" to, and exceeded, its 2004 baseline standards. The region contained more structures, greater total length of roads, greater access to roads, and an equivalent amount of *tambak* area. Despite such increases, the redistribution of structures throughout the region, the higher density, and smaller structure sizes may have provided problems of their own.

ROI NORTH

While similar in some respects, reconstruction in ROI North was distinct from that of its southern counterpart by more closely resembling its pre-disaster state rather than changing drastically. By 2008, the amount of structures (both by count and total area) in the region had returned to baseline levels. Relative to ROI South, there were much smaller changes in structure density and mean structure size in the northern study area, which remained far closer to their pre-disaster levels versus those in the south. Likewise, nearly 99% of structures were within 10m of their baseline counterparts. Therefore, despite some changes, ROI North as a whole had a very similar inventory of structures in 2008 as in pre-tsunami 2004.

More strikingly, the amount of roads in the ROI surpassed the pre-disaster level, extending the road network throughout the region. Additionally, greater numbers of structure were in closer proximity to roads, further enabling the population's mobility and access in the ROI. Conversely, *tambaks* in ROI North suffered greatly and far less reconstruction or rehabilitation had occurred by 2008. While the *tambaks* in ROI South returned to a total area similar to baseline, both the count and area of *tambaks* decreased substantially in ROI North, potentially resulting in losses of productivity or economic well-being.

ZONAL DIFFERENCES

Like ROI South, reconstruction did not occur in a uniform manner in the northern region of interest. By 2008, the zones proximate to the coast had lower structure counts and total structure areas for all periods, below or near their baseline figures. Meanwhile, the inland zones of ROI North generally increased in total structure area, in addition to having far larger mean structure sizes. Significant clusters of structures (both by area and count) were greatest in number in the zone farthest inland, evidence that the reconstruction in that part of the ROI did not simply occur by chance.

However, unlike the inland bias in the distribution of structures, the roads of ROI North were more heavily concentrated in the middle of the study area. The largest increase in road coverage occurred roughly one kilometer from the coast, where more than forty percent of roads in 2008 were "new roads" (i.e. those that did not exist in 2004). While there was significant clustering of "all roads" (2004 roads plus the later additions) throughout the ROI for most periods, the "new roads" were consistently clustered closer to the ocean. The increased clustering near the coastal zones may have supplemented lacking infrastructure from the pre-disaster period, or met new needs in the region. The lack of new road infrastructure inland may have been a result of lesser impacts from the tsunami due to increased distance from the coast, or that portion of the network was already sufficient to meet local needs and required fewer additions to that of baseline.

Last, the *tambaks* of ROI North were located solely along the coast, forming a northern boundary for the study area. Although there was a substantial decrease in the number and total area of the *tambaks*, they remained constrained to the coastal portion of the ROI for all periods. The large losses in *tambak* area may have resulted in negative impacts on the local economy, effecting the area's productivity and wellbeing of the population.

Altogether, ROI North returned to a state similar to that of its 2004 baseline with respect to structures and roads. Although the coastal areas remained below baseline in several respects, the overall region was very close to pre-disaster levels for the count, area, and density of structures. Roads throughout the ROI increased, particularly in areas closer to the coast that had previously lacked network coverage. However, unlike ROI South, there were still considerable losses of *tambak* area by 2008, potentially with very real consequences for the region.

CONCLUSION

While the two regions of interest had their own sets of findings, some general conclusions may be drawn. The first of which is the role of distance from the coast. Inland portions of the ROIs experienced relatively low rates of loss, increased structure reconstruction, and consistent clustering of structures. These findings indicate a preference (or compulsion) for the placement of structures in areas that were farther from the ocean. This makes intuitive sense for several reasons. First, land near the coast may have been less suitable to build on due to seawater inundation and damage to the environment; similarly, land at greater distances from the ocean were likely less affected and therefore more suitable to build upon Next, the tsunami may have spurred shifts in local knowledge, behaviors, or public policy dissuading rebuilding in the most disaster-susceptible parts of the city (Birkland 1997; Djalante et al. 2013; O'Brien et al. 2010). Regardless of the exact driving factors, greater development farther from the coast was a positive result, contributing to protective effects and impact mitigation in potential future disasters.

It is also important to assess the overall degree of reconstruction that occurred in Banda Aceh. At bare minimum, was the pre-disaster amount of infrastructure rebuilt? The answer to this question is "Yes" for the most part, as both structures and roads met and exceeded their 2004 totals in both study areas. As previously described, not only was there a return to baseline, but there were large increases in structure counts and road lengths. In addition, *tambaks* in ROI South did return to their pre-disaster total area, though not in count. Therefore, aside from the loss of productive area in the northern region, the examined portions of Banda Aceh returned to their baseline status.

However, despite "building back" to and beyond its previous state, there were changes in the two ROI that may have had real impacts on the local populations. The redistribution of structures had the overall benefit of increasing structures' distances from the coast and mitigating future impacts. Structures' improved proximity to roads and extensions in the road network may have had positive consequences by enabling greater mobility. Yet, the geographic shift inland, the decreased structure sizes, and increased densities may have caused "quality of life" impacts or externalities for the population (such as greater inconvenience in daily life, greater travel times, cramped living/work quarters, noise pollution). Although not examined in this study, extant research and reports have also identified problems in the reconstruction process, including the quality of structures, delayed building, and the lack of suitable infrastructure (Boen 2006; Kennedy et al. 2008; Masyrafah and McKeon 2008; United Nations Children's Fund 2007). Therefore, it is essential for planners and policymakers to not only ensure the right amount of reconstruction occurs, but that it also occurs in a proper fashion (e.g., through community participation, prioritizing local appropriateness, and well-coordinated actors).

Chapter 6: Discussion

Multiple institutions and scholars have recounted the complex story of the reconstruction of Banda Aceh, Indonesia. They have noted weaknesses or failures in the process, as well as assessments of the reconstruction as a whole (Arie 2009; Boen 2006; Da Silva 2010; Jayasuriya and McCawley 2010; Masyrafah and McKeon 2008; Steinberg 2007; World Bank 2012). Instead, this project aimed to examine the reconstruction process temporally and spatially in two specific regions in Banda Aceh, Indonesia. Two of the study's guiding research questions focus on the quantification of reconstruction, while the third centers on the institutional factors that contributed to the reconstruction effort. Understanding how the reconstruction took place and what the driving forces and crucial processes were will provide insight for future disaster responses. This section will compare the key findings from the previous chapter to this study's hypotheses; discuss the significance of these findings; and suggest recommendations for post-disaster reconstruction policy and practice.

I. Spatial factors and the reconstruction process

Hypothesis: Increased distance from the coast was associated with higher reconstruction rates

Human settlements are too frequently built in close proximity to potential hazards such as on flood plains, hillsides, or in the case of tsunamis – areas adjacent to the ocean (Bernstein 1992; Lall and Deichmann 2012; Taubenböck et al. 2011; Texier 2008). I hypothesized that post-disaster reconstruction would involve better planning and greater disaster mitigation measures, and therefore predominantly occur farther from the coast than what existed at baseline.

As detailed in the previous chapter, evidence from the southern region of interest (ROI South) clearly supports the hypothesis. The largest amount of structure reconstruction occurred in the two zones farthest inland, while the smallest amount occurred nearest the coast. Such building patterns yielded a considerable shift inland compared to the distribution of structures at the pre-disaster baseline, as well as an increase in the density of structures in the inland areas. The majority of the statistically-significant clustering of structures in the ROI was also found in the zone farthest from the coast, which again represented a dramatic change from the baseline arrangement of structures. Similarly, the reconstruction of roads followed suit, with the largest increase in road length occurring in the area farthest from the coast, while decreasing in the zone immediately adjacent to it. Road clustering was also the greatest in the most-inland areas, which served to connect clusters of structures. Together, these findings indicate that reconstruction of structures did in fact occur with greater distance from the coast, supporting the first hypothesis.

In the northern region (ROI North), a comparable, but less striking, pattern was observed. By 2008, only the zones in the middle and inland portions of the ROI had growth in structure count or area, as well as in structure density, while those zones near the coast were consistently below baseline. In particular, the zone farthest inland experienced the greatest increase in total structure area, while the coastal zones' totals were all substantially lower than baseline. Statistically significant clusters of structures also corroborate this finding of an inland bias. Such clusters did not occur in the two zones nearest the ocean in any year, while the greatest number of clusters was found 2.5 to 3.0km from the coast throughout the study period. Similarly, the largest quantity of roads ("all roads") in ROI North was within that same inland zone, and additional road clusters arose in the middle and inland portions of the ROI.[42] Therefore, the first hypothesis was supported by the findings from both regions of interest, particularly ROI South.

The ramifications of this finding are very positive for Banda Aceh. First, the lack of substantial development in the most hazardous areas, i.e. those closest to the coast, would put fewer people and less infrastructure at risk in the event of a future tsunami. A focus on "building back better" is one of the basic tenets of recent disaster literature, such as incorporating disaster mitigation measures into post-disaster reconstruction and rehabilitation (Arie 2009; Kennedy et al. 2008; Lyons 2009). As seen in the findings from 2005, losses were much lower in the zones farther from the ocean. Therefore, by locating the reconstruction of structures inland, particularly at greater distances from the coast, a measure of protection was provided. The non-random nature of structure cluster locations lend evidence that such mitigation measures were taken, whether implicitly or explicitly part of the reconstruction plan or design.

<u>Hypothesis</u>: Reconstruction was clustered, it was not randomly distributed

Accounting for the role of topography and existing geographic features (such as roads), it was hypothesized that reconstruction of structures would cluster spatially rather than in a

[42] However, the "new roads" in the northern study area were most numerous in the middle of the ROI, and not the zones farthest inland.

dispersed or random manner. In addition, survivors of the tsunami would likely wish to return to their own plots of land, and settlement relocation may be resisted or have negative consequences (Ingram et al. 2006; Mulligan and Nadarajah 2011). As a result, structures were hypothesized to be located in/near their original sites. In the cases where original plots were unusable, reconstruction would occur elsewhere in the vicinity (e.g., in same *kampung*, or village) or in neighboring areas where possible. For example, if coastal land became unusable or untenable, structures would be rebuilt farther inland.

According to the findings, both structures and roads were found to have statistically significant clustering in both regions of interest and were not randomly distributed. Structures were clustered by their location in each of the zones of ROI South, as well as the region as a whole, for all time periods examined. The Northern ROI as a whole was clustered in all years examined, while only one of the zones was also clustered for the entire study period. Although additional zones were clustered for one or more years, they were either dispersed or randomly-distributed in other years. Regardless of the mixed findings, there was indeed statically significant spatial clustering in both study areas at the ROI and buffer zone level in the period between 2004 and 2008.

In addition, significant clustering by value (structure count and area) was also present when a smaller unit of analysis (i.e. fishnet cells) was used. These clusters, based on the total number of structures or total structure area per cell, were more prominent in certain portions of the ROIs. Though slightly different patterns emerged for clustering by count versus clustering by area, both types of structure clustering decreased in the zone closest to the coast and increased in the zone farthest inland. Specifically, in ROI South from 2005 to 2008, there were clusters (of both types) that occurred in the same locations in all three years examined, almost exclusively in the zone farthest from the coast. Likewise, in ROI North, there was a clear pattern of clustering in the two inland-most zones, with overlapping location for all three years.

Similar to the structures, there was also significant clustering for roads (both “all roads” and “new roads”), as determined by total road length per fishnet cell. In ROI South, there was significant clustering in all zones for each of the time periods, and the overall distribution of the road clusters was similar at both baseline and 2008. In ROI North, there were also clusters of roads, though not in all of the buffer zones. Clustering was primarily limited to the middle and inland zones of the ROI, with little to no clustering in the two zones closest to the ocean and the zone farthest from it.

In the case of Banda Aceh, the significant clustering demonstrated an important shift away from the baseline distribution of the built environment (e.g., the hazard-prone coastline). The non-random locations of structures and roads indicate that there was likely some factor(s) driving reconstruction to these areas and it was not merely chance that they were being relocated inland instead of near the ocean. The clustering of these features was likely also a product of the reconstruction process itself, with NGOs or contractors opting for efficiency and/or economies of scale.

The second hypothesis could not be disproven based on the above findings, as there were indeed statistically significant clusters of both structures and “new roads” in the two ROIs. The existence of such clusters illustrates where concentrated reconstruction occurred, rather than random or uneven development. Likewise, the presence of dispersed or randomly-distributed structures or roads does not invalidate the existence of significant clusters; instead, these may be used as signals for locations where additional or improved development could take place if needed.

Hypothesis: Reconstruction of road infrastructure was positively correlated with structure reconstruction

Reconstruction is a resource-intensive activity, labor and materials playing crucial roles in rebuilding or repairing structures or infrastructure. Road networks provide conduits for the delivery of such resources, with the lack of access to reconstruction sites resulting in delays (Arie 2009). However, following a disaster, roads may need to be built or rebuilt in order to reach such locations. Hence, it was hypothesized that the construction/reconstruction of road infrastructure would be linked or correlated with that of structures.

The existence of a spatial link between the two phenomena was first assessed via the use of statistically significant spatial clusters of structures (by count) and "new roads".[43] In 2005, new roads in ROI South were significantly clustered both in the same cells and around structure clusters, particularly in the inland portions of the ROI. As the reconstruction effort continued into 2007, while there was less direct overlap between the two, clusters of new roads remained adjacent to structure hotspots, seeming to bridge gaps between structure cluster groups that did not exist at baseline. This trend continued into 2008, as

[43] "New roads" are those roads in 2005, 2007, and 2008 that did not overlap with any roads from the 2004 baseline, and thus are new additions to the respective road networks.

new road clusters connected and filled in areas structure clusters. In ROI North, similar trends were also seen in the same time period, although to a lesser extent. While there are fewer instances each year of direct overlap, the two cluster types were consistently adjacent to and around each other. In sum, during the three post-tsunami periods, there is evidence that newly-constructed roads were located in/around significant clusters of structures, thereby supporting the hypothesis.

To further explore this hypothesis, tests for statistical correlation were performed for the quantity of structures and roads per cell in the two study areas. There was weak to moderate positive correlation between structures and "all roads," for both ROIs in all periods. In particular, in ROI South, there was a moderate positive correlation at baseline (2004), and again by 2008; meanwhile, in ROI North, structures and roads were moderately correlated throughout the period from 2004 to 2008.[44] That is, for an increase in the number of structures or amount of structure area, there was also a moderate increase in the amount of roads in a given cell.

Different results were found for the correlation between structures and "new roads." In ROI South, there was a decrease from moderate to weak positive correlation between the two in ROI South from 2005 to 2008. However, there was a primarily negative correlation between structures and "new roads" in ROI North, meaning that increases in structures were correlated with decreases in the amount of new roads. While this may seem

[44] For ROI South, these findings apply to both structure count and structure area per cell. For ROI North, the moderate correlation was only between structure count and all roads, and not structure area per cell.

counterintuitive or undesirable, this finding corroborates that from comparison of cluster locations, where "new roads" were found to bridge gaps between structure clusters. It also indicates that roads from 2004, which may have been damaged and repaired (which were not captured in the "new roads" category) continued to play a major role in the placement of structures and thus factored into the positive correlation seen with "all roads."

The positive correlation between all roads and structures (particularly structure count), supports the hypothesis, that road and structures reconstruction were linked/correlated. However, the nature and locations of the "new roads" resulted in weak positive (ROI South) to weak negative (ROI North) correlation with structures, and thus did not support the hypothesis.

II. SIGNIFICANCE

Given the findings, did the reconstruction effort benefit Banda Aceh, and were the afflicted areas better off than their pre-disaster states? These questions may matter the most when assessing the success of such a process. The Indonesian government's Master Plan for the reconstruction aimed to restore "cities to their initial states of order" (Government of Indonesia 2005), and it was successful in doing so for both structures and roads in the two study areas. However, "building back better"[45] may be considered the true goal of modern

[45] "Building back better" has been a focus of the recent disaster response literature, emphasizing that not just is rebuilding to baseline critical, but it is also important to incorporate positive changes, such as disaster risk reduction or greater socioeconomic equity.

disaster reconstruction and recovery programs (Arie 2009; Government of Indonesia 2005; Kennedy et al. 2008; Keraminiyage 2011; Rodríguez, Quarantelli, and Dynes 2007). The following section will address three major categories of outcomes of the reconstruction of Banda Aceh, as well as their larger implications.

POSITIVE OUTCOMES

Based on the findings of this study, the reconstruction of Banda Aceh was successful in several respects. A key component of the BRR-led reconstruction effort was to ensure that there was housing for those that lost their homes due to the tsunami (Arie 2009; Government of Indonesia 2005). This goal was met overall as the reconstruction program yielded housing in excess of the pre-disaster totals for both study areas. The presence of more structures than at baseline allowed the local population to return to the area and to expand via the influx of new residents. As a result, there were new opportunities for homeownership for those previously unable to via a policy enacted to give assistance to renters, squatters, and those that stayed with family (and did not own their own homes) (Arie 2009). Through the Social Assistance Aid for Residence (*Bantuan Sosial Bertempat Tinggal*) program, a cadre of new homeowners was created, who could then take advantage of the rebuilt and repaired housing. Likewise, the Joint Land Titling initiative allowed women to have their names formally included on land title documents for the first time. Thus, married women and female heads of households could benefit firsthand from Banda Aceh's cache of rebuilt structures through the BRR's efforts to address gender inequality.

In addition to the increase in quantity, the majority of structures were farther from the coast in 2008 than in 2004, which provided a measure of risk reduction for future disasters.

Tsunamis are not uncommon in Indonesia, with twenty distinct events between 2000 and 2016 (National Geophysical Data Center 2016). As of 2008, there were nearly fifty percent fewer structures in the zone adjacent to the ocean in ROI South, and nearly forty percent fewer in ROI North, leaving far fewer people and structures in the most hazardous areas. Both ROIs, and the city as a whole, benefitted from such disaster risk reduction, leaving Banda Aceh "built back better" than it was before (Jha et al. 2010; Kennedy et al. 2008).

Banda Aceh also benefitted from the repaired and expanded road network, having an additional 34 kilometers of roads throughout both ROIs. The new roads extended the network in previously underserved areas, and bridged the gaps between significant groupings of structures, allowing for better mobility for the local population(Howe and Richards 1984; Hugo 1981; Jacoby 2000). This would have impacted economic activities by granting or reestablishing access to the various commercial/industrial facilities, *tambaks*, and productive land throughout the regions (Barwell 1996; Wilkie et al. 2000). During the reconstruction process, it would have been beneficial that structures were placed near roads due to the greater ease of transportation of people and supplies to the sites, granting improved efficiency for the contractors and NGOs carrying out the work. In addition, the expanded road network would also enable more efficient disaster responses in future events, both for residents utilizing evacuation routes and responders trying to reach those in need of aid.

MIXED OUTCOMES

Some of this study's findings may have had varied consequences for Banda Aceh, or those that were far more dependent on local need or individual contexts. As noted, while the number of structures rose considerably, their total and mean areas shrunk. Prior to the tsunami, a cultural norm was for extended families to live in a single, larger home (Arie 2009). However, as structures were rebuilt, particularly the "Type 36" housing,[46] families were faced with far smaller living spaces, no longer having room for (as many) additional family members. As a result, one consequence of these smaller homes was the division or displacement of family members. In recognition of such issues, the BRR enacted a policy of providing aid to those in such circumstances so that they could become new homeowners themselves (the aforementioned Social Assistance Aid for Residence program).

Mixed consequence(s) may have also resulted from higher structure densities. There are a range of benefits from concentrated urban development, such as more economical use of land and efficiency gains in the building process (Dave 2010; Schiller 2007). Similarly, economies of scale can lower per unit costs for infrastructure and basic service delivery in areas of higher density, such as for water distribution or sewerage. Yet there are also costs that may accompany increases in structure density, such as increases in congestion or pollution (Gallup, Sachs, and Mellinger 1999; Linn 1982). Although higher densities were observed in the ROIs in Banda Aceh, the changes were not overly dramatic, such as converting sparsely-populated areas to density urban ones in just a few years. Instead, the

[46] According to the BRR Type-36 houses were "36 m² and consisting of 2 bedrooms, 1 living room/dining room, a kitchen, a bathroom and a terrace. This minimum standard was planned based on accommodation for a family of 2 children, with individual basic space need calculated at 9 m²."(Arie 2009)

dense, inland areas became slightly denser, so the actual consequences may have been small, if not negligible.

Negative Outcomes

Last, there were negative consequences of the reconstruction (or the lack of reconstruction), whether by design or circumstance. Most notable was the drastic decline in aquaculture in the northern portion of Banda Aceh. Although ROI South appeared to have recovered its overall *tambak* area, the same certainly was not true of ROI North, where few ponds were restored. The lack of reconstruction of these *tambaks* would have had economic repercussions. The loss of 785,058 sq m (or 78.5 hectares) of pond area would equate to 47 tons of lost output per year.[47] Each hectare of *tambak* was also estimated to support between one and three individuals, thus the losses in ROI North would have impacted between 78 and 235 people. When the entire household of each *tambak* worker is accounted for, the total number of affected individuals could have been five times as high, up to 1,175 (FAO 2005). Individuals and households dependent on such productive land for their livelihoods would have been directly impacted through the loss of income or means of subsistence, the need to find alternative employment, the loss of assets and infrastructure, the costs of reconstructing *tambaks*, and/or increased debt or difficulties accessing credit. Associated or complementary industries (e.g., those in the aquaculture supply chain) would have also been affected, further affecting the local economy (FAO 2005; Griffin et al. 2013).

[47] According to the UN Food and Agriculture Organization, *tambaks* on average produce 0.6 tons per hectare per year (FAO 2005).

The redistribution of structures within the ROIs may have also impacted the lives of those forced to relocate farther inland or to other parts of Banda Aceh or Aceh Province. For example, those dependent on proximity to the ocean, such as those reliant on fishing, may have faced hardships due to the greater distance from their means of employment or livelihoods (Ingram et al. 2006). Relocation/displacement might have had a range of consequences, ranging from additional inconvenience and longer travel times, to being forced to find alternate means of livelihoods. In addition to economic impacts, there was also the potential for fractured social ties and reduced social capital, as occurred in coastal fishing communities in post-tsunami Sri Lanka (De Silva and Yamao 2007; Mulligan and Nadarajah 2011). For those whom relocation distances were minimized, the social and economic consequences may have been less substantial than those displaced to greater extents. Aside from geographic distance, the odds for displacement were exacerbated for certain subpopulations, such as those who lived in damaged areas, female heads of household, and those in "farm businesses" (e.g., agriculture and aquaculture) (Gray et al. 2014). As noted below, future research utilizing household-level data would help to address these potential consequences and how they were spatially distributed throughout Banda Aceh.

IMPLICATIONS

No reconstruction program is likely to be problem-free or able to provide a perfect, one-for-one recreation of the pre-disaster state. While the process of reconstruction is more limited in scope than that of "recovery,"[48] rebuilding and repairing the built environment can contribute to reestablishing a community's wellbeing and a sense of normalcy (i.e. "getting back to normal"). The successful reconstruction of structures, roads, and *tambaks* in the two ROIs restored means of shelter, transportation, sustenance, and employment, allowing routines and economic activity to be reestablished (Peacock, Dash, and Zhang 2007; Smith and Wenger 2007). Banda Aceh's reconstruction was successful at repairing damage done to the environment, economy, and communities, and the following section will offer recommendations based on its experience.

III. RECOMMENDATIONS FOR POLICY AND PRACTICE

The reconstruction effort in Banda Aceh, while not perfect, was an encouraging example of a city being built back after a devastating disaster. Funding was streamlined, actors and tasks coordinated, communities involved, and results delivered. Given the overall positive outcome, recommendations can be made for responses to future disasters wherever they may occur. Although contexts will vary across locations and disaster types, there are systems and practices that can be implemented in a variety of settings (given a minimum level of government capacity). Practitioners and policymakers in governments, aid

[48] Although there are multiple interpretations in the literature, disaster recovery may be defined as "the differential process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-event planning and post-event actions." (Smith and Wenger 2007)

organizations, and multilateral institutions can improve outcomes based on the results and lessons learned in Banda Aceh, and such recommendations are detailed below.

Location of Reconstruction

Displaced individuals and households will often wish to return to the sites of their homes or village of residence (Rofi, Doocy, and Robinson 2006). Although various factors contribute to whether or not one chooses to return to their original land or move elsewhere (Gray et al. 2014), it advantageous to rebuild settlements where residents have social, cultural, and/or economic ties, when it is safe and feasible to do so (De Silva and Yamao 2007; Mulligan and Nadarajah 2011). As demonstrated in the ROIs of Banda Aceh, structures and roads were reconstructed on or near their original locations, with some exceptions. The lower rates of redevelopment immediately near the coast was beneficial for the sake of risk reduction, although even greater protective measures should be considered, such as the "coastal exclusion zones" employed in Sri Lanka (Ingram et al. 2006; Jayasuriya, Steele, and Weerakoon 2006).

A Guiding Framework

The greatest strength of the Indonesian response to the tsunami was its organized approach to the crisis, and the systems put in place with which to deal with it. The GOI created and fostered an environment to support its response, supported by its leadership and ministries, and backed by legislation (e.g., the "Presidential Instructions").[49] The establishment of a Master Plan and its continued evolution provided an institutional and operational framework, as well as rules/regulations for the reconstruction process. This type of foundation is a crucial ingredient for providing a cohesive and focused program. Hence, a "master plan" or formalized strategy should be implemented before the reconstruction process begins. Based on the Indonesian model, such a plan should contain a vision or mission statement, policies and guiding principles, the sectors to receive aid (e.g., housing, infrastructure, and public health), funding mechanism(s), and structure/guidelines for the participants (Government of Indonesia 2005). Monitoring and evaluation requirements should also be specified, in addition to temporal or spatial bounds for the reconstruction operations. Although governmental capacity will vary across locations and events, and aid or technical assistance may be required from international institutions or other nations, such a plan will be imperative to direct the reconstruction and keep it on task.

A Specialized Agency

Another key feature from the Indonesian experience to be replicated is the formation of a specialized agency or entity. It may be a new governmental body created solely for that purpose, as in the case of the BRR, or comprised from or situated within existing

[49] Indonesia has an especially effective decentralized government, which enabled the division of responsibilities across levels of government. Countries with a strong central government should be able to institute top-down frameworks, but may lack capacity at the lower/local levels.

organizations or structures. Regardless of its exact institutional composition, the focus of the entity should wholly be the reconstruction and rehabilitation effort. Like the "master plan," the design of the agency should include a formal mandate with a clear mission and directives, as well as a target end date for its operations. The reconstruction agency should oversee the implementation of the master plan, as well as provide coordination for the vast array of actors and tasks involved. Local offices may need to be created near the site of a disaster in order for the agency to remain appraised of the latest conditions, and maintain contact with key actors, and local communities. Monitoring and evaluation will be among its critical tasks to ensure that policies and technical standards are being upheld, and to provide course-correction when needed. The agency may not necessarily be directly responsible for rebuilding housing or repairing roads, but it will need to make sure all the moving pieces are in place for the reconstruction to happen.

Inclusion of International Actors

It will be important to anticipate the presence of international actors and to incorporate them as early as possible in the reconstruction planning process. For example, the Global Shelter Cluster (GSC) exists to provide coordination and support to governments and international aid organizations, and their resources should be utilized wherever possible. The coordinating agency of the host country, as guided by the master plan, should guide the efforts of these actors, particularly through the GSC lead agency, and if necessary, establish a division of labor or redirect the aid organizations as appropriate. International actors can offer valuable aid and support, but there is also a need for oversight and caution, as organizations may seek to provide aid but have little to no experience in that area of reconstruction, or have familiarity with local needs, customs, and norms (Cosgrave 2007).

Pooled Funding

Efforts should be made to establish a single destination for international donors (both public and private), such as through one of the regional development banks. The World Bank's Multi-Donor Fund (MDF) provided a streamlined mechanism for bilateral and international donations and should be instituted in future scenarios. The MDF increased the efficiency of the donation process, as well as allowing the recipient, and not the donors, to allocate the funds. A single overseer can direct the funds to the host government for disbursement, or can itself allocate moneys where most needed instead of individual donors sending funds as they see fit in a piecemeal fashion. Used in conjunction with the local reconstruction agency and the guiding framework, pooled funding provides another means of coordinating and simplifying some of the complexity and chaos inherent in a process as vast as reconstruction.

Community Participation

Involving those affected is a critical ingredient in post-disaster planning and development, and is particularly necessary when it comes to rebuilding homes and communities. From the initial stages of needs assessment through the actual construction, individuals, households, and community leaders should be present and consulted to ensure the appropriateness of the process and its outcomes (BAPPENAS 2005; C. H. Davidson et al. 2007; Government of Indonesia 2005; Jha et al. 2010; Khan and Redmond 2011). In Indonesia, one type of participation included community mapping exercises, where individuals helped to establish pre-tsunami plot locations and land ownership, which was necessary due to the widespread destruction of official paperwork and land title documentation (Arie 2009; Da Silva 2010). Local communities may not excel in every task or phase of reconstruction, but their involvement and engagement allows for those affected to have a voice in the process.

Spatial Analysis and Evaluating Reconstruction

The rise in prevalence of computer- and Internet-based mapping provides a range of opportunities for planning and monitoring reconstruction programs (FAO 2005). Although common for assessing disaster impacts, there is untapped potential for the use of remote sensing (e.g., via satellite imagery) and spatial analysis throughout the reconstruction process. As in this study, such tools can be used to analyze reconstruction patterns, as well as measure and quantify outcomes, further enabling monitoring and evaluation (Jha et al.

2010). Universities in the host country may be a valuable resource to draw upon to complement or supplement government capabilities for data analysis (BAPPENAS 2005; Farquhar and Dobson 2004; Rofi, Doocy, and Robinson 2006). Although spatial data and software can be obtained at a cost, there are free alternatives, and imagery has been donated by providers for such purposes.[50] Specially-prepared maps and data may also be requested from UNOSAT (a branch of the United Nations Institute for Training and Research) by governmental agencies, international aid organizations, and NGOs.[51] With a single Internet-connected computer and one lightly-trained individual, a vast array of data and tools are available with which to plan, supervise, or correct reconstruction operations.

IV. DIRECTIONS FOR FUTURE RESEARCH

Some analyses were not feasible or were simply beyond the scope of this study. This section briefly outlines several directions for future research that may be pursued.

[50] For imagery, there are free online resources such as Google Maps/Google Earth, or Microsoft's Bing Maps that provide access to some current and historical imagery. There are also free mapping software and data, such as those offered by Google, QGIS, Open Street Maps, amongst many others. Data may also be donated directly from providers, such as the DigitalGlobe Foundation.

[51] UNOSAT Rapid Mapping: http://www.unitar.org/unosat/rapid-mapping

Housing and Density

The two main issues raised in the "Mixed Outcomes" section both warrant further investigation. Research on the division or displacement of families due to the decrease in the sizes of homes would help expand the literature on the impacts of post-disaster reconstruction and resettlement. An approach similar to that of Frankenberg et al. (2011) or Rofi et al. (2006) would be appropriate if adapted to smaller spatial scales, e.g., the city of Banda Aceh or smaller geographies. Likewise, the undetermined, or potentially mixed, outcomes from higher structure density should be pursued. Impacts on public health, the road network (e.g., congestion), and infrastructure (e.g., strain on preexisting/existing systems) are of particular relevance.

Structure Information

Based on the large number of observations, it was not possible to ascribe attribute data beyond size to each structure examined here. However, the addition of information on roof type, color, or material could prove useful in determining further patterns in reconstruction or the survivability/durability of structures. Roof-related data may indicate the prevalence of or changes in materials over time (particularly in light of documented materials supply problems in the reconstruction (Arie 2009)), or specific spatial building patterns (e.g., "are certain materials used in specific locations?"). Likewise, identifying which structures in 2005 were also present in 2004 would help identify which structures survived the impacts of the tsunami, and conversely, allow for the isolation of structures that were completely rebuilt or newly constructed after the tsunami. This sample of "new" buildings (those with no pre-disaster analog), excluding preexisting structures, could further illuminate trends in the reconstruction.

Additional Geographies

Beyond the two regions of interest used in this study (ROI North and ROI South), two other regions had also been created, and the same analyses should be performed. The addition of these areas would provide an even more complete picture of the city's reconstruction, as would ROIs farther to the north and south.

City sub-divisions, known as *kampungs/kampongs* ("villages"),[52] form cohesive, neighborhood-like units, which historically evolved in urban settings as enclosed-developments (Silas 1984; Winayanti and Lang 2004). In Banda Aceh, they are demarcated by formal signage, walls, and/or gateways, making them easily recognizable.[53] Further spatial analyses utilizing the *kampung* boundaries or the *kampung* as the unit of analysis would allow for the examination of differences between across space, developments, or population subgroups.

Additional Analyses

Population data was only readily available at significantly larger geographic scales, such as at the provincial-level. Based on the very spatially-specific nature of this study, *kampung*, *desa* (a distinct type of village boundary), or household survey data would be more

[52] While *kampung* is the more universal term, in Banda Aceh, *gampung* or *gampong* is frequently used instead.

[53] As witnessed during field observations in Dec 2014.

appropriate. Future research would benefit most from incorporating household-level population data, such as that from RAND's Indonesia Family Life Survey, or extant post-tsunami survey data (Frankenberg et al. 2011).

With the addition of such data, OLS and spatial regression models could also be analyzed, using independent variables such as household income, sex/gender of the household leader, number of household members in a structure before/after reconstruction, structure characteristics (e.g., amount of clustering, size, or roof material), and distance from the coastline.

Remote sensing analyses were not able to be included in this study, but would also lend valuable insight. Measures for the amount of vegetation using the Normalized Difference Vegetation Index (NVDI), as well as multi-spectral land cover classification methods, would bolster the GIS-centered spatial analyses performed here.

Last, greater examination of the individual actors and their roles in the observed rates and locations of reconstruction would be beneficial. Quantitatively and spatially tracking each actor's efforts (such as site locations and materials used, which can be compared against imagery), as well as semi-structured interviews with representatives of the organizations that participated in the reconstruction would further explain/elaborate on how the results evolved over time.

V. LIMITATIONS

This study examined spatial patterns in the reconstruction of Banda Aceh following the 2004 Indian Ocean tsunami, along with systemic factors that contributed to the process. While every attempt was made to preserve accuracy and precision, there were limiting factors in the analyses performed. Decisions were made during the spatial analyses with regard to geographic boundaries and zoom level (i.e. how close an image or map is to the ground when looking down from space) that directly impacted what was included in each study area and the findings therein. In addition, visual analysis is subjective by nature, and one's interpretation of the imagery can influence the results or introduce sources of error. For instance, differences in interpretation could affect the shape, area, or number of structures created in GIS. The ability to distinguish between structures depended on determining where one roof stopped and another began, whether or not roofs of two different materials or colors were part of the same structure, or if roofs that were connected were one or more structures. Again, painstaking care was taken in creating the more than 30,000 structure polygons, but factors such as the quality of the images and judgement calls by the researcher ultimately determined the results upon which analyses and conclusions were made.

Another limitation was derived from the nature of the data available. It was not feasible to compare the aggregated housing totals from the BRR and extant research with the findings of this study, which covered two specific regions of Banda Aceh. The reports and journal articles used lacked geographic specificity, rarely citing figures smaller in scale than the province or city level. With regard to the satellite imagery, there was no usable data for

2006, which detracted from the ability to quantify structures/roads or calculate precise rates of change during in the reconstruction.

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