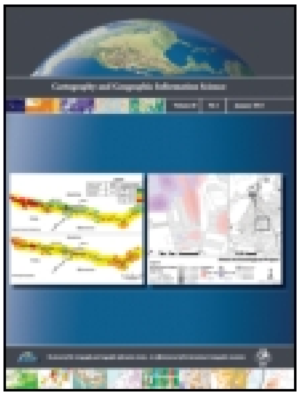

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Using Building Permits to Monitor Disaster Recovery: A Spatio-Temporal Case Study of Coastal Mississippi Following Hurricane Katrina

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ABSTRACT: The pace of disaster recovery varies considerably from one place to another. Even when places suffer impacts from the same event, recovery studies often lack the spatial and temporal resolution to fully understand such local variability in the recovery process and patterns. This paper discusses the novel use of building permits and a spatial scan statistic to identify the spatial and temporal dimensions of recovery in coastal Mississippi following Hurricane Katrina. Our work identifies significant space-time clusters of recovery activity and indicates that the amount of damage experienced and the amount of pre-event housing strongly influence the timing and location of building permit clusters. This analytical method and the use of publicly available data are valuable for a better understanding of long-term recovery processes.

KEYWORDS: Building permits, SaTScan, Hurricane Katrina, disaster recovery, rebuilding, Gulf Coast

Introduction

Recovery from a natural disaster is understood as a dynamic and multifaceted process, yet we know little about its spatial and temporal variability. The inability of most methods to provide information about the pace and progression of disaster recovery leads to the problematic conclusion that recovery is spatially uniform and consistent from one time period to another (Cutter et al. 2006; Zottarelli 2008).

Hurricane Katrina stands as the most damaging disaster in U.S. history. One model suggests that long-term recovery of the Gulf Coast could take 11 years (Kates et al. 2006). Within that time, several billion dollars of aid and countless hours will be spent rebuilding the damaged structures and impacted institutions. While many studies following Hurricane Katrina have revealed initial recovery disparities driven by class and gender (Cutter et al. 2006; Elliott and Pais 2006), few methods or metrics are capable of capturing trends of recovery throughout the entire impacted area and over longer time frames (Pais and Elliott 2008; Zottarelli 2008). A disaster of this magnitude affords an opportunity to study how long-term recovery is manifested within an affected landscape and to uncover the drivers of recovery as they shift through space and time.

In this paper we use a spatial scan statistic, SaTScan, to examine the space–time trends of built environment recovery following Hurricane Katrina. Scan statistics are a common tool used to determine if points (in this case, rebuilding activities) are randomly distributed in space and time or if they are clustered (Kulldorff 1997; Kulldorff 2005). This research specifically investigates the spatial and temporal patterns of recovery using building permits issued in three municipalities on Mississippi's Gulf Coast. The spatio-temporal relationships between permits issued, damage level, and the pre-event number of housing units in the affected area form the basis for this inquiry. We question whether spatial and temporal clusters of building permits, if they exist, are related to the level of damage caused by the storm or the density of pre-event housing. The techniques employed

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here improve our understanding of recovery with data and methods which highlight recovery as a process rather than as an outcome.

What is Recovery?

Defining what recovery is and what it means for affected communities is fundamental to finding appropriate ways to measure it. Recovery varies depending on the context of the disaster, the level of impact and the extent of the damage, and the pre-event conditions (Bates and Peacock 1989; Quarantelli 1999). In addition to physical destruction and disruption, disasters interrupt the highly connected social fabric of communities (Bolin 1976). While some of the literature addresses recovery as a multi-dimensional concept from a theoretical perspective, most case studies of recovery distill a single aspect of the recovery process for in-depth analysis, focusing on specific recovery topics such psycho-social (Gault et al. 2005), institutional (Rubin and Barbee 1985), economic and business (Chang 2000; Webb et al. 2002), built environment (Liu and Plyer 2009; McCarthy and Hanson 2008), or the natural environment (Orr and Ogden 1992).

Oftentimes, the term recovery has been used interchangeably with rebuilding, restoration, and redevelopment (Mileti 1999). These phases are instrumental to recovery. For example, rebuilding of residential, commercial, and public structures not only requires the largest amount of resources, but is also an important precursor to repopulation, and the reestablishment of commerce and social networks (Rubin et al1985; Kamel and Loukaitou-Sideris 2004). It must be acknowledged, however, that these other indicators are inadequate when trying to generalize about community recovery as a process, one that strives to restore, rebuild, and reshape the physical infrastructure, natural environment, and socio-economic systems through pre-event planning and post-event actions (Smith and Wenger 2006).

Another point of contention in the disaster recovery literature is whether recovery means returning to a stable state following a disaster, returning the affected area to pre-event conditions, or if recovery necessitates a betterment process (Bates and Peacock 1989; Mileti 1999; Quarantelli 1999; Kates et al. 2006; Anderson 2008; Alesch et al. 2008). For example, Rubin and Popkin (1990) describe a model of recovery which reconciles the view of recovery as both a return to normalcy and a betterment process. Recent research emphasizes the need to integrate betterment processes throughout disaster recovery, assess vulnerability issues which may have exacerbated the effects of the disaster, and use the recovery period following a disaster as an opportunity to address other pre-existing social and environmental issues (Cutter et al. 2006; Kates et al. 2006; Olshansky 2006; Rubin 2009).

The lack of clarity in the extant literature on recovery is easily defined by two simple questions: Recovery for whom? And recovery to what? The answers are social choices embedded in the politics of the local communities affected by the disaster. These choices, whether part of a "return to normalcy" or as sustainable redevelopment, result in measurable changes to the landscape.

Measuring Recovery

The process of recovery includes a set of activities which ameliorate the negative impacts of disasters and restore individuals, the built environment, and the natural environment to pre-disaster functioning. Recovery also includes outcomes, or the extent to which the recovery activities are judged as successful or complete, using subjective (qualitative) or more objective (quantitative) measures (National Research Council 2006). Unfortunately, there is a paucity of empirical studies on this point.

The most basic quantitative analyses and those most often reported by government agencies and aid organizations are simple numerical comparisons of pre- and post-event conditions. Examples include measuring household recovery by identifying when a home value returns to its pre-event level or comparing (at the county or city level) the number of housing units which have been rebuilt to what was in place before the event (McCarthy and Hanson 2008). These simple numeric approaches can provide useful measures of demographic trends and physical recovery post disaster, but do not provide information on the differential rates of recovery within the affected area.

An extension of these quantitative comparisons is the development of recovery indices. Indices more formally compare recovery to a data baseline in order to track the progress of recovery. *The New Orleans Index* reports extensively on several recovery indicators, including population recovery, the amount and location of new construction and repairs, housing and employment vacancy rates, school enrollment, retail sales, and the availability of schools, libraries, and childcare (Liu and Plyer 2009). Despite their ability to reflect several types of recovery and document them empirically, indices do not always answer the

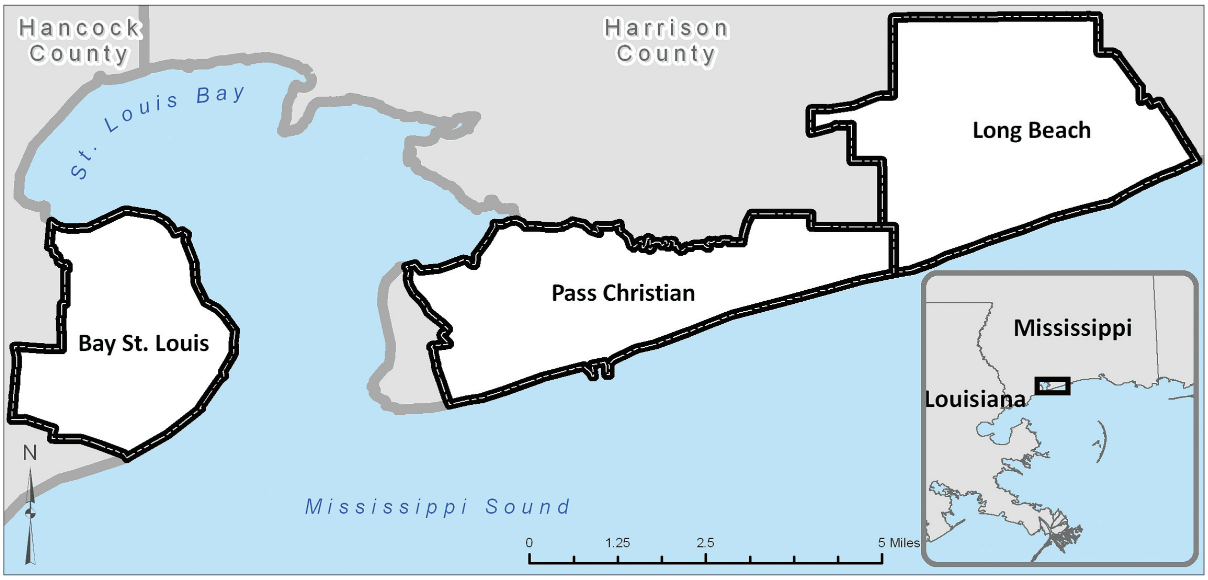

Figure 1. Coastal Mississippi study area.

	Total Population	Total Housing Units	Median Household Income ($)	% White/Black/Other
Bay St. Louis	8,209	3,817	34,106	80.2/ 16.6/ 3.2
Pass Christian	6,579	3,351	40,743	65.9/ 28.2/ 5.9
Long Beach	17,320	7,203	43,289	87.5/ 7.4/ 5.1

Source: American FactFinder (2000).

Table 1. Study area demographic comparisons.

important question of *why* or *where* certain recovery trends are occurring.

Physical and spatial indicators of recovery—changes to the built-environment—have been assessed through geographic information systems and other analysis and visualization techniques. These include aerial and satellite photography and spatial video acquisition systems (Jarmin and Miranda 2006; Curtis et al. 2007; Mills 2008; Liu and Plyer 2009). Unfortunately, many of these data sources only provide a snapshot of recovery at certain points in space and time and do not take into account the underlying spatial and temporal interactions between the drivers, activities, and outcomes of the recovery process itself.

To address some of these gaps in the literature and provide an improvement in measuring recovery, this paper empirically demonstrates temporal and spatial changes in recovery activities and outcomes. We explicitly focus on the built environment as our recovery measure.

Study Area

Hurricane Katrina struck the U.S. Gulf Coast on August 29, 2005, causing substantial damage and loss of life in Alabama, Louisiana, and Mississippi from wind, rain-induced flooding, breaches in flood containment structures, and storm surge. The eastern eye wall of the storm passed over Waveland and Bay St. Louis on the western Mississippi coast. Approximately 60 percent of the housing stock in Mississippi's three coastal counties suffered some level of damage (Jaycox et al. 2006). Three municipalities—Bay St. Louis, Pass Christian, and Long Beach—had some of the greatest and most direct impacts. These communities constitute our study area (Figure 1). Each community differs from the other in overall population size, racial composition, and median household income (Table 1).

Bay St. Louis (county seat of Hancock County) is a middle-income residential community with a largely white population. As one of the three oldest cities along the Gulf of Mexico, Bay St. Louis predates the founding of New Orleans. Bay St. Louis became a summer home destination for wealthy New Orleanians after the completion of the railroad between Mobile and New Orleans in 1870. Today, the community is focused on services such as tourism and gaming. Across St. Louis Bay is Pass Christian (Harrison County), a city that began as a summer resort community for the urban elite of

New Orleans. Pass Christian, the smallest of the study communities, was the birthplace of yachting in the South. Pass Christian is racially mixed, has a higher median household income level than Bay St. Louis, and retains its residential character and reliance on tourism. Long Beach (Harrison County) has the largest population of the three study areas, the highest median household income, and is the least diverse in terms of racial composition. Originally settled as an agricultural community engaged in lumbering, Long Beach found fame as a producer of radishes. Contemporary Long Beach is focused on consumer services and matches the high-density resort/residential community model seen elsewhere along the Gulf Coast.

Data and Methods

The process of rebuilding after disaster is lengthy and fraught with many challenges. A comprehensive assessment of spatio-temporal variability in the recovery process requires an assessment of both the recovery activities (reconstruction of the property) and associated outcomes (completed and occupied building). Building permits are used as the recovery measure in this study. The permits, required by law in every municipality/county along the coast of Mississippi, indicate the intent of a landowner to build, rebuild, or renovate a structure on a specific piece of land. Building permits can also be used as an outcome measure of recovery since issued permits generally result in completed construction. This is due to the initial cost of the permit to property owner and the legal requirement for municipal inspection prior to human occupancy. While the collected data are limited to an assessment of 2005-2008 and are not necessarily indicative of longer-term trends, the permits do provide an opportunity to assess spatial and temporal trends in recovery activities for the three coastal communities during our study period.

Building Permits

Building permits issued post-disaster represent a novel measure of physical recovery from the storm. Permits are issued in Mississippi by the Building Code Office or the Building and Development Department at either the city or county level. Permits are necessary to legally begin any construction, structural remodeling, utilities adjustments (including gas, electric, plumbing), demolition, or siting a mobile home. The permits typically include the name of the applicant, the street address where the work will be completed, the type of work being done, the approximate value of the work, the fee charged, and the issue date. Building permit data records come in four different formats: individual hard copy paper, scanned paper documents, digital reports, and geospatially enabled databases. For this research, we were able to acquire digital data through telephone and E-mail requests from the three municipalities examined in this study.

Latitude and longitude coordinates for each permit location were derived by using an address locator/geocoder created in ESRI's ArcCatalog. Of 17,529 individual permits from the three focus communities, 15,896 permits geocoded successfully. Those that did not geocode to a known address were excluded from all further analysis. Each of the geocoded permits was subsequently assigned a unique identification number. These permits include residential and commercial structures as well as schools, churches, and public buildings. To avoid representing the same property multiple times with separate permits for different work types, this study only focuses on construction permits for building and building repairs rather than permits for electricity, plumbing, or other building-related tasks requiring a different (additional) permit. The total number of construction permits covering all property types (residential, commercial, public, and other) was 8492.

This unique dataset does have some limitations. First, we were unable to confirm that work was completed, therefore we presumed that the issuance of a construction permit indicates recovery activity that eventually leads to a finished structure. Second, the data attributes varied among the municipalities as did the permitting process. For example, some municipalities did not charge for permits in the immediate aftermath of the storm, while others did not assess the value of the work to be completed or the value of the current structure. As such, some permit applications from this period of "free permitting" were possibly never acted upon.

Ancillary Data

Ancillary data were used to help explain recovery activity and outcome patterns. We used two different explanatory variables: the level of damage incurred in each census block based on National Geospatial-Intelligence Agency (NGA) damage polygons and pre-event housing units per block. The ancillary data were limited to residential structures, so we eliminated commercial, school, church, and public buildings from this analysis. Permits for temporary structures (FEMA trailers, MEMA cottages), those outside the study area, and those outside the time frame were eliminated as well. The total number of residential construction permits, which provides the basis for our analysis, is 6661.

Each permit location was attributed with a specific level of damage by spatially joining damage polygons—developed by the NGA for FEMA in response to Hurricane Katrina—with permit locations. The damage categories assigned to each permit location are described as:

1. No Damage: No observed damage to external structures.
2. Limited Damage: Generally superficial damage to solid structures…some mobile homes and light structures are damaged or displaced.
3. Moderate Damage: Solid structures sustain exterior damage…some mobile homes and light structures are destroyed, and many are damaged or displaced.
4. Extensive Damage: Some solid structures are destroyed, most sustain exterior damage…most mobile homes and light structures are destroyed.
5. Catastrophic Damage: Most solid and all light or mobile structures are destroyed.
6. Flood: Area under water or ground saturation.

The damage polygon dataset may not account for all damages in each enumeration area or to every structure; however, these data are the most comprehensive geospatially enabled damage information available for the entire study area. As discussed by Richardson and Renner (2007) in their evaluation of damage data and GIS in disaster response and recovery there are serious difficulties of trying to combine damage assessments which are not confined to political boundaries to enumeration units such as census blocks. Our solution was to use a GIS to overlay the damage category shapefile to the census blocks shapefile, thus creating smaller "sub-block" units containing a single damage category. We then aggregated our point permit and pre-storm housing unit data to these "sub-blocks." A final concern is that the broad and somewhat subjective damage categories do not provide detailed information about the type of structures damaged, insurance status, or any indication of the number of structures damaged in an area (Richardson and Renner 2007). This study's analysis is restricted to damages at the aggregate level and not on damage to individual homes.

The pre-event housing units were derived from the Mississippi Housing Recovery Data Project (Compass Group and SMPDD 2009). These data, which were created from building and property tax assessments and confirmed by on-the-ground sampling, offer a more accurate, up-to-date picture of the amount and location of housing units just prior to Hurricane Katrina than does the 2000 U. S. Census. Finally, as there is not a one-to-one correspondence for the permit data, damage data, pre-event housing, and post-event housing, the point data were aggregated to the block and sub-block levels for subsequent analyses.

Spatial Scan Statistic

Spatial Scan Statistic (SaTScan) version 8.0 (Kulldorff 2005) was used to identify clusters of permits in the study area throughout the entire study period (September 2005 to December 2008). Some recent work has expanded the use of the freely available SaTScan software from its original purpose—spatial analytics for epidemiology—into hazards applications. For example, Vadrevu (2008) used SaTScan to analyze the significance of wildfire occurrence clusters in India, Witham and Oppenheimer (2005) evaluated historic mortality clusters in England following the 1783-1784 Laki Craters eruption, and Kulldorff et al. (2005) detected disease outbreaks. However, SaTScan technology has not been utilized to track the progress of recovery from major disaster events. This is likely due to the historical lack of data with the level of spatial or temporal resolution needed to evaluate "clusters" of recovery.

SaTScan uses a scan statistic to analyze either spatial, temporal, or space-time point data (Abe et al. 2006). The software is useful for this study as it provides outputs in a format compatible with multiple commercial grade GIS software, including ESRI's ArcGIS. SaTScan makes no assumptions about if and where clusters exist. Therefore, unlike other clustering and spatial techniques, SaTScan does not require the user to define a number of clusters desired or any other parameters. Once clusters are identified by SaTScan, they are tested for statistical significance using a Monte Carlo test. The Monte Carlo statistic tests the significance (p value) of each cluster by analyzing its maximum likelihood, or the likelihood that a cluster could have occurred randomly in the data set. For this study, only those clusters with the highest significance (0.001 chance of occurring randomly) are discussed. The analysis is conditioned by the total number of observed points to calculate an expected value. The number of points in each scan

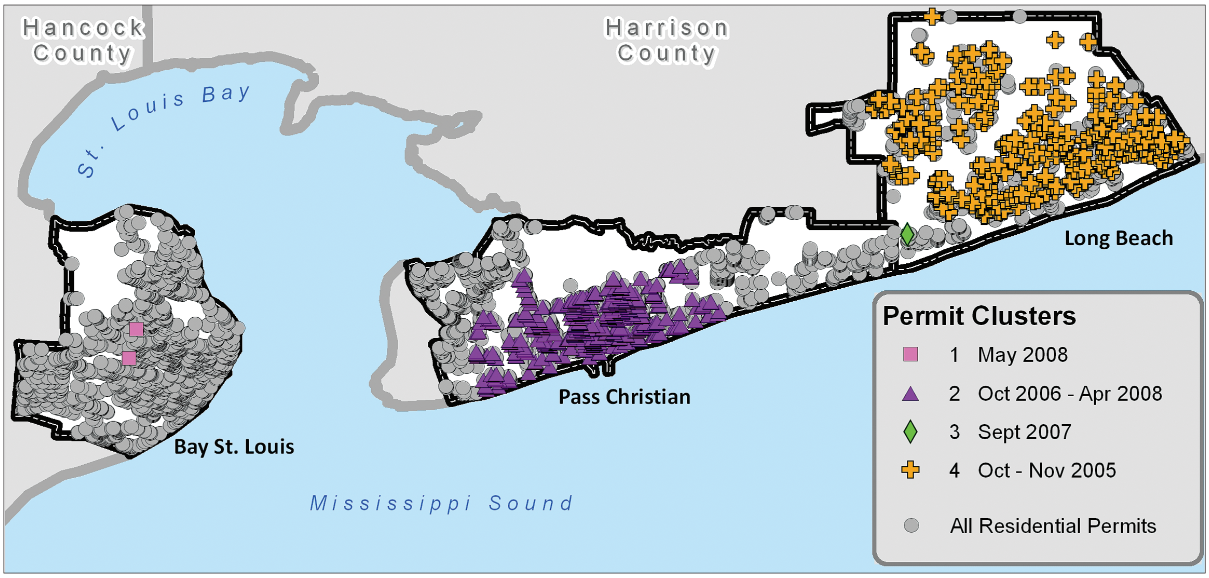

Figure 2. Residential building permits and spatial-temporal clusters.

window is then compared against the expected value to identify areas with higher-than-expected concentrations of permits (Kulldorff 1997; Abe et al. 2006). The scan window is composed of thousands of overlapping cylinders, with the base of the cylinder scanning the spatial component of the data and the height of the cylinder scanning the temporal component. For each window, the expected number of cases is compared to the observed number of cases in order to identify where clusters occur. The SaTScan output includes a list of all clusters, a list of the unique permit identification numbers associated with each cluster, the numbers of observed and expected cases, and the p value for each cluster.

The space–time probability model was chosen as the statistical test for this dataset as knowledge of both where and when permit clusters occurred is important in understanding the progression of recovery (as measured by building reconstruction). Although permits are recorded daily, time was aggregated by calendar month for this analysis.

Results

Time–Space Clusters of Recovery

A total of 6661 residential construction permits were used in this analysis, covering the period from September 2005 through to December 2008. For building permit analysis, only permit data, including the issue date of the permit and its location (latitude, longitude), were used in SaTScan. Four significant clusters (p value of 0.001) were found, each with varying spatial and temporal distributions. Each cluster identifies an area of higher-than-expected concentrations of construction permits based on location and date.

The first cluster (a .23 mi radius) is located in Bay St. Louis. The cluster consists of two large apartment complexes permitted in May 2008 (Figure 2). The first complex is the Bay Side Apartments at 701 Union Street. This complex has eleven buildings with 50 apartment units, a main service building, and a maintenance shop. The residential construction permits for each unit were issued over a three-day period from May 6-8, 2008. The second complex in Cluster 1, Sheffield Park, is located nearby, at 635 Carroll Avenue. Here there are seven buildings with 131 separate apartments. These were permitted between May 21, 2008 and May 29, 2008. Neither complex is beachside nor can they be considered luxury condominiums. The Sheffield Park apartments, for example, rent for $474 per month for a one-bedroom apartment (Gulf Coast Apartment Guide 2009). All permits associated with Cluster 1 are located completely within the moderate damage category.

The second cluster is located primarily along Pass Christian's gulf side. With a radius of 1.57 mi, the cluster includes much of the western half of Pass Christian. This cluster contains permits issued between October 2006 and April 2008. The expected number of permits for this area, 272, was far lower than the 537 cases identified by SaTScan. The majority of the permits were for single family residences; only nine percent of the permits were

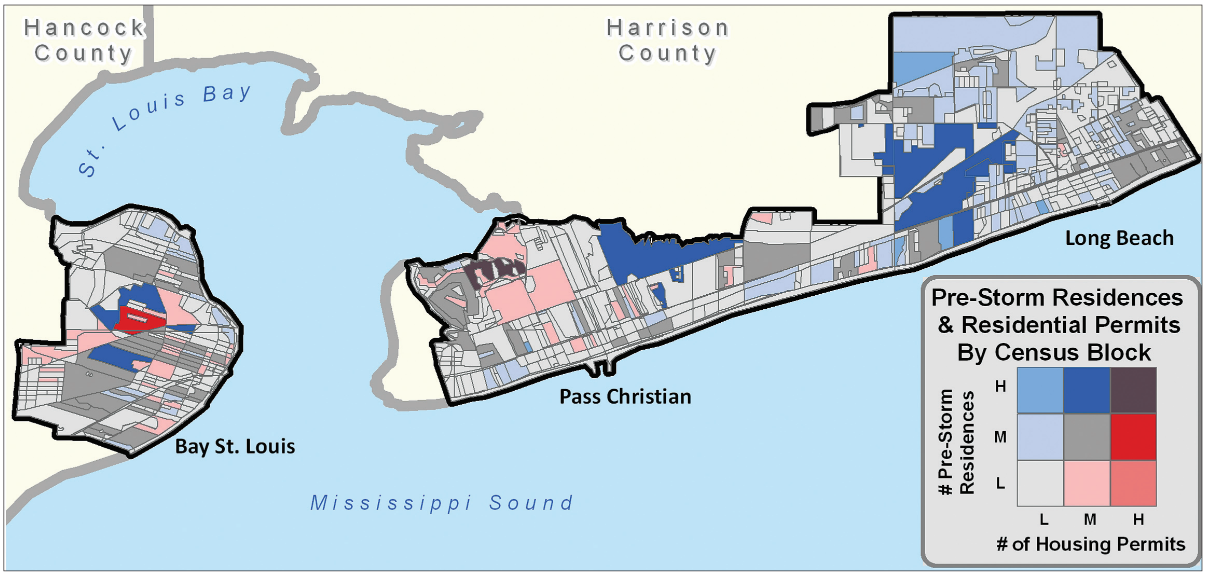

Figure 3. Relative levels of pre-storm housing units aggregated to block and the number of residential permits aggregated to block (H= high number per block based on natural breaks defined in GIS relative to entire dataset, M= medium, L=low).

for multi-unit residences. Accordingly, this cluster of rebuilding reflects individual homeowners applying for building permits. Approximately 67 percent of the permits associated with this cluster are located within the catastrophic damaged areas. The remaining permits are distributed throughout the moderate, limited, and no damage categories.

The third and smallest cluster is a complex of 15 buildings in a Long Beach resort condo/apartment development. Known as the "Beach Club," this cluster at 2012 West 2nd Street represents permits issued in September 2007. This development is owned by an out-of-state developer, and rental prices are upwards of $750 per month for a one-bedroom unit (Gulf Coast Apartment Guide 2009). All permits within this cluster are located within a catastrophic damage area close to the water front.

The final cluster is the largest (2.05 mi radius) and earliest in terms of permits issued (between October–November 2005). Also located in Long Beach, the cluster represents 464 different residential units compared to an expected 236 cases predicted by the likelihood calculation in SaTScan. This cluster is primarily characterized by single family homes. While occurring only 2-3 months following the storm, this cluster contains nearly 30 percent of all the building permits issued in Long Beach throughout the study period. Seventy percent of the permits in this cluster fall within limited and no damage areas, an indication that reconstruction decisions (i.e., the decision to stay in the same location) were more easily and quickly made where damages were less.

The identified spatio-temporal clusters of recovery activity correspond with the level of damage and the amount of preexisting housing in the area. For example, the larger Long Beach cluster not only appears earlier, but is also the cluster located farthest from the storm's eye path and its more damaging effects. This temporal variation is consistent in the clusters from East to West, with the earliest clusters appearing farther east than the western clusters which emerged later in the study period. The longer permitting activity period identified in Pass Christian suggests that greater damage levels slowed the rebuilding process. Similarly, we would expect more early activity in areas with limited damage where homeowners would simply rebuild on the same property. We explore these relationships further in the next section.

Recovery Activity and Pre-event Housing

A reasonable expectation is that areas with higher pre-storm housing concentrations would also see a higher number of construction permits, given the resident's investment in the land. What normally changes is the nature of the construction (e.g., conversion from lower density single family homes to condos, or from smaller single family homes to larger ones).

To test the relationship between pre-event housing and construction permits we first aggregated the number of pre-event housing units and the number of construction permits to the block level (Figure 3). A series of statistical tests were run to assess the relationship between these two factors for the entire study region and for the blocks contained within each cluster as a means for understanding the spatio-temporal differences.

Area	Blocks (N)	Pearson's R
Total study area	679	0.54**
Long Beach	228	0.68**
Pass Christian	230	0.71**
Bay St. Louis	221	0.69**

**Correlation significant at 0.01 level (2-tailed).

Table 2. Relationship between pre-storm housing and construction permits.

The pattern of reconstruction partially mirrors the pre-event housing distribution with permits concentrated north of Ocean Boulevard in Long Beach, in the central sections of Bay St. Louis, and in the protected bay area in Pass Christian. No areas of low pre-storm housing levels coincide with high levels of permits; therefore new construction is not exceeding what existed prior to the storm. In areas such as northern Long Beach (an area of higher pre-storm housing levels), a low or medium amount of permits exists. This demonstrates the relationship between location and event exposure.

NGA Damage Category	Percentage of Land Area in Each Damage Category			
	% of Study Region Land Area	Bay St. Louis	Long Beach	Pass Christian
Catastrophic	22.96	14.98	19.88	32.45
Extensive	3.54	12.74	0.14	0.94
Moderate	17.34	57.30	0.59	8.45
Limited	15.26	0.00	30.46	8.05
Flood	0.05	0.00	0.11	0.00
No Damage	40.86	14.97	48.81	50.10

Table 3. Percentage of land area by damage category for study region.

When examining the correlation between construction permits and pre-storm housing units, we find a significant and positive association (R=.54, s = 0.000) (Table 2). This remains true for each community. For example, in Long Beach, the relationship between pre-storm housing and construction permits at the block level is strong (R=.68, s = 0.000), as is the case in Bay St. Louis (R=.69, s = 0.000). The strongest relationship between pre-storm housing and construction permits is for Pass Christian (R=.71, s = 0.000) (Table 2). Recovery is progressing in places where pre-storm housing existed throughout the study area.

Recovery Activity and Level of Damage

Damage levels influence the timing and location of recovery activities. Such initial damage assessments (based on NGA damage polygons) are based on remote sensing and confirmed by on-the-ground assessments in the immediate post-event time period (Jarmin and Miranda 2006). The data are meant to present a quick assessment of the distribution and severity of damage following a major disaster and are widely used in recovery operations.

Catastrophic damage is seen along the Mississippi coast from Bay St. Louis to Long Beach and along the western side of St. Louis Bay (Figure 4). Most of this catastrophic damage is due to storm surge. Approximately 23 percent of the land in the study area was classified as "catastrophic" damage (Table 3). The damage categories then vary progressively from "extensive" to "limited" as distance increases from the coast. Nearly 60 percent of the study area experienced some level of damage.

Combining SaTScan outputs with GIS visualization techniques illuminates the association between the spatio-temporal clustering of construction permits and damage levels. Two clusters are either completely within (the smaller Long Beach apartment cluster) or have a majority of their permits (the Pass Christian cluster) within areas classified as catastrophic. The larger and more eastern Long Beach cluster covers both catastrophic and limited zones. However, these clusters have differing temporal dimensions. For example, the larger Long Beach cluster had an early and short period of significant recovery activity within the catastrophic zone. In contrast, significant recovery activity in the catastrophic zone in the Pass Christian cluster lagged by almost a year.

To further explore the influence of damage on the distribution of building permits, we ran a correlation between the number of pre-storm housing units per block in each damage category and the number of permits per block in each damage category. Our aim was to uncover how the level of damage influences the effect of pre-storm housing on permits issued. The relationship between

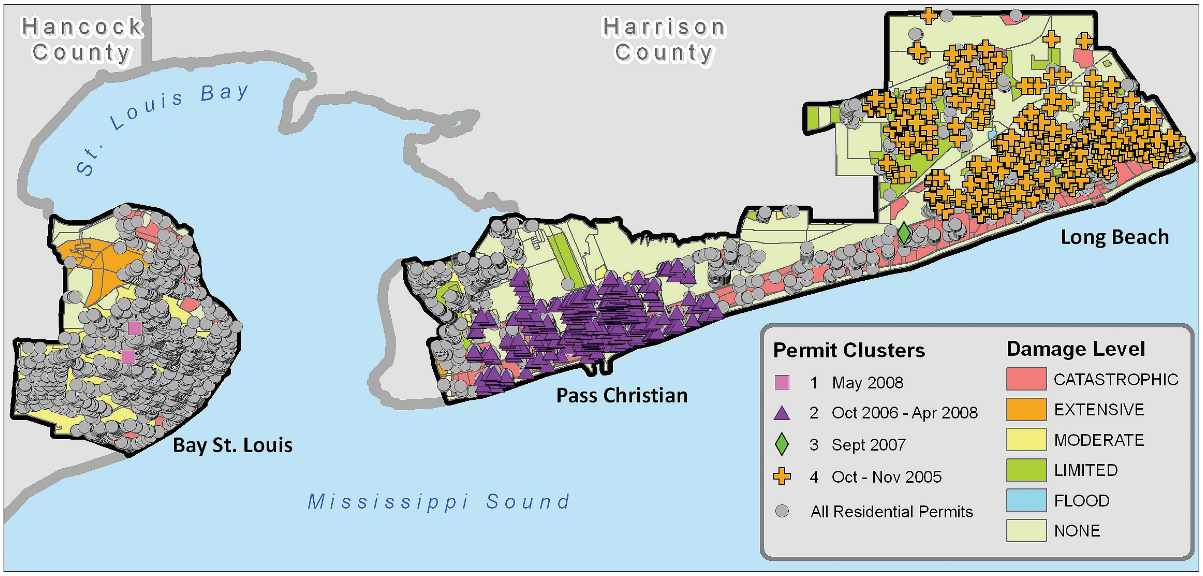

Figure 4. Residential permits, spatial temporal permit clusters, and storm damage.

	Correlation Between # Pre-storm Houses and Permits	Percentage of Permits in Each Damage Category			
		Entire Study Area	Bay St. Louis	Pass Christian	Long Beach
Catastrophic	.322**	28.04	11.35	47.52	35.67
Extensive	.859**	4.02	8.12	0.98	0.18
Moderate	.679**	42.02	78.39	21.35	0.59
Limited	.731**	15.99	0	14.84	45.87
None	.743**	9.92	2.14	15.31	17.69
N=	679 Blocks	6,661 Permits	3,031 Permits	1,938 Permits	1,692 Permits

**Correlation significant at 0.01 level (2-tailed).

Table 4. Relationship between pre-storm housing and construction permits by damage category.

pre-storm housing and building permits remains strong and positive for all damage categories except the catastrophically damaged area. In catastrophically damaged areas there is a modest (R=.322) but significant correlation between pre-event housing and building permits. This relationship indicates that either 1) rebuilding is occurring in these areas at a slower rate than in the other damage categories, or 2) there are other factors (e.g., the damage) that explain the variance in residential permits (Table 4). Sharply contrasting this relationship is the strong positive correlation between pre-event housing and building permits in areas categorized with extensive damage (R=.859). For the remaining damage categories, including no damage, there are equally strong and significant positive relationships (R=.679 for moderate damage; R=.731 for limited damage, and R=.743 for no damage) between pre-storm housing and building permits. In the no damage category, the positive association between pre-storm housing and permits could reflect renovations to existing structures. A second possibility is the establishment of new subdivisions that reflect new post-storm settlement patterns.

Discussion and Conclusion

The analysis of building permit clustering, both spatial and temporal, provides strong evidence of differential rebuilding across coastal Mississippi and is a novel approach to understanding long-term rebuilding from disaster events. Additional information from building permits may provide a more thorough understanding of the processes at work along the Mississippi Gulf Coast following Hurricane Katrina. Our analysis specifically focused on the built environment characteristics of the landscape and their effect on the progression of reconstruction, however, an analysis of data such as the type of work or the value of housing would enrich our understanding beyond time and space. This information could be linked to underlying social data (e.g., pre-event housing stock, socio-economic status, demographics) to provide a glimpse into who is rebuilding and what is being rebuilt.

Two of our clusters were small (in area) and consisted of an apartment or a condo complex—two in Bay St. Louis in close proximity, and the other in Long Beach. Both clusters occurred later in the recovery period (2007 and 2008). In contrast, the earliest cluster in Long Beach consists of rebuilding in the most heavily damaged area, closest to the coast, but also some new construction in the no damage area further inland. In Pass Christian, the recovery is largely due to rebuilding of existing structures in heavily damaged areas. What we see are three different types of recovery: the building/rebuilding of multiple family unit structures; the rebuilding of single family structures in heavily damaged areas (Pass Christian and parts of Long Beach); and the building of new single family housing in areas with no damage (Long Beach). This new construction may help explain why the correlation between permits and pre-storm housing in the catastrophic damage zone is so low. We speculate that we might be seeing a retreat from the coastline, with new residential construction taking place further inland, rather than simply replacing the waterfront housing. To document this explicitly is beyond the scope of this present paper but is worth future study.

Our results indicate that rebuilding following a disaster does not occur uniformly. The process is concentrated at various points in space and time and is under the influence of damage levels and the pre-event housing concentration. Specifically, we find that the amount of damage experienced by an area in conjunction with the pre-event number of houses influences the timeliness of rebuilding and how that rebuilding is spatially distributed. Areas experiencing higher levels of damage also have new building code requirements related to base flood elevations which often reduce the number of people who are capable of rebuilding within a confined space and time. The lack of clusters in any specific geographic area does not indicate that no rebuilding was occurring, simply that recovery activities were spatially and temporally diffuse (equal to or less than the expected statistical amount of recovery).

The amount of pre-event housing correlates with rebuilding in general for the study area. Specifically, analyzing damage levels in conjunction with pre-event housing numbers provides a much more detailed understanding of the recovery process. While other studies have described the unequal distribution of recovery, few have been able to quantify exactly where and when recovery is taking place. In this work we see that while there is some indication that new building is occurring in areas which received less hurricane damage, in the rush towards "normalcy" residents are mostly rebuilding in the same vulnerable locations. Arguably, rebuilding and resettlement away from the coast appear to be a more sensible course to follow, but past investments in land and the memories attached to those landscapes are difficult to leave behind.

Clearly, recovery varies spatially and temporally. Although there has been an increased interest in understanding the dynamics of long-term recovery following Hurricane Katrina, it is still under-studied and the mechanisms driving recovery as a process are not well understood. While these results are relatively intuitive, a major contribution of this research is the application of a technique, a spatial scan statistic, and the utilization of building permit data to empirically assess locally based trends in disaster recovery. The application of this technique demonstrates that space–time clusters of rebuilding during the period of recovery following Hurricane Katrina (or any disaster) can be identified and analyzed using freely available data and software. This research also fills a significant gap in the current literature by providing a much higher temporal resolution for the recovery process.

In this work, the pace and distribution of recovery were examined utilizing both SaTScan and ArcGIS software. This method focuses on long-term recovery to understand where and when recovery has occurred. Researchers such as Laben (2002) and Curtis et al. (2007) have developed tools to track various aspects of recovery, make decisions about aid distribution, and identify the drivers of recovery. Taken together, such work can identify the major influences on rebuilding and "best practices" that can be utilized for areas which have not experienced the desired level of recovery.

This research can act as a springboard for future investigations into the relationships between the level of damage, pre-event housing densities, and other variables with spatial and temporal clusters of rebuilding. In addition to increasing our understanding of how long-term rebuilding and recovery occur in space and time, the tools and techniques presented are available to most municipal or county building and development offices. This method can help planners and long-term recovery managers identify areas where rebuilding has been concentrated and help them better understand how to focus and distribute their resources.

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