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Toward a New Normal: Trauma, Diversity, and the New Orleans Urban Long-Term Research Area Exploratory (ULTRA-Ex) Project

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Though it is widely held that social-ecological diversity is critical for resilience and the recovery of post-trauma urban systems, there is disagreement over issues of causes and impacts. In this paper, we present analysis and findings of the impact of trauma on patterns of social-ecological diversity in New Orleans in the years following the Hurricane Katrina disaster (August-September 2005). We first provide an overview of conceptualizations of trauma and urban ecosystem resilience, and discuss programmatic research questions and objectives. We then examine city-wide land use / land cover change, showing that flood trauma reduced landscape-level ecological diversity across New Orleans. By reconstructing archival biotic surveys of indicator organisms, we also show that many ecological communities within New Orleans experienced an acute decline, followed by recovery over time. Census-based analyses indicate that ethno-racial diversity also increased over time. Unlike pre-Katrina conditions, ethno-racial and landscape-level ecological diversity were negatively correlated after the disaster as a consequence of contrasting responses to flooding. Our analyses and findings highlight the complexity and challenges of conceptualizing, operationalizing, and measuring social-ecological diversity and related processes of resilience.

Keywords
Trauma, Diversity, Resilience

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INTRODUCTION

Over the past two decades, scholars in a variety of disciplines have explored the connections between trauma, diversity, and social-ecological resilience in urban landscapes. Trauma refers to political, socio-economic, and environmental forms of destabilization and disruption that are linked to coupled human and ecological response (Figley 2006; Alexander 2012). The term resilience is important for understanding how social-ecological systems respond to traumatic events and what factors explain the pace and trajectory of recovery and change. It serves as a linking concept for understanding how both humans and natural ecosystems respond to traumatic events and what factors explain the pace and trajectory of urban ecosystem recovery. Pickett, et al. (2004, p. 373) view resilience as "the ability of a system to adapt and adjust to changing internal or external processes." Resilience in ecological systems is often thought to be the amount of exogenous disturbance or trauma that a system can absorb without changing basic structural properties (Gunderson 2010). In disaster studies, urban resilience is often defined as "the capacity of a city to rebound from destruction" (Vale and Campanella, 2005), with the focus often being on whether the city has recovered, in quantitative terms, its economy, population or built form. This emphasis on adaptive capacity in the face of changing conditions eschews a notion of resilience as reaching an end-point or terminal condition and examines resilience as a non-linear and multidimensional process (Folke 2006; Redman 2005).

In this paper, we examine the extent to which traumatic events can alter ecological and social diversity focusing on post-Katrina New Orleans. Variability in responses of different human groups, social institutions, and species within functional groups to trauma can be critical to the resilience of urban ecosystems (Norberg et al 2001). Because different groups (i.e., humans and other species) can respond differently to the same disturbance, more diverse systems have a higher likelihood of post-trauma persistence and regeneration (Elmqvist et al. 2003). Elmqvist et al. (2003) refer to this property as *response diversity* and argue that the diversity of species responses to environmental change contribute to ecosystem functionality and thus resilience. Measures of ecological and societal diversity consequently have become common indicators of recovery and transformation, despite little understanding of possible parallels and interactions

Understanding these linkages between trauma, diversity, and resilience represents a core objective of the NSF-funded New Orleans Urban Long-Term Research Area Exploratory (ULTRA-Ex) Project. As a broad-based, interdisciplinary research program, the New Orleans ULTRA-Ex project has sought to target the human and natural drivers and outcomes of post-trauma urban ecosystem changes. The overall objective of the New Orleans ULTRA-Ex project is to determine whether and how catastrophic events, disasters, and other forms of trauma affect ecological and social diversity in urban ecosystems. The project has involved fostering an unprecedented range of interdisciplinary collaborations to generate new knowledge about social-ecological interactions within the city. These efforts have given rise to an interdisciplinary research network that includes ecologists, biologists, sociologists, geographers, anthropologists, a civil engineer, a trauma psychologist, a U.S. Forest Service researcher, urban planners, plus members of the community with traditional knowledge of the region. The coordinated network of researchers and scholars from the social and ecological sciences, who predominantly reside within New Orleans, has served as an exceptional platform for integrative research that brings together knowledge, capacities, programs, and infrastructure to better understand post-trauma urban landscapes and communities. By investigating impacts of Hurricane Katrina, including flooding from levee breaches, the ULTRA-Ex project team aims to demonstrate how Greater New Orleans can serve as a model for understanding the nature of resilience in urban social-ecological systems.

THEORETICAL FOUNDATIONS AND HYPOTHESES

We use the phrase “new normal” to describe the shift from dysfunction or distress to stability and security following a major disaster. Post trauma functioning may not be the qualitative equivalent of pre-trauma functioning when there is a need to adapt to an altered environment. For ecologists and social scientists, “new normal” characterizes the period following disasters as a phase of relative stability and routine that replaces confusion, chaos, and turbulence (Norris, et al 2008; Chang 2010; Tierney 2007; Abrams et al. 2004). Ecological and social services exhibit a pattern of relative stability, sudden trauma, complex and chaotic tumult, and relative stabilization, with the last of these stages usually settling at levels deviating from pre-trauma conditions.

For human communities, the phrase “new normal” reflects the perception that while many aspects of residents’ lives differ substantially from pre-trauma circumstances, their day-to-day endeavors have generally stabilized and suffer less of the perceived and actual uncertainty, disruption, threat, and unpredictability that prevailed during the initial emergency phase. While socio-economic and cultural services (ranging from population return rates, adequate housing, governmental and commercial operations, employment and finances, environmental health concerns, and cultural functions) may indeed have stabilized, they rarely if ever replicate pre-trauma conditions. In other words, circumstances have evolved into a “new normal” (Vale and Campanella 2005).

The “new normal” concept is reflected in ecological theory by the idea that ecological communities can exhibit alternate states, also referred to as alternate stable states or alternate community configurations (Beisner et al 2003). Research suggests that alternate community states can be stochastic, dependent on the availability of colonization of different species, the availability of recruits, and the size of the original disturbance (Petraitis and Dudgeon 1999). Bertness et al (2002) suggests that alternate states can be deterministic and independent of disturbance size.

The term resilience provides a linking concept for understanding of how both humans and urban ecosystems respond to traumatic events and what factors explain the pace and trajectory of human-ecosystem recovery and the shift to a “new normal” condition. Here we do not conceptualize resilience as a return to normality, but rather as the ability of complex socio-ecological systems to change, adapt, and transform in response to trauma (Carpenter et al., 2005; Simin, et al. 2012). In this conception, urban ecosystems therefore represent “coupled human and natural systems” (e.g. Liu et al 2007) or “social-ecological systems” (Folke 2007; Walker and Meyers 2004) that exhibit nonlinear dynamics with thresholds, reciprocal feedback loops, time lags, vulnerabilities, resilience, and heterogeneity (Berkes, et al. 2003). Accordingly, we treat urban ecosystems as entities with nested hierarchies in which people and nature interact reciprocally across diverse organizational, spatial, and temporal levels. Thus, we view "ecological" and "social" factors as reciprocally related, "fundamentally combined" (Swyngedouw 2004, p. 11), or displaying "conjoint constitution" or "mutual contingency" (Freudenburg et al. 1995). Rather than seeing humans as outside or apart from ecosystems, humans are considered agents of change acting within socio-ecological systems (Balee 2006; Grimm et al. 2000; Grimm and Redman 2004).

Examining relationships between trauma, resilience, and social-ecological diversity can advance understanding of diversity as a conceptual nexus for integrating social and ecological research. Diversification characterizes all social species and patterns of organization. In the case of natural ecosystems, the development and dynamics of spatial heterogeneity regulate flows and cycles of critical resources (for an overview, see Pickett et al 2001). In the case of humans, social diversity and related conditions such as differentiation and morphology are a reflection of geography as well as socioeconomic and political organization (for an overview, see Portes and Vickstrom 2011). Folke (2006) has suggested that diversity is essential in the self-organizing ability of complex adaptive systems to regenerate and reorganize following trauma. With respect to human systems, neighborhood diversity can provide opportunities for exposure and interaction between whites and minorities, which appears to contribute to greater tolerance, fair-mindedness, and openness to diverse networks and settings. In contrast, low-income, ethnic and racially homogeneous neighborhoods tend to concentrate poverty and social distress and enhance vulnerability to trauma (for an overview, see Turner and Rawlings 2009).

Understanding the effects of trauma on ecological and social diversity also directs attention to the ways in which conflicts, natural disasters, extreme events, and other catastrophes can affect the allocation of critical resources, including natural, political, socio-economic, and cultural resources. All societies allocate critical resources on the basis of rank hierarchies and social differentiation. Unequal access to and control over political, economic, and cultural resources reflects and reinforces social inequalities, patterns of spatial segregation, and differential life chances. As Pickett et al. (2001, p. 145) have pointed out, wealth, power, status, knowledge, and territory are socio-cultural hierarchies that are "critical to patterns and processes of human ecological systems" (see also Low 2007).

Furthermore, traumatic events can provide opportunities for assessing the nature and strength of relationships between diversity and resilience across multiple scales of organization. There is a growing recognition that diversity is a key requirement for long-term (sustainable) functioning of ecological and social systems. Diverse systems are thought to be more resilient systems because of "their individuality of components;

localized interactions among those components; and an autonomous process that selects from among those components, based on the results of local interactions, a subset for replication or enhancement" (Levin 1998, p. 432). Ecological diversity is frequently associated with functional redundancy (Tilman, et al. 1997), where highly diverse communities are thought to be highly resilient to disturbance (Pickett et al, 2008).

Though diversity can be a central factor of ecosystem resilience (Wallace and Wallace 2008), the extent to which catastrophic events, disasters, and other forms of trauma affect ecological and social diversity is not well understood. Similarly, little is known about the drivers of change following traumatic events. In landscapes with tightly coupled or coincident social and ecological systems, such as metropolitan regions, social diversity and ecological diversity may increase or decrease according to the magnitude of the trauma experienced, local land-use patterns, land management practices, infrastructure, and the spatial distribution of political and economic resources (e.g. jobs, housing, schools, cultural amenities). It is also possible for contrasting outcomes or scalar trade-offs to occur where some forms of ecological diversity increase while some forms of social diversity decline, or vice versa. That is, the diversity of species, functional groups, or human activities and organizational forms at one scale of diversity may be accompanied with homogenization at other scales (Bennett, Peterson, and Gordon 2009; Kneitel and Chase 2004).

Here we examine the extent to which traumatic events alter ecological and social diversity, and their attendant spatial distributions, in a coupled human-natural ecosystem. We explored the diversity of responses of urban ecological and human communities to an acute trauma, assessing the related hypotheses that (1) city-wide ecological diversity and social diversity respond in parallel to acute, traumatic events; and that (2) ecological diversity and social diversity are correlated across post-trauma urban landscapes. Utilizing survey and GIS-based approaches, we tested our hypotheses by characterizing how social and ecological diversity have changed in the city of New Orleans following the acute disturbance of flooding from Hurricane Katrina. We predicted that city-wide patterns of ecological and social diversity declined following Hurricane Katrina. However, recognizing that interactions or feedbacks (e.g. post-trauma reconstruction can influence ecological diversity) may lead to divergent or stochastic trajectories of change, we also predicted that flood-related trauma has given rise to novel relationships between ecological and social diversity across post-Katrina New Orleans.

MATERIALS AND METHODS

Study Site

Understanding human-ecosystem response to trauma requires knowledge of change and ecosystem conditions at well circumscribed sites. We selected New Orleans, Louisiana as our study area for three reasons. First, the trauma triggered by Hurricane Katrina and the subsequent failure of the federal levee system in New Orleans on August 29, 2005 presents a prime case study of the impact of trauma on a major urban area. Hurricane Katrina was one of the deadliest and most destructive hurricanes in U.S. history, resulting in at least 1,833 fatalities (including 986 in Louisiana) and estimated damages of $135 billion. The hurricane flooded over 80 percent of the city of New Orleans, with some parts of the city under twelve feet of water through September 2005. Katrina damaged more than a million housing units in the Gulf Coast region. About half of these damaged units were located in Louisiana. In New Orleans alone, 134,000 housing units — 70 percent of all occupied units — suffered damage from Hurricane Katrina and the subsequent flooding (Plyer 2012). Approximately 90,000 square miles of the Gulf Coast region were designated as federal disaster areas, an area almost as large as the United Kingdom. All told, 1.1 million people, including 86 percent of the New Orleans metropolitan population, lived in areas that were in some way affected by the storm, either through flooding or other forms of damage (Brookings Institution. 2005, pp. 14-15).

Second, high levels of environmental exposure, demographic exposure, and social vulnerability in New Orleans render the city particularly susceptible to subsequent catastrophe. These factors make New Orleans comparable to other coastal and deltaic cities, as warming climates and rising seas continue to threaten coastal urban geographies (Törnqvist and Meffert, 2008). It has been noted that "Human vulnerability to storms — due to growing numbers of people living in exposed and marginal areas — is increasing the risks associated with climate change, while human endeavors (such as local governments) try to mitigate possible effects" (U.S. Long Term Ecological Research Network 2007, P. II-15). In many respects, New Orleans is the archetype for coastal urban ecosystems under immediate threat by climate change, particularly accelerated sea-level rise and tropical cyclone activity. As reflected in the Intergovernmental Panel on Climate Change, environmental challenges and rising sea levels currently affecting New Orleans constitute a harbinger for what can be expected for many of the largest coastal metropolises around the world over the next century (Nicholls et al., 2007).

Greater vulnerability of coastal regions to disasters also reflects historical socio-demographic disparities and resource management decisions that not only aggravate potential impacts on natural and built environments, but also complicate short-term response and long-term recovery efforts. Some decisions can result in feedbacks that iteratively heighten vulnerability in coastal regions. For example, in the northern Gulf Coast region, oil exploration and industrial production may directly (via habitat conversion) and indirectly (via global warming and sea level rise) accelerate loss of wetlands that protect major cities like New Orleans against storm damage. Thus, New Orleans offers an ideal site for examining and understanding the coupled social-ecological nature of extreme events, complex interactions of post-traumatic recovery, and land-use changes driven by a returning population, private investments, and governmental policies.

Biotic Survey Data Collection and Analysis

To reconstruct trends in ecological diversity across the Katrina event, we compiled data on species richness and relative abundance from published and unpublished biotic surveys that included all or some of the New Orleans metropolitan area (Table 1). Site-specific, city-wide, and regional survey records were compiled through online searches of: peer-reviewed published literature; archives of thesis and dissertation research; conference proceedings; as well as government and non-governmental organization (NGO) reports. We also obtained unpublished survey records by contacting individual investigators and institutional administrators. Though searches were not constrained to a specific subset of flora and fauna, available records largely correspond to widely recognized indicator organisms and human commensals.

Each survey was characterized according to a suite of descriptor variables (Table 1). We first determined the taxonomic resolution of the survey, as some inventories provide species accounts whereas others provide lower and higher resolution information (e.g. population abundance of a single species). We also determined whether surveys spanned the Katrina event and we documented the sampling strategy and method, sampling frequency, sample size (i.e., number of individual records), spatial extent, and unit of observation. Finally, we determined whether the survey provided data on species richness and / or abundance of the target organism(s).

Data from each survey were tabulated by year to determine population, species, and community-level trends across the Katrina event. Annual average values of species richness and / or abundance were calculated for survey records with finer temporal resolution. Similarly, city-wide averages were calculated for survey records with finer spatial resolution. Trends of murine rodent abundance, butterfly species richness and abundance, as well as avian species richness and abundance (standardized among surveys) were then qualitatively compared to describe change over time within and among indicator groups.

Landscape and Socioeconomic Data Collection and Analysis

We used a mixed methods research design to characterize city-wide trends in socioeconomic and landscape diversity. This involved (1) a GIS-based analysis coupled with census data to estimate the impact of trauma on blockgroup-level and landscape-level social diversity; and (2) a satellite imagery-based GIS analysis of land cover to estimate blockgroup-level and landscape level ecological diversity within the urban core of New Orleans. For the GIS analysis, we gathered and spatially aligned (to a consistent map projection, datum, coordinate system, and footprint) vector and raster GIS datasets relevant to measuring and analyzing pre- and post-trauma changes in social and ecological diversity. Vector datasets were compiled from U.S. Census data on blockgroup-level population, race and ethnicity, class according to median household income, nativity at state and national level, age breakdown, children breakdown, head of households by gender, renter/homeowner breakdown, and tax-assessed land and home values.

For the land cover analysis, raster datasets were compiled on data classified from multispectral satellite imagery spanning the Katrina event supplemented with data from digital elevation models and LIDAR measurements of tree and structural height. We relied on the following blockgroup-level landscape metrics as proxies to better understand the distribution and variability of ecological responses to Katrina-related flooding: greenness, indicated by normalized difference vegetation indices computed from multi-spectral satellite imagery; land cover including permeable versus impermeable surfaces, which was classified through high-resolution multi-spectral satellite imagery before and after the trauma; and tree location and height, measured through circa-2000 LIDAR data matched with pre-trauma and post-trauma high-resolution multi-spectral satellite imagery.

Our GIS analysis of land cover within the urban core of New Orleans relied on satellite images spanning a seven year interval, from 2001 to 2008. We acquired a September 2001 IKONOS multispectral satellite imagery to map pre-Katrina land covers (e.g., water, urban surfaces, mature arboreal foliage, grassy and bare soil, and marshes) throughout metropolitan New Orleans. A 2008 SPOT satellite image served as a post-trauma counterpart to the 2001 IKONOS imagery. The 2001 scene was captured in early autumn whereas the 2008 scene was captured closer to mid-autumn. The approximately 6 week stagger between the two scenes is a consequence of the limited availability of cloud-free archived satellite images of the study area. Stagger between images can influence estimates of change due to seasonality of vegetative land covers (i.e., the degree of leaf on, leaf off). However, New Orleans is a subtropical landscape in which vegetative land surfaces changes generally do not become spectrally detectable until early to mid-winter months. Thus the early autumnal stagger between the two images we used represents a minimal contribution to the landscape changes mapped and measured over the seven year study period.

Both images were processed following the same classification scheme to produce one-to-one comparisons of land use / land cover in New Orleans on either side of the Katrina event. This enabled calculation of changes in landscape diversity from 2001 and 2008, according to the Gibbs-Martin Index (1962), to assess whether ecological landscape diversity increased or decreased after the 2005 trauma of Hurricane Katrina. The Gibbs-Martin (1962) index is defined as:

$$D = 1 - \sum_{i=1}^{N} P_i^2$$

Where *P* equals the proportion of individuals or objects in a category, and *N* equals the number of categories. A perfectly homogeneous population would have a diversity index score of 0. A perfectly heterogeneous population would have a diversity index score of 1 (assuming infinite categories with equal representation in each category). The land use / land cover datasets also were spatially intersected by U.S. Census blockgroups to tabulate land cover composition at the blockgroup level. This enabled spatially consistent comparisons of landscape conditions to an extensive array of socioeconomic statistics, ranging from population to social diversity to income levels to home ownership. This also allowed comparisons to be made between parallel measures of ecological and socioeconomic diversity before and after Hurricane Katrina.

A major goal of this study was to identify which neighborhoods became more socially homogeneous and which neighborhoods became more diverse after the deluge. We therefore assessed the impact of trauma on processes and patterns of social homogenization and diversification at the neighborhood scale through Census blockgroup data. We used the Gibbs-Martin index described above to measure changes in ethnoracial diversity, which served as our primary measure of social diversity. Ethnoracial diversity can illuminate pre- and post-disaster changes in forms of demographic richness and socio-spatial inequality. Understanding post-disaster changes in ethnoracial diversity can elucidate processes of neighborhood transition and recovery, changing forms of social stratification, and emerging patterns of segregation or demographic integration. In the Gibbs-Martin index, P is the proportion of individuals in the nominal racial/ethnic category in a given U.S. Census blockgroup. We used this diversity index as a statistic to measure the probability that two randomly selected individuals from a given geographical area are of different racial/ethnic backgrounds. If all people of a given area are of the same racial/ethnic background, the diversity index is zero (perfect homogeneity). Indices closer to 1 indicate a highly diverse racial/ethnic composition, toward perfect heterogeneity. We used the index as a measure of racial mixing and concentration, where low levels can be seen as evidence of racial clustering and lack of interaction and contact with other ethnic and racial groups. High levels indicate more intergroup variation and interaction.

We then examined relationships between flooding, ethnoracial diversity, and ecological diversity utilizing index values of diversity alongside our compilation of GIS data on socioeconomic and landscape conditions. Paired t-tests of blockgroup level data were carried out to determine whether demographic and landscape parameters changed across the Katrina event. Pearson correlation tests were conducted to assess relationships between flood depth, demographic parameters, and ethnoracial diversity index values with respect to the Katrina event (Blum et al. 2012). Similarly, Pearson correlation tests were conducted to assess relationships between flood depth, land use / land cover parameters, and landscape diversity index values. Pearson correlation tests also were conducted to examine relationships between social diversity and landscape diversity, as well as change in diversity index values, relative to the Katrina event (Blum et al. 2012). All statistical tests were carried out with Systat 13 (SPSS, Chicago, IL, USA).

RESULTS AND DISCUSSION

Biotic Survey-based Analysis of Ecological Change

We identified 13 biotic surveys with information on terrestrial and semi-aquatic flora and fauna in metropolitan New Orleans (Table 1). The surveys predominantly characterized species richness of traditional indicator assemblages– including trees, amphibians, ants, birds, and butterflies– in the metropolitan area (Table 1). Other surveys characterized changes in abundance of targeted species including human-commensal pests such as termites and murine rodents. The time period of records varied among the surveys. Though many surveys spanned the Katrina event, few extended back before 2003. Several surveys were designed to answer focused questions about post-Katrina fragmentation and connectivity, and therefore exhibit a spatially and temporally restricted structure (see Table 1).

Comparisons of biotic records that span the Katrina event show that indicator organisms exhibit similar but not fully consistent responses to trauma in urban landscapes. The Christmas bird count program and the annual North American Butterfly Association surveys provide the longest and most continuous records of biotic change within metropolitan New Orleans (Table 1). The Christmas bird count surveys show that post-trauma richness and abundance are greater than pre-trauma levels, but that both have achieved even higher levels in the recent past (Figure 1). On the other hand, the diversity and abundance of butterfly species within the city increased dramatically after the storm. While abundance has remained relatively high, species richness appears to have peaked in 2008, declining in subsequent years (Figure 1). Rat infestation reports, which serve as a proxy record of murine rodent abundance throughout the city, suggest that rodent populations also increased and declined following Hurricane Katrina (Figure 1).

Because of historically limited interest in urban biota, storm-related damage, and surging interest in biotic responses to extreme climate-related events, post-Katrina conditions are disproportionately represented in biological surveys of the city. Consequently, pre-trauma reference conditions and trends are only known for a small proportion of organismal diversity within the city. All pre-Katrina municipal records of murine rodent populations, for example, were lost when flood waters destroyed the City of New Orleans Health Department facility located in the Lower Ninth Ward. Similarly, nearly all pre-Katrina records of the New Orleans urban forest compiled by the Louisiana Department of Agriculture and Forestry were destroyed when the city flooded. Though the paucity of pre-trauma data cannot be easily overcome through space-for-time substitutions and similar study designed, several comprehensive surveys have been initiated that will provide a basis for tracking future biotic change across the city, including inventories of the New Orleans urban forest and murine rodent populations (see Table 1).

Though the available records illustrate some similarities among indicator organism responses to the Katrina event (Figure 1), more detailed comparisons likely will uncover signatures of greater response diversity. The Christmas bird count survey and related academic surveys (Table 1), for example, suggest that species responses differ according to habitat specialization, where some birds preferring forested habitat exhibit an inverse response relative to birds preferring open habitat (Yaukey 2007, 2008). More detailed analyses must be carried out cautiously, however, to account for the source and quality of the data (i.e., was it compiled by citizen-scientists?), the scale of data collection efforts (i.e., was it taken from a single or multiple locations within the city? are there equivalent sample sizes?), and the biological characteristics that have been measured (i.e., species richness versus relative abundance).

Table 1: Biotic surveys that provide data on pre-trauma and/or post-trauma organismal diversity in New Orleans.

Organism(s)	Taxonomic resolution	Start date	End date	Richness	Abundance	Sample size	Sample unit	Sampling strategy	Spatial extent	Temporal resolution	Sampling method
Amphibians	species	1997	1999	√	√	135	observation	stratified random block sampling	New Orleans	annually	Passive auditory survey
Ants	species	2003	2012	√	√	>300000	individual	multiple sites	Orleans, St. Bernard, Plaquemines Parishes	monthly, annually	Opportunistic and leaf litter collection, bait traps
Birds	species	2000	2010	√	√	442061	observation	single location	New Orleans	annually	Point count
Birds	species	1948	2012	√	√	283	observation	multiple random sites	Orleans, Jefferson Parishes	continuous	Passive visual and auditory survey
Birds	species	1994	2009	√	√	>150	transect	multiple transects	New Orleans	weekly, annually	Passive visual and auditory observation
Lepidoptera	species	2000	2011	√	√	3667	individual	single observation site, driving miles	New Orleans	annually	Visual survey
Trees	species	1991	2005	√	√	unavailable	individual	multiple sites	New Orleans	single effort per site	Plot inventory
Trees	species	2010	2011	√	√	300	plot	stratified random block sampling	Orleans, Jefferson Parishes	single effort per site	Plot inventory
Birds	species	2009	2010	√	√	233	individual	multiple sites	Orleans, Jefferson, St. Tammany Parishes	annually	Point count
Frogs	species	2009	2010	√	√	53	individual	multiple sites	Orleans, Jefferson, St. Tammany Parishes	annually	Passive auditory survey
Arthropods	Order	2009	2010	√	√	6123	individual	multiple sites	Orleans, Jefferson, St. Tammany Parishes	weekly	Plot inventory
Termites (*Coptotermes formosanus*)	Population	2005	2011		√	17513	individual	multiple sites	French Quarter	monthly, annually	Light traps, bucket traps
Rodents	Population	2006	2012		√	10547	report	multiple sites	New Orleans	continuous	Phone-in complaints

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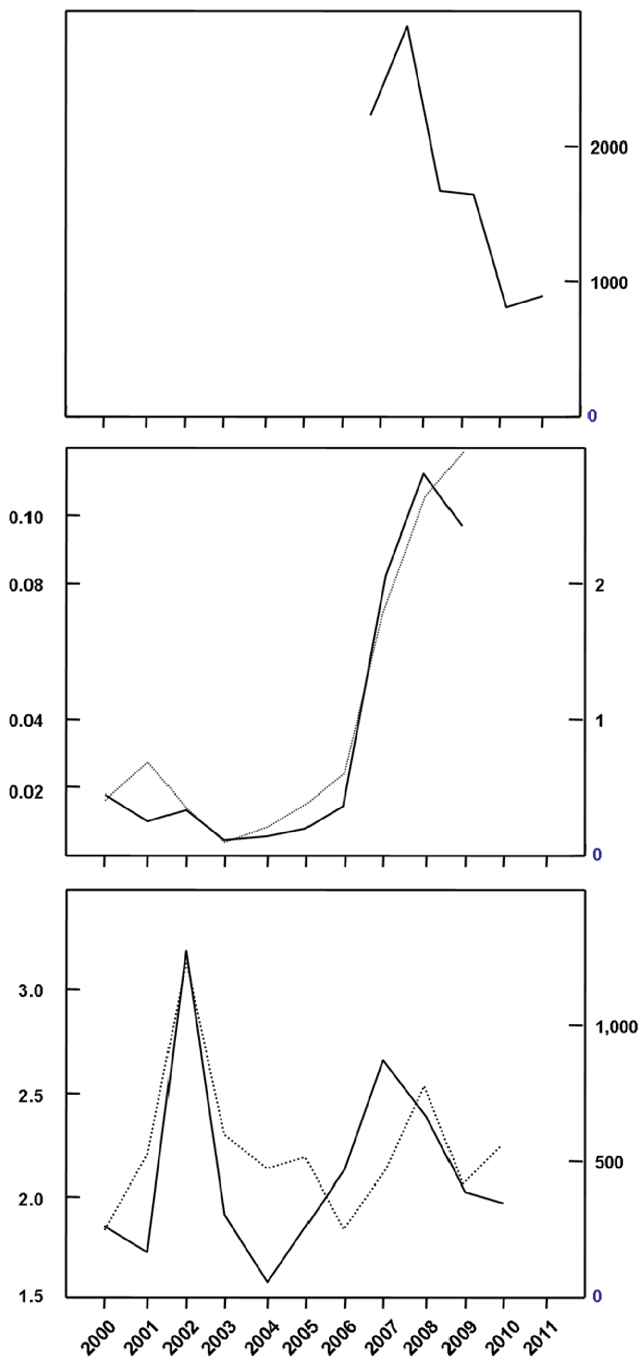
Figure 1: Biotic Surveys of Organismal Diversity Within New Orleans. Bottom: average and standardized bird species richness (solid line, left axis values); average and standardized bird abundance (dashed line, right axis values). Middle: average butterfly species richness (solid line, left axis values); average butterfly abundance (dashed line, right axis values); rodent reports (dashed line; right axis values).



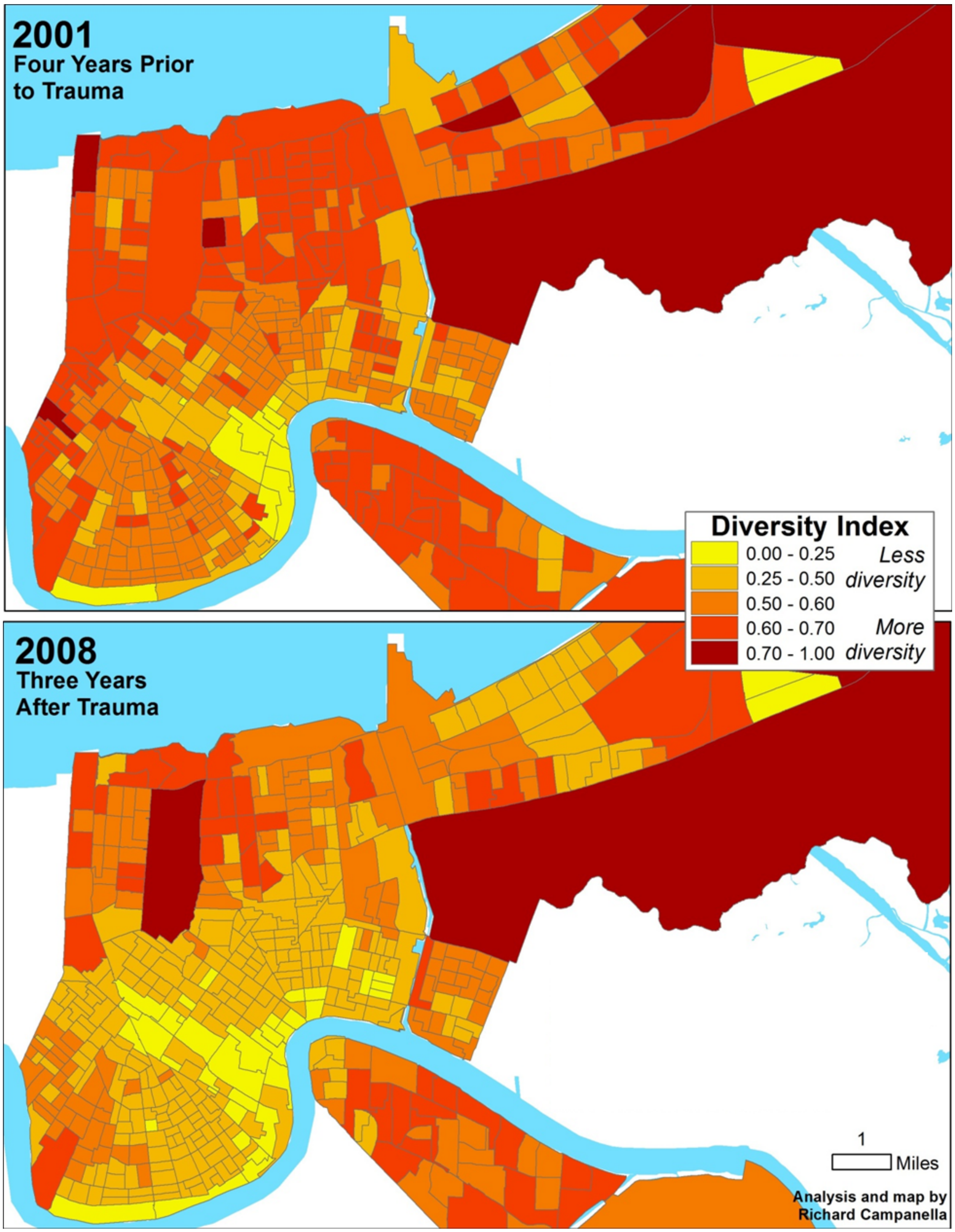
Landscape Analysis of Ecological Change

Our city-wide analysis of land cover change by Census blockgroup demonstrates that landscape diversity declined following Hurricane Katrina (Figure 2). Index values of landscape diversity were significantly lower after the storm ($t = 15.223$, $df = 968$, $p < 0.001$). Blockgroup-level comparisons similarly affirm that land use / land cover across post-Katrina New Orleans is significantly different from pre-Katrina conditions. Some changes are associated with the reduction in total population and destruction of the built environment. For example, the number of vacant lots and urban land cover significantly increased following the storm ($t = -10.356$, $df = 968$, $p < 0.001$; $t = -2.221$, $df = 968$, $p = 0.027$). On the other hand, tree and herbaceous cover declined following the storm, though the changes were not significant ($t = 1.284$, $df = 968$, $p = 0.199$; $t = 1.037$, $df = 968$, $p = 0.30$).

Changes for some land covers were stronger in areas that flooded in 2005, as compared to those that evaded the inundation. For example, spaces in the city that were forested in 2001 and flooded in 2005 were 43 percent less forested in 2008, compared to 31 percent less forested in areas that did not flood. Nevertheless, much landscape change occurred even in areas that flooded moderately or not at all. Grassy areas between 2001 and 2008, for example, shrunk by 23 percent in unflooded areas, 33 percent in moderately flooded areas, and 24 percent in deeply (over three feet) flooded areas. When we look at the diversity indices for unflooded versus flooded areas, we see that both areas diminished in their diversity of land covers—by -0.09 for unflooded and -.012 for flooded—suggesting that the presence of water intensified the loss of diversity but by no means drove it exclusively. It is likely that the affiliated traumas associated with the Katrina event, such as wind damage and ensuing anthropogenic alternations to the postdiluvian cityscape, affected land cover change even if those spaces did not actually suffer the deluge.

Block-group level comparisons similarly affirm that the land use / land cover across post-Katrina New Orleans is significantly different from pre-Katrina conditions. Some changes are associated with the reduction in total population and destruction of the built environment. For example, the number of vacant lots and urban land cover significantly increased following the storm ($t = -10.356$, $df = 968$, $p < 0.001$; $t = -2.221$, $df = 968$, $p = 0.027$). Tree and herbaceous cover declined following the storm, though the changes were not significant ($t = 1.284$, $df = 968$, $p = 0.199$; $t = 1.037$, $df = 968$, $p = 0.30$). Index values of landscape diversity, however, were significantly lower after the storm ($t = 15.223$, $df = 968$, $p < 0.001$).

Figure 2: Land Cover Changes in New Orleans, 2001 to 2008, aggregated by Census blockgroups.



The observed decline in landscape-level diversity can be partially attributed to the direct impact of hurricane-driven wind falls and post-storm flooding. However, the loss of landscape diversity also reflects management interventions undertaken during the post-trauma recovery phase. Though ecological diversity can increase the availability of valuable services and resources (i.e. flood and storm protection, heritage tourism, recreation, and aesthetic value), increase functional redundancy and promote adaptive capacity, post-trauma management of urban landscapes does not always aim to enhance ecological diversity. Following Hurricane Katrina, trees were removed and cut back from power lines to restore power and reduce ecological impediments to the flow of aid and resources into the city. City-wide programs also were implemented to remove vegetation to reduce exposure risk to zoonotic pathogens and to increase aesthetic value of flood-damaged neighborhoods. Such interventions reflect trade-offs between ecological and socioeconomic recovery, and illustrate how ecological diversity can be depressed when government agencies implement policies to encourage human repopulation of post-trauma landscapes, especially in the context of real or perceived risks to human health and well-being.

Post-Katrina Changes in Social Diversity

Hurricane Katrina and the ensuing deluge disrupted longstanding and entrenched patterns of class and racial segregation and set in motion major demographic and population shifts in the socio-spatial organization of the city and metropolitan area. Overall, population and demographic data suggest that New Orleans diversified following the Hurricane Katrina disaster. Blockgroup-level comparisons affirm that the demography of post-Katrina New Orleans is significantly different from pre-Katrina conditions. Approximately 61% of all 485 blockgroups witnessed increases in ethnoracial diversity while 38% of blockgroups moved toward greater homogeneity (Figure 3). Index values of ethnoracial diversity significantly increased after the storm ($t = -2.357$, $df = 968$, $p = 0.019$).

Hispanic population growth combined with declines in the total, white, black, and Asian populations were the major drivers of social diversification. Census data show that the city's population contracted by as much as 60% following Hurricane Katrina. The total population is significantly smaller ($t = 7.091$, $df = 968$, $p < 0.001$), which is largely accountable to a decline in the African American and non-Hispanic white populations ($t = 6.631$, $df = 968$, $p < 0.001$; $t = 2.293$, $df = 968$, $p = 0.02$) in the city. Census data show that by 2010, 118,526 fewer African Americans and 24,101 fewer non-Hispanic whites resided in the city.

Figure 3: Racial and ethnic composition of Census blockgroups that homogenized (top) and that diversified (bottom).

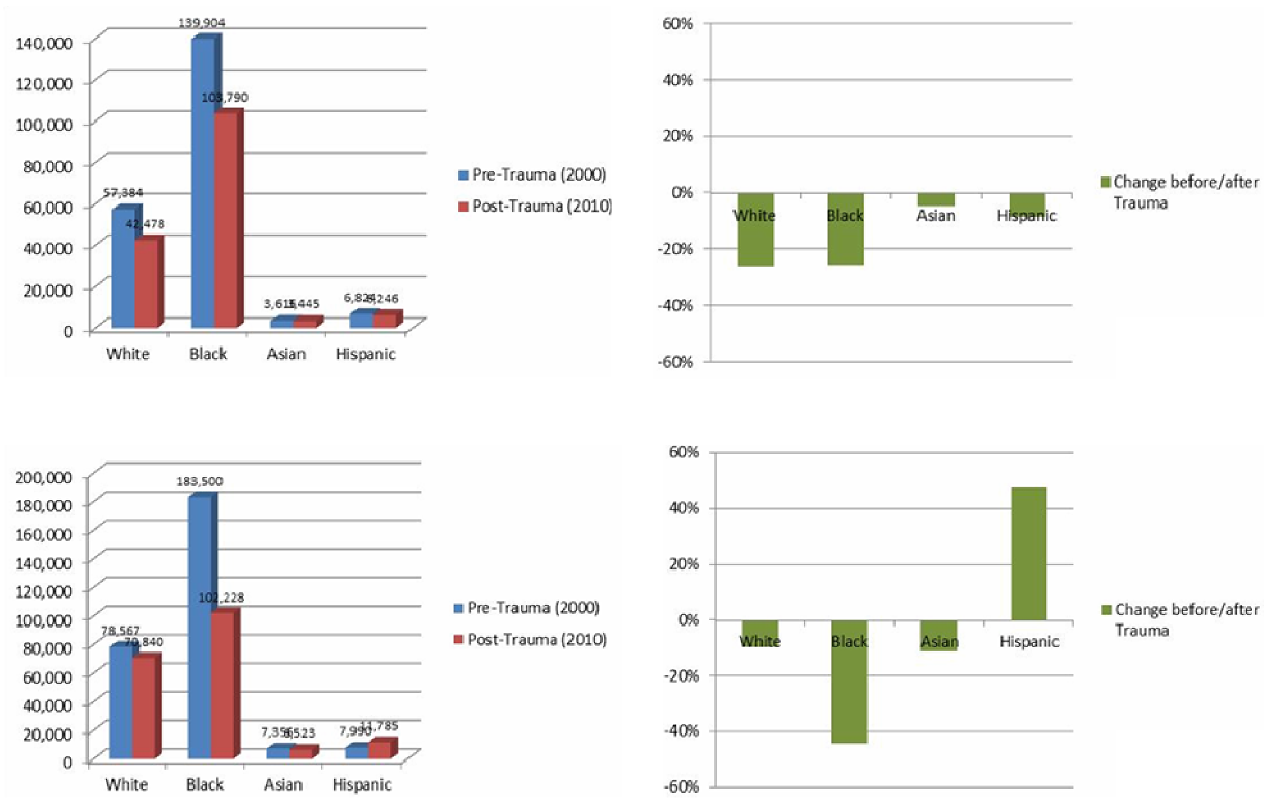


Figure 4: Racial and ethnic composition of Census blockgroups that did not flood (top) and that flooded deeply (bottom).

Figure 4 shows the racial and ethnic composition of U.S. Census blockgroups that did not flood and those that flooded deeply. Data used to create the figure show that the 86 blockgroups that did not flood following the storm became more racially and ethnically diverse. The average social diversity index of these blockgroups rose from 0.386 in 2000 to 0.414 in 2010. The percentages of non-Hispanic whites, African Americans, and Asians living in blockgroups that did not flood all declined by approximately 10 percent. The percentage of Hispanics increased by 20 percent in blockgroups that did not flood. Despite some shifts in composition, little change occurred in the overall diversity of blockgroups that deeply flooded (i.e., more than one meter of water). The average social diversity index of deeply flooded blockgroups (195 out of 485 blockgroups) was 0.218 in 2000 and 0.224 in 2010. The slight rise in diversity within these blockgroups reflects an influx of Hispanics and declining percentages of non-Hispanic whites, African Americans and Asians.

While the non-Hispanic white population declined by less than 10 per cent, the African American population declined by more than 40 percent in areas that diversified. Despite declines in numbers of African Americans living in the city, African Americans still represent the majority of the city's population at 60 percent, down from 67 percent in 2000. The Hispanic population and the number of individuals identifying themselves as "other", however, significantly increased in the city after the storm ($t = -2.708$, $df = 968$, $p = 0.007$; $t = -3.711$, $df = 968$, $p = 0.007$). The metropolitan area gained 33,507 Hispanics from 2000 to 2010, corresponding to a population growth increase of 57 percent (as compared to the national increase of 43 percent over the same time period). The Hispanic population increased by more than 40 percent in blockgroups with higher post-Katrina diversity index values. No significant change occurred among Asian, Native American, or Pacific Islander populations (all, $p > 0.05$), though an additional 3268 Asian residents lived within the city by 2010.

Flooding, Social Diversity and Landscape Diversity

Post-Katrina shifts in ethnoracial diversity reflect flooding intensity across the city. Table 2 shows changes in the index of diversity at the Blockgroup Level (2000-2010) based on U.S. Census Bureau data for New Orleans. As the table shows, blockgroups exhibited modest increases in diversity with the exception of wealthier than average areas that flooded deeply (> 1 M). Comparison of blockgroup level values using paired t-tests and pearson correlation tests uncovered significant relationships between storm-related flooding and social diversity (Figure 5). Pre-storm and post-storm social diversity are both negatively correlated with flood depth ($r = -0.235$; $p < 0.001$; $r = -0.304$, $p < 0.001$), which suggests the presence of a pre-existing relationship with elevation across the city. However, the change in social diversity across the Katrina event is also negatively correlated with flood depth ($r = -0.108$; $p = 0.017$), indicating that less severely flooded areas became more diverse after the storm. This finding is partly attributable to greater numbers of Caucasian, African American, and Hispanic residents in less severely flooded areas ($r = -0.262$; $p < 0.001$; $r = -0.159$; $p < 0.001$; $r = -0.148$; $p = 0.001$).

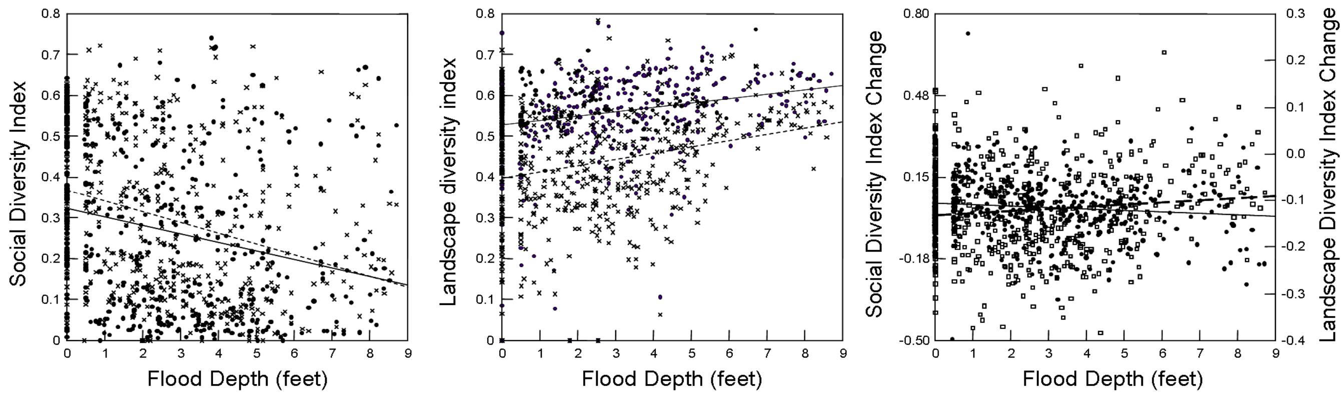
Table 2: Changes in Index of Diversity at the Blockgroup Level, 2000-2010

	Number and percentage	Gibbs-Martin Index of Diversity 2000	2010
Blockgroups that did not flood	86 (17%)	.386	.414
Blockgroups that flooded deeply	195 (40%)	.218	.224
Blockgroups where Hispanic population doubled	97 (20%)	.197	.309
Blockgroups that gained Whites	185 (38%)	.262	.360
Blockgroups that gained Blacks	79 (16.3%)	.322	.370
Poorer than average blockgroups that did not flood	31 (6.4%)	.320	.380
Wealthier than average blockgroups that did not flood	40 (8.2%)	.420	.430
Poorer than average blockgroups that flooded deeply	90 (18.6%)	.120	.170
Wealthier than average blockgroups that flooded deeply	81 (16.7%)	.280	.260

Note: Total Number of Blockgroups = 485

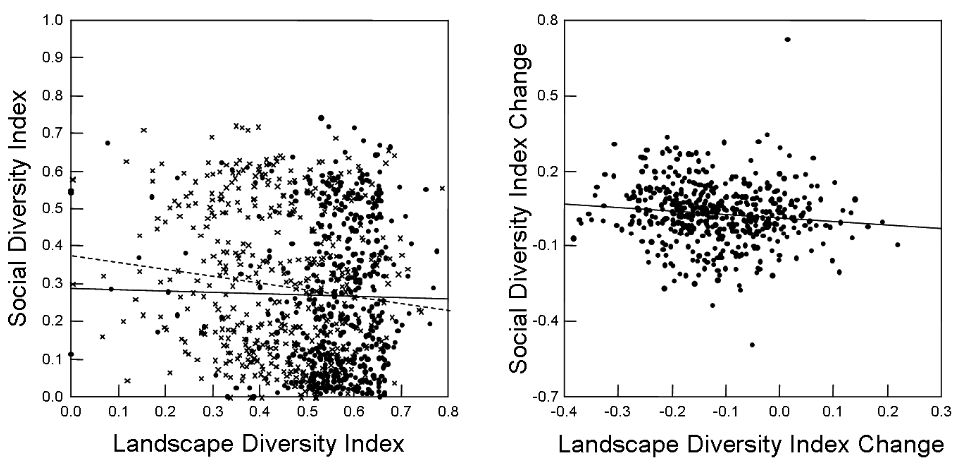
Source: Authors' calculations of U.S. Census Bureau blockgroup data for New Orleans

Figure 5: Social diversity and landscape diversity relative to flood depth across New Orleans before and after Hurricane Katrina. (Left) Social diversity in 2001 (solid circles, solid line) and 2010 (crosses, dashed line); (Middle) Landscape diversity in 2001 (solid circles, solid line) and 2008 (crosses, dashed line); (Right) Social diversity index change (solid circles, solid line) and landscape diversity index change (open boxes, dashed line) across the Katrina event. Correlation values are given in the text.



Statistically significant relationships were also recovered between storm-related flooding and landscape diversity (Figure 6). Both pre-storm and post-storm landscape diversity are positively correlated with flood depth ($r = 0.231$; $p < 0.001$; $r = 0.257$, $p < 0.001$), suggesting the presence of a pre-existing relationship with elevation across the city. However, the change in landscape diversity across the Katrina event is also positively correlated with flood depth ($r = 0.101$; $p = 0.026$), indicating that more severely flooded areas became more diverse after the storm. More severely flooded areas harbored a greater number of vacant lots after the storm ($r = 0.123$; $p = 0.007$), an increase in herbaceous land cover occurred in more severely flooded areas ($r = 0.114$; $p = 0.012$), and greater tree cover occurred in less severely flooded areas ($r = -0.150$; $p = 0.001$).

Figure 6: Relationships between Social Diversity and Landscape Diversity Across New Orleans Before and After Hurricane Katrina. Solid circles and solid line show relationships between social diversity and landscape diversity across New Orleans before Hurricane Katrina. Crosses and dashed line show relationships between social and landscape diversity after Hurricane Katrina. The box on the right shows relationship between social and landscape diversity change across the Katrina event. Correlation values are given in the text.



The relationship between social diversity and landscape diversity changed across the Katrina event (Figure 6). Though it appears there were counter-gradients of social diversity and landscape diversity with elevation in the city (described above), social diversity and landscape diversity were not directly correlated before the storm ($r = -0.018$; $p = 0.688$). In contrast, a significant negative correlation was recovered between post-Katrina social diversity and landscape diversity ($r = -0.118$; $p = 0.009$). A significant negative correlation also was recovered with social and landscape diversity change ($r = -0.118$; $p = 0.009$), indicating that social diversity increased more in areas that underwent less change in land use / land cover across the Katrina event. These findings are consistent with less severely flooded areas becoming more ethnoracially diverse and more severely flooded areas becoming more ecologically diverse after the storm.

CONCLUSIONS

A primary goal of the New Orleans ULTRA-Ex project has been to assess the influence of Hurricane Katrina on patterns of ecological and social diversity, and their attendant spatial distributions, in the New Orleans area. Social and ecological diversity represent a conceptual nexus for integrating social and ecological research and, by using interdisciplinary perspectives and a diversity of methods and approaches, we have attempted to describe organismal responses, landscape alterations, and socioeconomic transformation. Integrating concepts of diversity from the physical and social sciences offers a basis to theorize and examine possible parallels and divergences between socio-economic and ecological systems that are not well understood (Adger 2000, Holling 1973, 2001). Moreover, examining the interplay between ecological diversity and societal diversity endeavors to promote conceptual unification of disparate fields of research on the assembly, structure, and resilience of communities.

We have examined relationships and interactions between social and landscape diversity to understand processes of post-disaster adaptation and transformation, the shift to a new normal. Scholars have used the phrase "new normal" to describe the shift from dysfunction or distress to stability and security following a major disaster, where post-trauma community structure and functioning may not be the equivalent of pre-trauma conditions (Chang 2010; Tierney 2007; Vale and Campanella 2005; Beisner et al. 2003; Petraitis and Dudgeon 1999, Bertness et al. 2002; Norris, et al. 2008; Abrams et al. 2004). Our contribution to this literature is to examine possible parallels and interactions of ecological and social diversity in contributing to social-ecological recovery. Post-Katrina changes in the relationships between social diversity and landscape diversity express continuities with pre-Katrina relationships but are nevertheless qualitatively different. Coupled relationships between social and ecological systems have changed and adapted in response to the disaster, rather than merely returning to normalcy or resuming to pre-Katrina forms.

New Orleans was the fastest growing large city in the United States between 2010 and 2011 according to the U.S. Census Bureau. As of July 2011, the city supported a population of 360,740, or 74 percent of its 2000 population of 484,674. The metropolitan area, with 1,191,089 residents, supported 90 percent of its 2000 population of 1,316,510. According to data and analyses by the Greater New Orleans Community Data Center (GNOCDC), neighborhoods most heavily flooded by the levee failures have had the highest growth, as old and new residents move in to rebuilt homes and new apartments financed with multi–family tax credits. Seven years after the flood, almost half of the 72 neighborhoods in the city have recovered to over 90 percent of their pre-trauma population size. Ten neighborhoods have a larger number of active addresses than prior to the levee failures. Only four neighborhoods have less than half the population that was present prior to the storm. Two of these neighborhoods are public housing development sites that have been demolished to make way for new mixed–income housing (Ortiz and Plyer 2012).

Although the ongoing population recovery is a promising sign of revitalization, the city and metropolitan area continue to face troubling socioeconomic inequalities and environmental vulnerabilities. New Orleans is a more ethnically diverse place than before the storm, stagnant poverty rates (Plyer 2012) and persistent social and ecological vulnerabilities nonetheless suggest that the city and metropolitan level continue to face intense challenges in mitigating inequalities and enhancing sustainable development. Since 1932, 29 percent of the wetlands that help protect the New Orleans metro area from hurricanes have been lost to subsidence and climate change induced sea-level rise (Colten 2009; Campanella, Etheridge, and Meffert 2004). Hurricane Katrina heightened vulnerability to storms by resulting in a pulsed loss of approximately 220 square miles of coastal wetlands in southeastern Louisiana.

We examined the shift to a new normal in New Orleans by examining relationships and interactions between social and landscape diversity to better understand processes of post-disaster adaptation and transformation, We tested whether social and ecological diversity exhibited parallel responses to Katrina-related flooding, and whether measures of diversity were correlated across post-Katrina New Orleans. Contrary to our first prediction, social diversity and ecological diversity exhibited contrasting responses to Katrina-related trauma, which resulted in higher social diversity and lower ecological diversity across the city. However, we did find evidence consistent with our second prediction that flood-related trauma might give rise to novel relationships across the city. Post-Katrina relationships between social diversity and landscape diversity express continuities with pre-Katrina relationships, but are nevertheless qualitatively different. A negative correlation was found between social and ecological diversity following storm-related trauma, which suggests that less severely flooded areas of New Orleans became more ethnoracially diverse and more severely flooded areas became more ecologically diverse after the storm.

Social and ecological diversity appear to have become more tightly coupled following the storm rather than merely returning to pre-Katrina normalcy. Though further analysis is necessary to better understand processes of change, evidence of a relationship between the magnitude of social and ecological change across the Katrina event (Figure 6) suggests that interactions and feedbacks contributed to the emergence of new normal conditions in the city. It is possible, then, that storm-related trauma acted as an initial driver of change, while subsequent feedbacks continued to influence the distribution and magnitude of diversity across the city. The close proximity and coincident footprints of urban ecological and societal communities increases the likelihood of interactions, particularly when both communities are assembling such as during periods of post-trauma recovery. Accordingly, our findings suggest that traumatic events can establish initial conditions that influence the trajectory and outcomes of coupled assembly, and that the assembly of ecological and societal communities in post-trauma urban landscapes is a coupled dynamic, with outcomes (e.g. diversity) being contingent on interactive responses to common drivers (or conditions). Therefore coupled assembly can be considered an operational form of socio-ecological transformation, where "ecological" and "social" factors have reciprocal feedback effects.

Though understanding of the linkages between trauma, diversity, and resilience in New Orleans is still rudimentary, our findings demonstrate that diversity is much more than a static characteristic of a system at a single point in time. Recognizing that the value and outcomes of diversity can differ according to historical, socio-economic, cultural, and political contexts, other (perhaps very different) measures may be required to understand key feedbacks and relationships between ecological and social dimensions of post-trauma urban landscapes. For example, additional work may show that the diversity of responses to trauma, not diversity of groups or species per se, may be more important in determining the pace and trajectory of post-trauma ecosystem regeneration and renewal (Elmqvist et al. 2003). More expansive efforts will be necessary to clarify the feedbacks of interlinked social–ecological systems, the role of the diversity of cross-scale interactions in contributing to both increased resilience and vulnerability, and the role of adaptive capacity and post-trauma innovation at multiple scales. Examining the interplay between ecological diversity and societal diversity endeavors to promote conceptual unification of disparate fields of research on the assembly, structure, and resilience of communities, which could yield incentives to stimulate the emergence of adaptive governance for sustaining economic integrity without sacrificing ecological sustainability.

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