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Socioecological disparities in New Orleans following Hurricane Katrina

Joshua A. Lewis,[1,2,]† Wayne C. Zipperer,[3] Henrik Ernstson,[4,5] Brittany Bernik,[2,6] Rebecca Hazen,[6] Thomas Elmqvist,[1] and Michael J. Blum[2,6]

[1]*Stockholm Resilience Centre, Stockholm University, Kräftriket, 104 05 Stockholm Sweden*
[2]*Tulane-Xavier Center for Bioenvironmental Research, Tulane University, New Orleans, Louisiana 70118 USA*
[3]*USDA Forest Service, Gainesville, Florida 32611 USA*
[4]*KTH Environmental Humanities Laboratory, KTH Royal Institute of Technology, 114 28 Stockholm Sweden*
[5]*Department of Geography, School of Environment, Education and Development, University of Manchester, Manchester M13 9PL UK*
[6]*Department of Ecology & Evolutionary Biology, Tulane University, New Orleans, Louisiana 70118 USA*

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Abstract. Despite growing interest in urban resilience, remarkably little is known about vegetation dynamics in the aftermath of disasters. In this study, we examined the composition and structure of plant communities across New Orleans (Louisiana, USA) following catastrophic flooding triggered by levee failures during Hurricane Katrina in 2005. Focusing on eight neighborhoods that span a range of demographic and topographical conditions, we assessed whether plant communities in post-Katrina New Orleans reflect flooding disturbance and post-disaster landscape management policies. We then contextualized vegetation patterns and associated ecosystem services and disservices with census-based demographic trends and in-depth interviews to draw inferences about the drivers and outcomes of urban land abandonment in the aftermath of Hurricane Katrina. We found that areas subject to the greatest flooding disturbance exhibit the highest rates of vegetation response. Disturbance intensity and elevation, however, are relatively weak drivers of vegetation differences among the studied neighborhoods. Rather, we found that household income, racial demographics, and land abandonment are important drivers of vegetation community composition and structure across the city. Our findings indicate that resettlement and landscape management policies can mediate post-flooding ecological outcomes and demonstrate that unmanaged, emergent vegetation on abandoned lands can be an environmental justice concern in underserved and historically marginalized communities.

Key words: abandonment; disturbance; environmental justice; resilience; urban ecology; vegetation.

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† **E-mail:** jlewis9@tulane.edu

Introduction

Catastrophic flooding in New Orleans, New York, and other densely populated coastal areas has ignited considerable interest in socioecological (or social–ecological) responses to disturbances and disasters in urban landscapes (Wallace and Wallace 2008, Evans 2011, Tyler and Moench 2012, Grimm et al. 2017). A growing literature suggests that responses are driven by policy-driven resettlement and landscape management that reconfigures ecological communities and associated ecosystem services or disservices (e.g., Ernstson et al. 2010, Gotham and Campanella 2011, Gotham et al. 2014, Gulachenski et al. 2016, Rael et al. 2016). If so, then further understanding of post-disaster socioecological relationships could help prevent the emergence or reinforcement of disparities in vulnerability and recovery following catastrophic events (Gulachenski et al. 2016, Rael et al. 2016).

The catastrophic flooding of New Orleans following Hurricane Katrina in 2005 has yielded an exceptional landscape for investigating disturbance, vegetation management, and resultant changes in urban ecological communities. One of the deadliest and most destructive hurricanes in U.S. history, Katrina and the subsequent deluge caused over 1500 deaths and damages estimated at $125 billion across the New Orleans metropolitan area. Soon after Katrina's landfall on 29 August 2005, storm surge and heavy rain triggered widespread and catastrophic infrastructure failure that flooded over 80% of the urbanized East Bank of New Orleans, putting some parts of the city under 3 m of water for nearly a month. Flooding affected over 12,000 business establishments (41% of total businesses) and 228,000 occupied housing units (45% of the metropolitan total). All told, 1.1 million people (86% of the metropolitan population) were adversely affected by Hurricane Katrina (Brookings Institution 2005). Precipitous depopulation of the city proceeded following the storm. Striking disparities in community vulnerability and recovery have arisen—or have intensified—in New Orleans in the decade since Katrina, driven in part by massive flood damage, varying patterns of population return and housing costs, the demolition of thousands of structures, the inability or reluctance of homeowners to rebuild, and disparate land management policies (Fig. 1).

As in other counter-urbanizing or shrinking cities, land abandonment has emerged as a major public policy challenge in New Orleans (Langner and Endlicher 2007, Mathey and Rink 2010, Dewar and Thomas 2012, Haase 2013, Safransky 2014, Gulachenski et al. 2016). Management interventions on abandoned urban lands can generate broadly shared ecosystem services including food provisioning, stormwater management, and hazard mitigation (Langner and Endlicher 2007, Mathey and Rink 2010, Haase 2013). Others have suggested that emergent exotic trees on abandoned lands may generate important ecosystem services (Riley et al. 2017). However, the difficulty and costs of controlling emergent vegetation and managing abandoned urban land in New Orleans have challenged returning residents and policymakers working to attract capital investment and repopulate flooded neighborhoods. State and municipal land managers have developed a suite of management programs that strive to maintain lawn-like grasslands, yet the mass demolition of homes and businesses, and the limited redevelopment of some neighborhoods, has resulted in new space for the proliferation of opportunistic (i.e., ruderal or spontaneous) trees, shrubs, and grasses (Sukopp 1971, Zipperer 2002, Muratet et al. 2007, Hobbs et al. 2009, Gandy 2013, Lachmund 2013). Management efforts have succeeded in some neighborhoods, but stark patchworks of overgrown and carefully maintained lots remain prevalent in others (Fig. 2). Thus, services and amenities associated with urban vegetation may be accruing unevenly across the city, possibly following physiographic or socioeconomic fragmentation (Heynen 2003, Heynen et al. 2006, Pham et al. 2012, Ernstson 2013, Berland et al. 2015).

Contrary to perspectives that vegetation only provides valued ecosystem services, urban "greening" can generate ecosystem *disservices* in urban landscapes. As the flipside of ecosystem services (Lyytimäki and Sipilä 2009), disservices emerge through a complex interplay between ecosystem functions, landscape dynamics, built infrastructure, and human activity (Lyytimäki and Sipilä 2009, Douglas 2012, Gómez-Baggethun et al. 2013, Von Döhren and Haase 2015). Disservices related to urban vegetation include reduced visibility, crime, and personal safety, especially at night and especially for women (Koskela and Pain 2000, Brownlow 2006, Jorgensen and Anthopoulou 2007, Jansson et al. 2013). A service or benefit in one context or at one scale also can be a disservice or nuisance at another. For instance, Escobedo et al. (2011) found that 35% of the carbon sequestration performed by a subtropical urban forest was generated by invasive and undesirable species. The potential for discord thus requires viewing urban ecosystems as more than "service-providing units" (Kontogianni et al. 2010) to better capture the discontinuous and unequal character of vegetation in socioecological systems.

Urban land abandonment highlights how an overemphasis on ecosystem services can obscure the hazards and disservices associated with urban vegetation (Lyytimäki et al. 2008, Lyytimäki and

Fig. 1. Immediate aftermath of Hurricane Katrina in the Lower 9th Ward (top), Gentilly (bottom left), and St. Bernard Parish (bottom right). Note defoliation of trees and shrubs, and deposition of sediment on ground layer. Top and bottom left photos courtesy Infrogmation of New Orleans via Wikimedia Commons. Bottom right image courtesy FEMA News Service.

Sipilä 2009, Baró et al. 2014, Haase et al. 2014). For example, abandoned lots traditionally treated as "blight" can be important habitat for songbirds (Rega-Brodsky et al. 2016), and abandoned lots are increasingly becoming re-purposed as green infrastructure for stormwater retention (HUD 2016). Unlike cultivated and managed tree canopies that are broadly endorsed as providers of public goods and ecosystem services (e.g., carbon sequestration, mitigation of heat and air pollutants), ruderal vegetation also can generate hazards for human health and community well-being (Nowak and Dwyer 2007, Haase 2008, Schetke and Haase 2008, Escobedo et al. 2011, Grove et al. 2014, Locke and Baine 2014, Schwarz et al. 2015, Gulachenski et al. 2016). Recent work indicates that abandonment can favor commensal pests, such as rodents and mosquitos, and thus elevate zoonotic pathogen exposure risk (Hamer et al. 2012, Gulachenski et al. 2016, Rael et al. 2016). Illegal dumping of used tires, for instance, can collect water and serve as mosquito habitat (O'Meara et al. 1995, Blackman and Palma 2002, Rojas-Caldelas and Zambrano 2008). Unmanaged tree roots

Fig. 2. Mosaics of land abandonment in the Lower 9th Ward (top two images) and St. Bernard Parish (bottom image). State-managed lots, when interspersed with lots overgrown with emergent vegetation, have become

(Fig. 2. *Continued*)
popular sites for illegal dumping (top). Alternative land uses such as urban agriculture have been implemented on a limited basis, often directly abutting state-managed properties and overgrown lots (middle). In St. Bernard Parish, officials have more intensively managed vegetation on abandoned lands, producing lawn-like grasslands across large swaths of the community. Photos by Joshua A. Lewis, December 2016.

may also disturb infrastructure networks or building foundations, and damaged or diseased trees might fall, posing hazards for people and structures (Escobedo et al. 2011). Additionally, the visual aesthetic of unmanaged emergent vegetation can generate social stigmas around green space and adjacent residences, depressing property values and reinforcing patterns of capital disinvestment (Brownlow 2006, Lyytimäki and Sipilä 2009).

Despite increasing interest in urban resilience and land abandonment (Alberti and Marzluff 2004, Ernstson et al. 2010, Jha et al. 2013), remarkably little is known about plant communities in cities following disasters. It is possible that disturbance and post-disturbance interventions create more productive ecosystems that support more species (sensu Gaston 2005), but the reverse might also be true, where habitat loss reduces biodiversity and ecosystem function (sensu Rapport et al. 1985). Alternatively, disturbance and interventions might create novel communities that exhibit little semblance to conditions preceding a disaster (Sukopp 1971, Hobbs et al. 2009, Lachmund 2013). Similar to nearby natural areas (Chambers et al. 2007, Stanturf et al. 2007, Chapman et al. 2008, Kupfer et al. 2008, Wang and Xu 2009), forest cover appears to have sharply declined across New Orleans following Hurricane Katrina (Nowak and Greenfield 2012). Landscape heterogeneity also appears to have fallen across the city (Gotham et al. 2014). In this study, we examined how the composition of plant communities varies across post-Katrina New Orleans. We assessed how vegetation disturbance and response as well as plant species richness and community composition compare between flooded and unflooded areas of the city. We also examined the extent to which vegetation outcomes and associated ecosystem services and disservices have been mediated by management practices applied to abandoned lands. We then contextualized vegetation patterns with census-based demographic trends and in-person interviews to draw inferences about the socioeconomic implications of abandoned land management following prolonged urban flooding.

Methods

Study area

Our study was conducted in the City of New Orleans (Orleans Parish) and adjacent areas of St. Bernard Parish (Fig. 3). The city spans approximately 900 km^2, and in 2015 supported a population of approximately 389,000. The areas of St. Bernard Parish assessed in the study—the municipalities of Arabi and Chalmette—are home to roughly 20,000 residents. Our focal study area is the Bienvenue Basin, an urbanized estuarine basin along the eastern margin of New Orleans, which extends from the historic center of the city eastward through St. Bernard Parish and into Lake Borgne (Fig. 3). We divided the study area into four sub-units that we refer to as "basin neighborhoods," which encompass the Lower 9th Ward, Upper 9th Ward, the 7th and 8th Wards of downtown New Orleans, and the Arabi and Chalmette communities of St. Bernard Parish (Fig. 3). Study neighborhood delineations were based on hydrological boundaries, municipal-political geography, and 2010 census boundaries. In some cases, census tract and neighborhood boundaries were slightly altered to capture nearby green areas, and to exclude large industrial zones with limited access for inventorying vegetation.

The Bienvenue Basin was severely inundated by storm surge following the 2005 levee failures and was also impacted by hurricane-related flooding in 1965, 1947, and 1915 (Lewis 2015). The Industrial Canal, a deepwater shipping canal, bisects the basin (Fig. 3). Before the construction of a storm surge barrier in 2010, the Mississippi River–Gulf Outlet and the Gulf Intracoastal Waterway connected the Industrial Canal to the Gulf of Mexico. Storm surge was pushed into this canal network during Hurricane Katrina, which caused levee walls to fail in multiple locations. Flood protection measures also

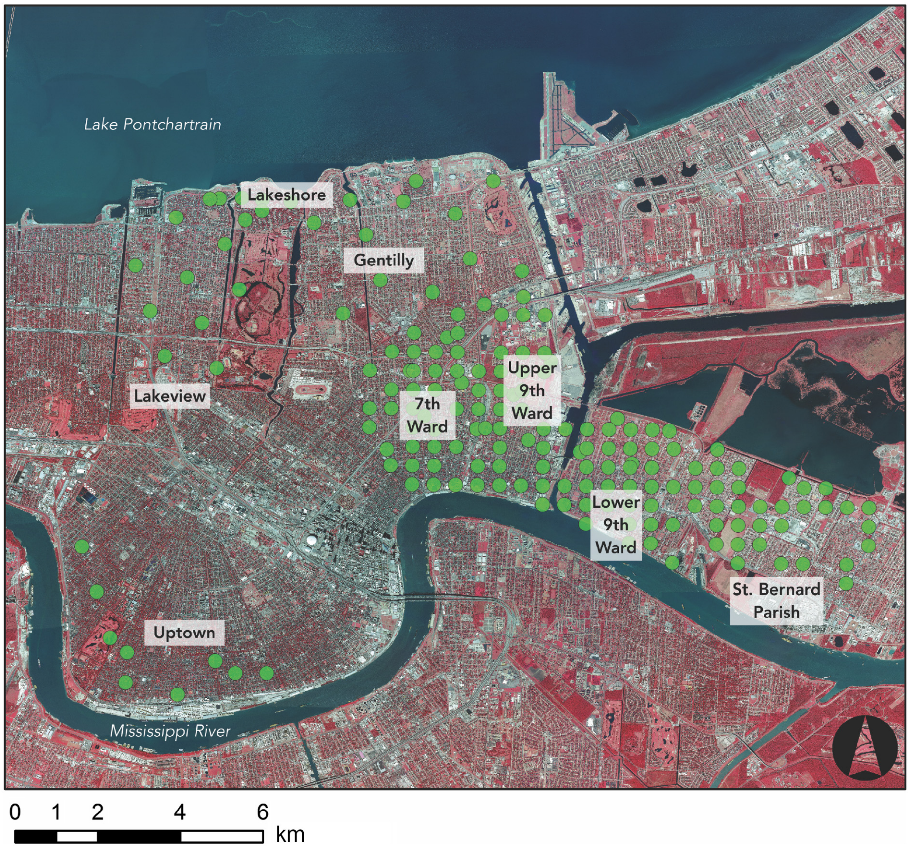

Fig. 3. Study neighborhoods and context in New Orleans, Louisiana. Green circles indicate vegetation inventory locations. Study neighborhoods are labeled. Base imagery is DOQQ aerial photos, courtesy of U.S. Geological Survey 2008.

failed along canals intended to provide drainage to the city (Seed et al. 2008). Floodwater stood for up to a month in low-lying areas. Thick layers of sediment settled as the waters receded, leaving a mat of mud and soil from a few centimeters to over a meter thick across basin neighborhoods and other areas across the eastern flank of the city (Plumlee et al. 2006).

For comparison, we also examined "non-basin" neighborhoods outside of the Bienvenue Basin. Four non-basin neighborhoods were selected to better characterize outcomes of flooding and recovery trajectories across the city. The four neighborhoods included segments of the Lakeview, Lakeshore, Gentilly, and Uptown neighborhoods, all within the City of New Orleans (Fig. 3). The Uptown and Lakeshore areas (as delineated in our study) had little to no flooding, whereas Gentilly and Lakeview were severely inundated via drainage canals that filled with storm surge from Lake Pontchartrain. Though severely flooding, these areas did not experience the hydrological intensity of the storm surge that flooded the Bienvenue Basin (Seed et al. 2008). Sediment deposition in the non-basin neighborhoods was more localized and differed in composition to neighborhoods east of the Industrial Canal (Plumlee et al. 2006).

Vegetation disturbance and response indices

We calculated a disturbance index and a response index to assess the effects of Hurricane Katrina on vegetation in each study neighborhood. Both indices were based on a Normalized Difference Vegetation Index (NDVI), which was generated using ArcGIS v10.3 (ESRI, Redlands, California, USA) software and aerial photographs taken in January 2004, October 2005, and October 2013 (i.e., before and after Hurricane Katrina). The

January 2004 and October 2005 images were U.S. Geological Survey (USGS) digital orthophoto quadrangles (DOQ). The National Agricultural Imagery Program produced the October 2013 aerial imagery. All imagery was downloaded using the USGS Earth Explorer downloader (http://earthexplorer.usgs.gov/). Normalized Difference Vegetation Index was calculated using the near-infrared and green bands. The aerial images were merged into a mosaic of the study area. The calculated NDVI measures were intended to capture overall vegetative cover, including trees, shrubs, and herbaceous material. Pixels classified as non-vegetative cover (roads, structures, water) were eliminated by cross-referencing NDVI outputs with the original aerial images. The zonal statistics function in the spatial analyst extension for ArcGIS v10.3 was used to generate vegetation pixel counts on a 20-m circle surrounding the vegetation survey point.

To capture how vegetative cover shifted across Hurricane Katrina, we calculated a vegetation disturbance index using the following formula (Eq. 1):

$$\mathrm{VD}_i = -\frac{\mathrm{NDVI}_{2005i} - \mathrm{NDVI}_{2004i}}{(\sum_{j=1}^{n} \mathrm{NDVI}_{2005j} - \mathrm{NDVI}_{2004j})/n}. \quad (1)$$

To capture how vegetative cover has shifted since Hurricane Katrina, we developed a vegetation response index by examining the vegetative cover change between October 2005 and October 2013 (i.e., the time period over which the city gradually repopulated). The vegetation response index was calculated using the following formula (Eq. 2):

$$\mathrm{VR}_i = -\frac{\mathrm{NDVI}_{2013i} - \mathrm{NDVI}_{2005i}}{(\sum_{j=1}^{n} \mathrm{NDVI}_{2013j} - \mathrm{NDVI}_{2005j})/n} \quad (2)$$

Estimating vegetation disturbance and response from NDVI presented some complications that warrant recognition. First, image quality differed between 2004 and subsequent years of interest. Accounting for this required calculating NDVI for each quadrant image from 2004 and building a mosaic of the resulting NDVI layers. Also, because October 2004 imagery is not available, we were unable to directly compare the extent of divergence in NDVI relative to October 2005 (i.e., 1.5 months post-Katrina landfall). Though January 2004 imagery represented winter, or "leaf-off" conditions, no temperatures below 0°C were recorded during the autumn or winter preceding the imagery. Additionally, New Orleans is a subtropical environment and maintains high vegetative reflectance even during seasonal low conditions. The extent that NDVI in October 2005 diverged from the January 2004 NDVI thus serves as a surrogate value of the intensity of disturbance effects, which are captured in our vegetation disturbance index. Accordingly, the vegetation disturbance indices do not report true "loss" but instead capture the extent that Hurricane Katrina resulted in vegetative cover deviating from the seasonal low of the previous year. While this is less than ideal set of comparisons, it is based on the best available imagery for estimating disturbance, and the approach is supported by response trends that are consistent with flooding intensity (i.e., depth and duration). As described below, neighborhoods that suffered very little or no flooding exhibit relatively stable NDVI readings between January 2004, October 2005, and October 2013. Neighborhoods that experienced intense flooding exhibited NDVI values that dramatically declined, and then spiked over the same period.

Vegetation inventory

Following U.S. Forest Service protocols for urban forest inventories (Nowak et al. 2008, USDA-FS 2016), we surveyed plant community composition to further explore spatial patterns of socioecological relationships. From late May to early August in 2013 and 2014, we inventoried vegetation across a total of 180 circular plots (400 m^2) spanning the study neighborhoods. In basin neighborhoods, we surveyed 140 plots that were identified using a 500-m point-line grid generated in ArcGIS v10.3. The following number of plots were surveyed per basin neighborhood: 7th Ward (33); Upper 9th Ward (37); Lower 9th Ward (30); and St. Bernard (40). We surveyed an additional 20 plots in basin neighborhoods that were distributed across a 1-km grid established for a forest inventory conducted in 2010. These plots were reassessed in 2013, which added a dimension of non-uniformity to the distribution of plots in the basin neighborhoods (Fig. 3). We examined a minimum of eight plots in each non-basin neighborhood, as follows: Gentilly (14); Lakeshore (10); Lakeview (8); and Uptown (8). The plots were selected for accessibility from a larger network of locations arrayed across a 500-m point-line grid.

We applied standard field protocols and definitions utilized by the USDA Forest Service and the iTree protocol (USDA-FS 2016). Each plot was assessed according to percent values for the following land cover categories: plantable space, cover by buildings, cement, tar, soil, rock, herbaceous/ivy, maintained grass, unmaintained grass, duff/mulch, and water. Each woody stem ≥2.5 cm diameter at breast height (dbh) was designated as a tree, and all woody stems ≥30 cm height and <2.5 cm dbh were designated shrubs. We recorded percent cover and height by species within the entire plot. To assess percent cover of herbaceous species and woody stems <30 cm height (hereafter described as the herbaceous layer), we examined five randomly located 1-m^2 sub-plots confined to pervious surfaces in each plot. Total percent cover was allowed to exceed 100% to account for species varying in height.

Field manuals included Allen et al. (2004), Miller and Miller (2005), Kirkman et al. (2007), and Schummer et al. (2011). Unknown species were collected and, when possible, identified according to archival accessions at the Tulane University Herbarium. Unidentifiable specimens were grouped into morphospecies based on observable characteristics to include in species richness counts.

Social demographics, land management, and land abandonment

Demographic data were collected at the U.S. Census tract and block group levels from three sources: the 2000 decennial census, the 2010 decennial census, and the 2009–2013 American Community Survey data sets. These data include measures of overall population, median household incomes, and reported race. Occupied housing recovery was determined by comparing the number of occupied housing units in 2000 to those in 2010. Due to changes in census tract boundaries between 2000 and 2010, some 2000 tract data were aggregated into the larger 2010 boundaries.

We assessed the influence of agency-led landscape management on vegetation across the study region, focusing on how housing recovery programs shaped patterns of land abandonment. In particular, we examined policies linked to the Road Home program, a housing recovery program initiated by the U.S. Department of Housing and Urban Development and the Louisiana Recovery Authority, widely considered to be the most expansive housing recovery program in U.S. history (Gotham and Greenberg 2014). After Hurricane Katrina, participating owners of storm-damaged properties were offered three options for assistance. Option 1 provided financial assistance for property owners to repair or rebuild their homes on the original property. Option 2 enabled owners to sell their properties to the State of Louisiana, with the owner's intent to stay in Louisiana. Option 3 was also a state buyout of the property, but with the owner's intent to leave Louisiana. State-owned properties obtained under Options 2 and 3 were transferred to the Louisiana Land Trust (LTT), which was tasked with demolishing any remaining structures, and passing the property to programs that sell lots to new or adjacent owners, manage the vegetation on the lot, or re-develop the site with an alternate land use. The management of these properties was ultimately passed to parish (i.e., county)-level agencies. In Orleans Parish, the New Orleans Redevelopment Authority (NORA) was tasked with the sale and management of properties bought by the state. In St. Bernard Parish, the LLT worked with the parish government to re-develop abandoned lots, sell abandoned lots to adjacent homeowners, and manage emergent vegetation.

We examined data from the State of Louisiana, the City of New Orleans, and St. Bernard Parish on properties participating in the Road Home program and subsequent land management programs. The Orleans Parish data included addresses of properties sold by NORA, and properties remaining in the NORA inventory as of 2014. In St. Bernard Parish, the addresses for properties remaining under LLT ownership were available as of 2012. After geocoding all addresses, we used the spatial join function in ArcGIS v10.3 to assess the number of state-owned properties in each tract and study neighborhood. This enabled us to determine the extent of public management of vacant land across the study area, and where lots have been circulated back into private ownership or management through redevelopment mechanisms.

We also generated a private lot abandonment index because properties falling into this category are often the most poorly maintained and thus provide habitat for emergent vegetation.

The index accounts for housing units lost in a census tract between 2000 and 2010, minus the number of properties under state maintenance and management in a given tract:

$$R_i = (\mathrm{HUnits}_{2000_i} - \mathrm{HUnits}_{2010_i}) - \text{State managed lots}_i.$$

While coarse, this metric is an improvement beyond U.S. Census vacancy metrics that do not capture widespread abandonment and demolition following Katrina. Thus, we consider it the best available estimate of the number of properties where housing units have been demolished or abandoned, but that remain under private ownership.

Additionally, we conducted in-depth interviews with representatives of NORA and St. Bernard Parish to better understand outcomes of agency-led landscape management practices associated with recovery programs. We also attended public meetings related to post-disaster planning, neighborhood association meetings, and other events between 2006 and 2015, to assess community involvement in land use planning and environmental management in the study area.

Statistical analyses

Shapiro–Wilk tests identified variables with significant departures from normal distribution, which were subsequently analyzed through nonparametric approaches. All tests were performed with an alpha of 0.05. With the exception of income, all other neighborhood profile variables (Table 1; i.e., flooding, social demography, and land management variables) were treated as proportions, and neighborhood differences were tested using χ^2 tests. Kruskal–Wallis H tests were conducted to test for differences in median household income among neighborhoods, followed by Dunn's post hoc tests to identify significant differences among means. This was repeated for vegetation disturbance and response, vegetation attributes (Table 2), and land cover categories (Table 3), with the exception of maintained and unmaintained grass. Chi-square tests were used to test for differences in the presence of maintained and unmaintained grass among plots because of the high proportion of zero values in the data set. Variation in growth forms between neighborhoods was examined by calculating

Table 1. Study neighborhood demographics and landscape profiles.

Plot	N	Elevation (m)	Flooded (%)	Pop. recovery (%)	Housing recovery (unit^{-1})	Abandonment rate (km^{-2})	State-owned lots: Re-sold (km^{-2})	State-owned lots: Managed (km^{-2})	Median household income (USD)	Black pop. (%)	White pop. (%)
Uptown	9	1.2^{a} ± 0.2	0^{-}	99^{+}	1.00^{+}	21^{-}	0^{-}	0^{-}	$61{,}321^{a}$ ± 6,548	15^{-}	79^{+}
Lakeshore	10	0.3^{ab} ± 0.1	0^{-}	99^{+}	1.18^{+}	0^{-}	1^{-}	0^{-}	$94{,}242^{a}$ ± 7,729	9^{-}	85^{+}
Lakeview	8	-2.1^{e} ± 0.2	100	80^{+}	0.78	255^{-}	77^{+}	0^{-}	$69{,}953^{a}$ ± 4,655	5^{-}	88^{+}
Gentilly	14	-1.4^{e} ± 0.2	100	83^{+}	0.93^{+}	156^{-}	68^{+}	9^{-}	$37{,}447^{ab}$ ± 3,309	80^{+}	15^{-}
7th Ward	33	-0.5^{d} ± 0.2	85	84^{+}	0.87^{+}	246^{-}	30^{-}	11^{-}	$26{,}642^{b}$ ± 2,401	75^{+}	21^{-}
Upper 9th Ward	36	-0.2^{cd} ± 0.2	75	80^{+}	0.67^{-}	387	26^{-}	19	$27{,}846^{b}$ ± 3,243	62^{+}	34^{-}
Lower 9th Ward	29	-0.6^{d} ± 0.2	97	47^{-}	0.35^{-}	790^{+}	65^{+}	96^{+}	$27{,}738^{b}$ ± 3,079	95^{+}	3^{-}
Saint Bernard	40	0.0^{bc} ± 0.1	98	53^{-}	0.59^{-}	268^{+}	82^{+}	104^{+}	$36{,}602^{ab}$ ± 2,467	18^{-}	76^{+}

Notes: Reported are the number of plots surveyed, mean elevation (averaged across plots ± standard error [SE]; $H_{7,\ 171} = 60.58$, $P < 0.001$), percent of plots that were flooded ($\chi^2_7 = 96.78$, $P < 0.001$), percent of the population (pop.) recovered 2000–2010 ($\chi^2_7 = 3195.14$, $P < 0.001$), proportion of housing units recovered 2000–2010 ($\chi^2_7 = 2741.73$, $P < 0.001$), density of abandoned lots ($\chi^2_7 = 1793.81$, $P < 0.001$), density of state-owned lots that were re-sold ($\chi^2_7 = 249.83$, $P < 0.001$) or kept under state management ($\chi^2_7 = 550.27$, $P < 0.001$), mean value (±SE) of household income ($H^2_{7,61} = 41.07$, $P < 0.001$), Black population percentage ($\chi^2_7 = 5944.7$, $P < 0.001$), and White population percentage in the neighborhood ($\chi^2_7 = 47{,}015.0$, $P < 0.001$). Population and housing unit recovery are estimated based on differences between the 2000 and 2010 U.S. Census (i.e., before and after Hurricane Katrina). Significant differences among neighborhoods are distinguished by letters for variables tested by rank sums, and by + or − for positive or negative departures from expected values using χ^2 tests. Standard error given in parentheses.

Table 2. Vegetation attributes and richness across study neighborhoods (mean ± SE).

Vegetation attributes	Uptown	Lakeshore	Lakeview	Gentilly	7th Ward	Upper 9th	Lower 9th	St. Bernard
Tree richness (sp./plot)	1.11 ± 0.20	1.40 ± 0.37	1.38 ± 0.46	0.86 ± 0.21	0.55 ± 0.20	0.75 ± 0.22	0.93 ± 0.23	0.25 ± 0.09
Shrub richness (sp./plot)	3.00[a] ± 0.94	2.70[a] ± 0.63	1.88[ab] ± 0.20	1.21[ab] ± 0.62	0.67[b] ± 0.17	0.53[b] ± 0.16	1.21[ab] ± 0.25	0.75[b] ± 0.32
Herbaceous richness (sp./plot)	9.44 ± 1.59	8.90 ± 0.86	9.50 ± 2.38	11.71 ± 1.34	12.27 ± 1.38	12.75 ± 1.13	13.66 ± 1.08	10.85 ± 0.92
Diameter at breast height (dbh; cm)	41.40[a] ± 8.86	40.85[a] ± 7.63	29.45[ab] ± 7.18	17.33[bc] ± 5.25	25.75[ab] ± 5.85	11.28[c] ± 1.53	16.41[b] ± 1.72	26.35[abc] ± 9.21
Stem density (stems/plot)	3.78[a] ± 1.75	2.30[abc] ± 0.87	4.12[ab] ± 1.73	1.57[abcd] ± 0.51	1.06[cd] ± 0.36	2.69[bcd] ± 1.14	3.03[abc] ± 0.91	0.52[d] ± 0.22
Tree density (trees/plot)	2.11[a] ± 0.68	1.90[ab] ± 0.57	3.12[a] ± 1.08	1.29[abc] ± 0.38	0.76[cd] ± 0.25	1.72[bcd] ± 0.83	1.62[abc] ± 0.49	0.30[d] ± 0.11
Tree basal area (m^2/plot)	0.52[a] ± 0.22	0.41[a] ± 0.15	0.52[ab] ± 0.32	0.08[abcd] ± 0.05	0.09[cd] ± 0.06	0.04[cd] ± 0.01	0.05[bc] ± 0.02	0.04[d] ± 0.03
Shrub cover (%/plot)	8.44[ab] ± 2.46	8.50[a] ± 1.83	4.38[bc] ± 3.05	3.00[c] ± 1.53	2.33[c] ± 0.69	2.07[c] ± 0.57	2.76[bc] ± 0.87	1.45[c] ± 0.50
Herbaceous cover (%/plot)	20.67 ± 3.64	39.70 ± 4.89	37.88 ± 11.11	46.00 ± 5.52	34.64 ± 5.27	40.28 ± 4.75	50.83 ± 5.02	51.40 ± 5.92

Notes: Mean values (±standard error [SE]) are reported per plot across strata (tree: $H_{7,\ 171} = 28.83$, $P < 0.001$; shrub: $H_{7,\ 171} = 29.62$, $P < 0.001$; herbaceous: $H_{7,\ 171} = 12.65$, $P = 0.08$), tree dbh ($H_{7,\ 219} = 44.55$, $P < 0.001$), tree stem density ($H_{7,\ 171} = 28.57$, $P < 0.001$), tree density ($H_{7,\ 171} = 31.55$, $P < 0.001$), tree basal area ($H_{7,\ 171} = 42.45$, $P < 0.001$), percent cover for shrub ($H_{7,\ 171} = 26.78$, $P < 0.001$), and herbaceous strata ($H_{7,\ 171} = 13.43$, $P = 0.06$). Significant differences among neighborhoods are distinguished by letters for variables tested by rank sums.

mean values for tree density, basal area, and dbh, as well as for percent cover of shrub and herbaceous layers by plot.

For comparisons of neighborhood-wide species richness, we accounted for differences in sampling intensity among neighborhoods by generating estimates of expected species richness (S_{exp}) from interpolated neighborhood-specific species accumulation curves through sample-based rarefaction over 100 randomization runs with the software package EstimateS (Colwell et al. 2004, Colwell 2005).

We used multidimensional scaling ordination to examine relationships and to identify potential drivers of variation in community structure among neighborhoods (Ramette 2007). Metric

Table 3. Study neighborhood land cover profiles.

Land cover	Uptown	Lakeshore	Lakeview	Gentilly	7th Ward	Upper 9th	Lower 9th	St. Bernard
Plantable space (%)	18.3[ab] ± 7.3	28.5[ab] ± 5.3	31.9[ab] ± 6.5	40.4[ab] ± 5.1	31.5[ab] ± 4.6	29.6[b] ± 4.4	50.9[a] ± 5.3	48.3[ab] ± 5.8
Building (%)	37.2[a] ± 8.0	19.0[b] ± 7.7	21.9[ab] ± 7.4	22.1[b] ± 6.7	22.3[b] ± 4.0	16.6[ab] ± 3.8	12.1[a] ± 3.3	10.9[b] ± 3.2
Impervious (%)	68.1 ± 7.2	52.5 ± 5.7	46.5 ± 9.1	49.4 ± 5.4	62.6 ± 5.2	57.0 ± 5.2	45.4 ± 4.9	43.6 ± 5.8
Mulch (%)	4.7[ab] ± 1.7	7.8[a] ± 2.7	7.5[ab] ± 3.5	1.6[bc] ± 0.8	0.9[c] ± 0.6	1.4[c] ± 1.0	0.3[c] ± 0.2	0.9[c] ± 0.6
Herbaceous/Ivy (%)	6.6[ab] ± 3.6	0.7[b] ± 0.5	1.6[ab] ± 1.3	4.4[b] ± 3.3	3.2[b] ± 1.3	10.1[ab] ± 3.3	16.3[a] ± 3.9	9.1[b] ± 4.2
Maintained grass (%)	14.1[+] ± 4.0	39.0[+] ± 4.7	36.2[+] ± 11.3	39.4[+] ± 6.0	21.4[+] ± 4.2	25.4[+] ± 4.3	19.0[−] ± 5.2	31.8[+] ± 5.2
Unmaintained grass (%)	0.0[−] ± 0.0	0.0[−] ± 0.0	0.0[−] ± 0.0	2.1[−] ± 2.1	10.1[−] ± 4.9	4.7[−] ± 2.4	15.5[+] ± 4.1	10.5[−] ± 4.3

Notes: Mean (±standard error) value of land cover percentages in inventoried neighborhoods, showing mean percent area ± standard error categorized as plantable space ($H_{7,\ 171} = 18.09$, $P = 0.01$), building ($H_{7,\ 171} = 17.58$, $P = 0.01$), impervious ($H_{7,\ 171} = 13.09$, $P = 0.07$), mulch ($H_{7,\ 171} = 53.69$, $P < 0.001$), herbaceous/ivy ($H_{7,\ 171} = 28.03$, $P < 0.001$), the presence of maintained grass ($\chi^2_7 = 26.48$, $P < 0.001$), and the presence of unmaintained grass ($\chi^2_7 = 20.02$, $P < 0.01$). Significant differences among neighborhoods are distinguished by letters for variables tested by rank sums, and by + or − for positive or negative departures from expected values using χ^2 tests.

Metric Dimensional Scaling (MDS) analyses were employed to enable use of a dissimilarity metric appropriate for the presence of zero values in the data set. Pairwise community dissimilarity among plots was calculated according to binomial deviance, which improves on the Bray–Curtis measure when a large proportion of plots have no species in common or when species abundance is highly variable (Anderson and Millar 2004). All demographic, physiographic, land cover, and management variables were regressed onto the resulting ordination axes to assess relationships with community variation (given by the coefficient of determination, r^2). Fitted variables were permutation-tested for significance. To remove extraneous variables, redundancy was identified based on a priori definitions (e.g., the re-sold component of state lots, which is captured by housing recovery and abandonment), which was confirmed by calculating pairwise correlations. For each redundant set of variables, we retained the variable most strongly correlated with ordination axes of vegetation community structure. We also excluded variables that were rarely encountered among the study plots (e.g., water cover) or that constituted small proportions of total measures (e.g., races other than African American and White).

To facilitate interpretation of MDS ordinations of community composition in neighborhoods, we calculated species importance values for each vegetation layer (i.e., trees, shrubs, and the herbaceous layer). An importance value represents the relative contribution of a particular species to community structure (Curtis and McIntosh 1951). The importance value of a tree species for a given neighborhood was calculated from relative density and basal area. For the shrub and herbaceous layers, importance values were calculated from relative percent cover and relative frequency where relative frequency was the proportion of plots in which a species occurred. We then plotted the contributions of species with high importance values in multiple neighborhoods on ordination axes.

Results

Vegetation disturbance and response

Vegetation disturbance across the Katrina event varied significantly by neighborhood ($H_{7,\ 167}$ = 68.11, $P < 0.001$; Table 1), as did vegetation response following Katrina ($H_{7,\ 167}$ = 74.83, $P < 0.001$; Table 1). Vegetative cover was less disturbed in areas at higher surface elevations (r^2 = 0.30, $P < 0.001$) that experienced lower flooding depths, like the Uptown and Lakeshore neighborhoods (Table 1, Fig. 4). Notably, vegetation disturbance in St. Bernard and the Lower 9th Ward exceeded that of Lakeview and Gentilly, despite having higher elevation profiles.

The neighborhoods that suffered the highest vegetation losses following Hurricane Katrina (St. Bernard and Lower 9th) also exhibited the highest rates of positive vegetation response. Those response values were also negatively correlated with elevation ($r^2 = -0.31$, $P < 0.001$). However, patterns of response (Fig. 4) also indicate that the expansion of vegetative cover between 2005 and 2013 was greater in neighborhoods with widespread residential demolitions, land abandonment, and state management (Upper 9th, Lower 9th, St. Bernard) as opposed to neighborhoods with the lowest mean elevations (Lakeview and Gentilly).

Vegetation traits and land cover patterns

Mean tree diameters and basal areas were significantly different among neighborhoods ($H_{7,\ 219}$ = 44.55, $P < 0.001$; $H_{7,\ 219}$ = 42.45, $P < 0.001$). Neighborhoods suffering more intense flooding and lower median incomes (U9, L9, SB) had trees with smaller diameters and basal areas (Tables 1, 2). Basin neighborhoods supported trees with lower tree basal areas as compared to non-basin neighborhoods, with the exception of Gentilly, which supported a canopy structure similar to that found in basin neighborhoods (Table 2). The Lakeview, Uptown, and Lakeshore neighborhoods, which are more affluent and predominantly White communities, exhibited higher tree densities and tree basal areas (Tables 1, 2).

Differences in other land cover profiles also were evident among neighborhoods. With the exception of Lakeview, higher shrub coverage was evident in non-basin neighborhoods (Table 2). The same pattern held for mulch cover, which is an indicator of landscape maintenance. Non-basin neighborhoods had higher mulch cover, excepting Gentilly, which grouped with basin neighborhoods (Table 3). The proportion of plots with unmaintained grass differed among neighborhoods (χ^2_7 = 20.02, $P < 0.01$), with the Lower 9th

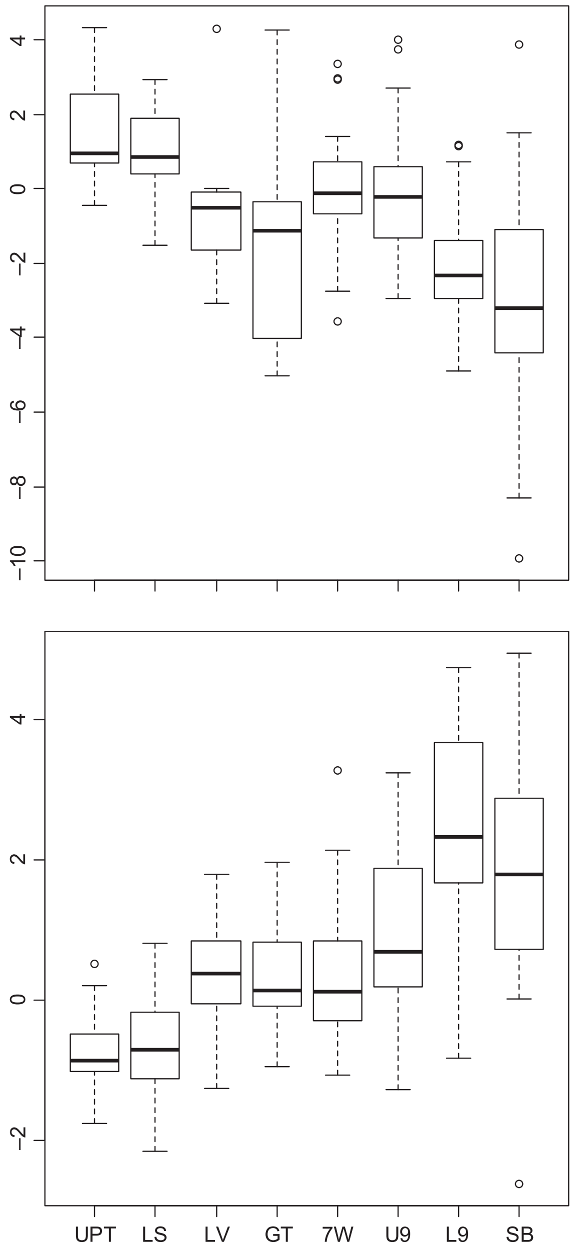

Fig. 4. Box plots comparing (top) vegetation disturbance index by Normalized Difference Vegetation Index (NDVI)-derived vegetation loss/gain between January 2004 and October 2005 (over Katrina event) and (bottom) vegetation response index by NDVI-derived loss/gain vegetative cover between October 2005 and October 2013 among neighborhoods. Letters designate significantly different groups. Vegetation disturbance across the Katrina event varied significantly by neighborhood ($H_{7,\ 167}$ = 68.11, P < 0.001), as did vegetation response following Katrina ($H_{7,\ 167}$ = 74.83, P < 0.001).

Ward having a greater proportion than all other neighborhoods. Similarly, the Lower 9th Ward had a lower proportion of plots with maintained grass (χ^2_7 = 26.48, P < 0.001; Table 3).

Species richness

Although sample sizes limited the precision of neighborhood-wide estimates (Appendix S1), certain differences among neighborhoods could still be inferred from estimates of species richness. For example, despite a broad error distribution in S_{exp}, species richness for trees was significantly higher in the Upper 9th Ward than in the St. Bernard, Uptown, and Lakeshore neighborhoods. S_{exp} values also suggest that Lakeshore has the least diverse tree assemblage, with significantly lower S_{exp} than St. Bernard and the Lower 9th Ward. The 7th Ward exhibited intermediate S_{exp} for trees. There was less differentiation among neighborhoods in shrub richness according to S_{exp} values; only St. Bernard and Lakeview registered significantly higher shrub richness compared to other neighborhoods. Similar to observations for trees, the Upper 9th Ward exhibited the highest herbaceous richness, with significantly higher S_{exp} values than those found for the Lower 9th Ward and St. Bernard. Uptown and Lakeshore exhibited significantly lower herb S_{exp} values than all neighborhoods except Lakeview.

Examining patterns at a finer spatial grain (Table 2), average species richness per plot significantly differed among neighborhoods for trees ($H_{7,\ 171}$ = 28.83, P < 0.001) and shrubs ($H_{7,\ 171}$ = 29.62, P < 0.001), but not for herbs ($H_{7,\ 171}$ = 12.65, P = 0.08). Unlike neighborhood-wide estimates of diversity, plot-level tree diversity tended to be higher in non-basin neighborhoods, particularly Uptown and Lakeshore, and lower in basin neighborhoods, with the lowest values occurring in St. Bernard. Differences between plot and neighborhood-level comparisons suggest that basin neighborhoods have higher tree species turnover among plots (i.e., beta diversity). Shrubs exhibited a similar pattern, while herbaceous species did not (Table 2). Regardless of neighborhood, plots that were flooded (Appendix S2: Table S1) exhibited significantly lower tree and shrub species richness (H_1 = 6.57, P = 0.01; H_1 = 8.31, P = 0.004) and significantly higher herbaceous species richness per plot (H_1 = 19.65, P < 0.001).

Plant community composition

Though response to socioecological drivers varied among trees, shrubs, and the herbaceous layer, neighborhood designations and land abandonment consistently explained a large proportion of variation detected in plant community structure (Figs. 5–7).

The ordination restricted to trees indicates that assemblage composition reflects species provenance (i.e., native, ornamental, and non-native species designations; Fig. 5). The ordination also shows that composition varies among neighborhoods (r^2 = 0.20, P = 0.011) and that differences among neighborhoods reflect ecological and sociodemographic factors. Non-native and/or opportunistic species (i.e., native or invasive species with growth and reproductive strategies favored following disturbance, like elderberry [*Sambucus nigra*], white mulberry [*Morus alba*], and Chinese tallow [*Triadica sebifera*]) are associated with higher land abandonment (r^2 = 0.32, P = 0.001), higher vegetation response index values (r^2 = 0.14, P = 0.006), greater plantable space (r^2 = 0.17, P = 0.002), and a higher percentage of Black residents (r^2 = 0.16, P = 0.002). On the other hand, native and culturally valued species such as southern live oak (*Quercus virginiana*) and bald cypress (*Taxodium distichum*) are associated with sites and neighborhoods (e.g., Lakeshore) with higher household incomes (r^2 = 0.1581, P = 0.004), higher percentages of White residents (r^2 = 0.15, P = 0.002), high rates of housing unit recovery since Katrina (r^2 = 0.29, P = 0.001), and higher percent cover of mulch (r^2 = 0.24, P = 0.001). Though widespread across basin and non-basin neighborhoods, ornamental species such as cabbage palm (*Sabal palmetto*), queen palm (*Syagrus romanzoffiana*), and crepe myrtle (*Lagerstroemia indica*) were especially

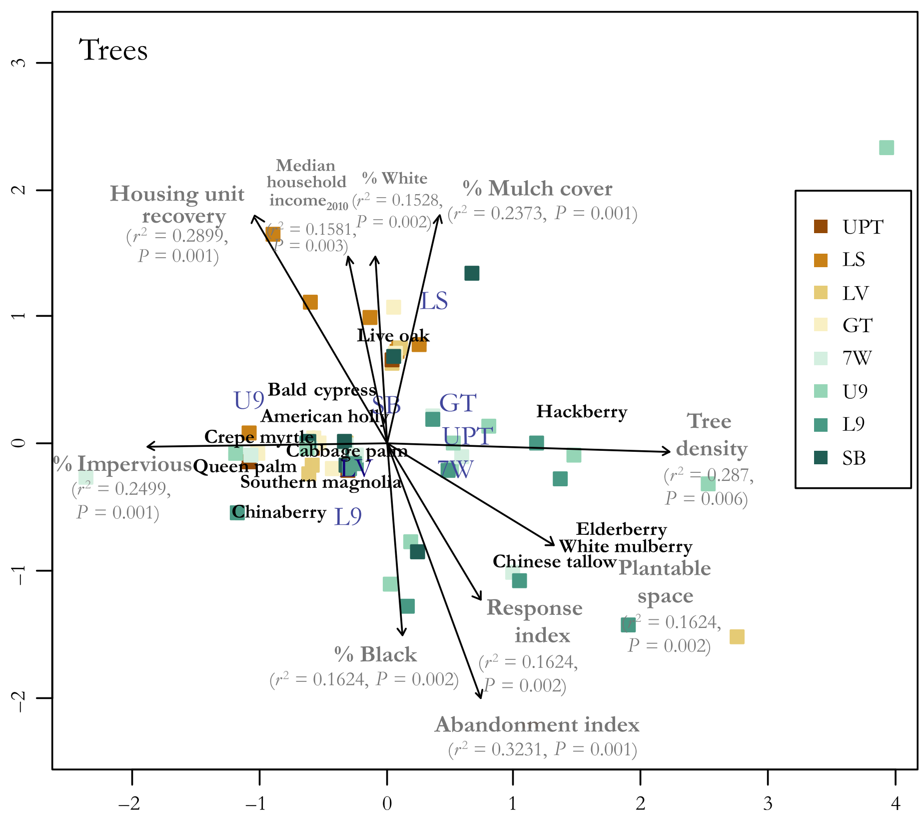

Fig. 5. Ordination analyses for trees. Squares display plots (basin neighborhoods in blues and non-basin in browns). Explanatory factors and related statistics in black lines and gray text. Species common names in black text. Neighborhood codes are as follows: UPT, Uptown; LS, Lakeshore; LV, Lakeview; GT, Gentilly; 7W, 7th Ward; U9, Upper 9th Ward; L9, Lower 9th Ward; SB, St. Bernard Parish.

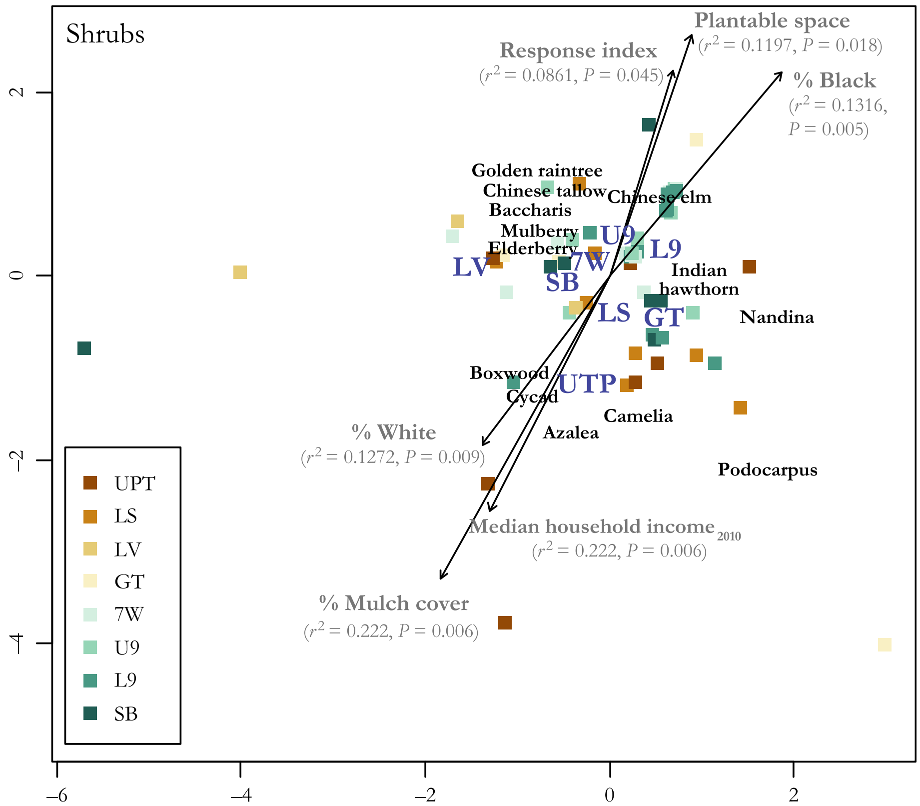

Fig. 6. Ordination analyses for shrubs. See Fig. 5 legend for details.

prevalent in areas with higher percentages of impervious cover (r^2 = 0.25, P = 0.001), reflecting their use in street tree plantings.

The ordination limited to shrubs also indicates that assemblage composition reflects species provenance, but with less separation between ornamental and non-native species (Fig. 6). Composition varies among neighborhoods (r^2 = 0.18, P = 0.023). Basin neighborhoods cluster together, for example, reflecting the prevalence of non-native species such as Chinese tallow, Chinese elm (*Ulmus parvifolia*), golden raintree (*Koelreuteria paniculata*), white mulberry, and the native opportunist saltbush (*Baccharis halimifolia*). The prevalence of opportunistic and non-native species corresponds to higher percent cover of plantable space (r^2 = 0.12, P = 0.018), higher percentage of Black residents (r^2 = 0.13, P = 0.005), and higher vegetation response (r^2 = 0.09, P = 0.0861). The prevalence of ornamental species such as Boxwood hollies (*Buxus* spp.), azaleas (*Rhododendron* spp.), and camellias (*Camellia* L.) was more evident in non-basin neighborhoods, especially Lakeshore and Uptown, and corresponded to higher household incomes (r^2 = 0.13, P = 0.01), higher percentages of White residents (r^2 = 0.13, P = 0.009), and higher percent cover of mulch (r^2 = 0.22, P = 0.083).

Herbaceous community composition reflected a divide among ornamental turfgrasses in non-basin neighborhoods and opportunistic forbs and grasses in basin neighborhoods (Fig. 7). Overall, the herbaceous layer showed a high degree of spatial dependency, with neighborhood (r^2 = 0.38, P = 0.001) and drainage basin (r^2 = 0.36, P = 0.001) explaining a relatively high degree of variation. Opportunistic forbs and grasses were predominantly associated with neighborhoods with higher rates of land abandonment and vegetation disturbance (e.g., the Lower 9th Ward and St. Bernard Parish). Opportunistic forbs and grasses also corresponded to the number of state-managed lots (r^2 = 0.25, P = 0.001) and vegetation response index values (r^2 = 0.10, P = 0.002). The importance of forbs with tall growth forms such as the aster *Bidens pilosa* and giant ragweed (*Ambrosia*

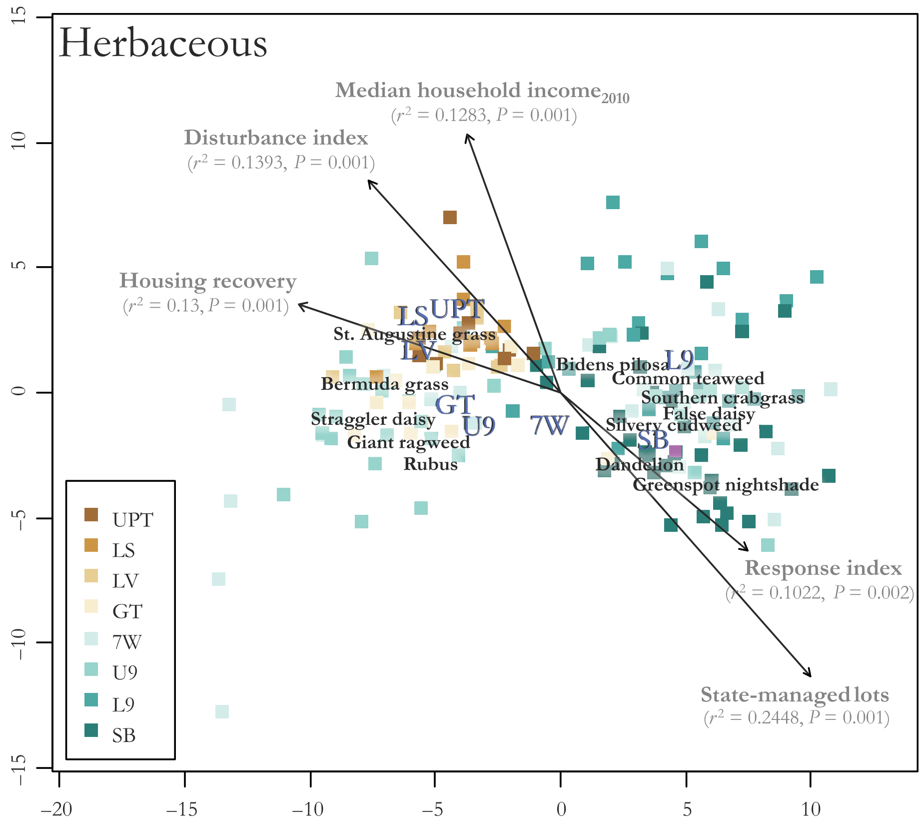

Fig. 7. Ordination analyses for herbaceous plants. See Fig. 5 legend for details.

trifida) indicates that the herbaceous layer in these areas is reaching more mature stages of growth compared to grass-dominated areas. Turfgrasses such as St. Augustine (*Stenotaphrum secundatum*) and Bermuda grass (*Cynodon dactylon*), which require regular maintenance to overcome competitors, were by far the most important herbaceous species in the Lakeview, Lakeshore, and Uptown neighborhoods. The prevalence of turfgrasses corresponds to higher median incomes (r^2 = 0.13, P = 0.001), lower vegetation disturbance (r^2 = 0.14, P = 0.001), and higher housing recovery (r^2 = 0.13, P = 0.001).

Discussion

In this study, we assessed the relative influence of topography, flooding disturbance, sociodemographic factors, and landscape management on plant communities across post-Katrina New Orleans. We found that ecological differences among neighborhoods align with measures of response as much or more so than flooding disturbance, where patterns of vegetative cover and community composition reflect post-Katrina land abandonment and landscape management. Our findings also indicate that the uneven implementation of resettlement and recovery programs has reinforced historically persistent social, economic, and racial disparities in the city's landscape configurations (Talarchek 1990). Thus, while vegetation disturbance was tied to flood depth and intensity, vegetation response and expansion was a more complex process, where disaster recovery programs and land abandonment patterns—mediated by the city's unequal social geography—influenced vegetation composition dynamics following Katrina. Viewing unmanaged, emergent vegetation on abandoned lands through the lens of environmental justice highlights how reducing "green blight" (Gulachenski et al. 2016) could prevent or disrupt negative feedback cycles (i.e., between landscape aesthetics, social stigmas, redevelopment, and public policy) in affected neighborhoods that might otherwise become bound in a downward spiral of declining capital investment, land abandonment, and population loss.

Signatures of flooding disturbance and responses to landscape management

We detected clear signatures of flooding disturbance in comparisons of vegetative cover and attributes across the city. Neighborhood differences in disturbance index values, which are indicative of Katrina's direct impact on vegetation, are consistent with expectations that neighborhoods at the lowest elevations (e.g., Lakeview and Gentilly) as well as neighborhoods at relatively low elevations and proximate to levee breaches would exhibit the highest rates of vegetation disturbance. These asymmetries are evident in comparisons of vegetative cover across basin and non-basin neighborhoods. For example, basin neighborhoods exhibit greater herbaceous cover and lower shrub and tree cover, which suggests that flooding disturbance has reinforced historically persistent spatial inequalities in the tree canopy across the city, where wealthier neighborhoods on the western flank of the city have greater tree cover (Talarchek 1990). Patterns of plot-level species richness largely parallel shifts in vegetative cover. For instance, basin neighborhoods harbor fewer tree and shrub species (Table 2). Notably, trees in basin neighborhoods also exhibit attributes such as lower basal areas that reflect a sparser tree canopy. Additionally, trees in basin neighborhoods that experienced particularly severe flooding (i.e., the Upper and Lower 9th Wards) exhibit attributes (e.g., low dbh, high stem density) that are consistent with young stand age (Table 2).

Our results indicate that many aspects of vegetation structure and composition are less reflective of disturbance than of post-disturbance responses to landscape management. For example, tree and stem density are lower whereas trunk size is greater in St. Bernard than in the adjacent Lower 9th Ward neighborhood, which is consistent with contrasting municipal land management approaches to comparable flooding, population loss, and land abandonment. The Lower 9th Ward also exhibited exceptionally high cover of unmaintained grass and exceptionally low cover of maintained grass (Table 3). We also found that while the disturbance index was an important predictor of the herbaceous layer (Fig. 7), the response index was a significant predictor of community composition across all vegetation layers (Figs. 5–7). Notably, higher estimates of the response index corresponded to the prevalence of opportunistic and non-native species. Higher estimates of the response index paralleled metrics indicative of unmanaged emergent vegetation on abandoned lands including available growing space, indices of abandonment, and state management. The relationship between the response index and the presence of Chinese tallow (an opportunistic non-native species that tends to form monospecific stands) in the tree and shrub assemblages illustrates this observation, as does the frequent co-occurrence of Chinese tallow with other opportunistic species such as golden raintree, Chinese elm, and chinaberry (Figs. 5, 6). It is also consistent with records of native hardwoods transitioning to a canopy dominated by Chinese tallow in an unmanaged, impounded bottomland hardwood forest in eastern New Orleans (Howard 2012). Evidence of high importance values of invasive trees and shrubs in the Upper and Lower 9th Wards similarly illustrates that the trajectory of vegetation in the city reflects interventions (or the lack thereof) that increase site availability for colonization.

Social determinants of land abandonment

Interest in the socioecological dimensions of urban vegetation has been growing over the past decade, with much of the interest focusing on spatial patterns of urban tree canopies (Heynen 2003, Hope et al. 2003, Martin et al. 2004, Perkins et al. 2004, Kinzig et al. 2005, Heynen et al. 2006, Grove et al. 2009, Conway et al. 2011, Pham et al. 2012, Ernstson 2013, Locke and Baine 2014, Rega-Brodsky and Nilon 2016). Many studies have shown that sociodemographic disparities, particularly differences in household wealth, are predictors of urban tree canopy (Schwarz et al. 2015). Consistent with this, our findings indicate that severe and prolonged flooding did not necessarily translate into higher rates of land abandonment and that land abandonment in post-Katrina New Orleans is not evenly distributed across neighborhoods and social groups. We found that the prevalence of unmanaged vegetation on abandoned lands differed among neighborhoods and social groups, which illustrates that all vegetation—not just urban tree cover—can be mediated by social geographies.

Like persistent land use legacies (Talarchek 1990), our findings indicate that patterns of land abandonment reflect geographies of race and income, which are highly intertwined across New Orleans. For example, 2013 median household income for Black residents was $27,812, as opposed to $60,070 for White residents (The Data Center 2015). We found more pronounced land abandonment in basin neighborhoods than in non-basin neighborhoods, especially in the Upper 9th Ward, Lower 9th Ward, and St. Bernard Parish. We also found that higher rates of land abandonment coincide with higher rates of Black residency, with the notable exception of St. Bernard (Table 1). Indicators of greater landscape maintenance, such as higher percent cover of mulch, track higher rates of White residency as well as higher median household income and rates of housing recovery. Consistent with this, higher rates of Black residency were associated with forbs and opportunistic and non-native trees and shrubs, whereas areas with higher median household income and predominantly White residency exhibited a higher prevalence of commercial turfgrasses, ornamental shrubs, and hurricane-resilient native trees, regardless of elevation.

Abandonment and landscape management policies

We found clear evidence that post-Katrina landscape management policies have mediated vegetation recovery on abandoned lands across the study area. Differences between St. Bernard and the Lower 9th Ward illustrate the influence of landscape management on vegetation structure and species composition. St. Bernard and the Lower 9th Ward experienced comparable severity and duration of flooding. Both neighborhoods also have been redefined by population loss and land abandonment, but land abandonment in the Lower 9th Ward has taken on a dramatically different form than in neighboring St. Bernard Parish. Our findings indicate that limited management of privately owned lots has afforded greater site availability for more ruderal vegetation to take hold in the Lower 9th Ward, while regular maintenance of nearly all abandoned lots across St. Bernard Parish has inhibited the emergence of opportunistic species and produced urban grasslands interspersed with trees at exceptionally low density. Consequently, the highly manicured landscapes of St. Bernard stand in sharp contrast to the unmanaged emergent vegetation that prevails across the Lower 9th Ward.

Notably, landscape management of abandoned lands in St. Bernard Parish reflects coordinated measures taken by individuals and municipal institutions. Extensive participation in the "lot next door" program—intended to enable remaining residents to expand property boundaries by purchasing adjacent state-owned properties at low cost, with the expectation that vegetation will be managed in accordance with municipal ordinances—placed more than half of all abandoned lots back into management as residential yards. The St. Bernard Parish government has aggressively managed remaining vacant and abandoned properties under its stewardship. Land managers also explained in interviews that they have been directed to mow abandoned lots regardless of ownership status. Though this comes at higher public expense—management of emergent vegetation has become a major financial and operational burden for state and local authorities where population return has lagged—parish officials have argued that the practice helps encourage redevelopment and stabilizes property values.

The structure and composition of vegetation in the Lower 9th Ward reflect enduring controversy over post-flooding redevelopment and landscape management policies in New Orleans. Soon after Katrina, catastrophically damaged homes were demolished throughout the neighborhood. And, though Lower 9th Ward residents enjoyed very high rates of homeownership prior to Katrina, financial institutions have been reluctant to issue loans for commercial and residential construction (Landphair 2007, Campanella 2008). Market demand in the Lower 9th Ward has been much lower than in other flooded neighborhoods like Lakeview and Gentilly following Katrina (Table 1). Population return also has been inhibited as many property owners have faced funding shortfalls with the Road Home program. Disinvestment and the Road Home program's policies of determining grants to homeowners based on pre-Katrina property value rather than projected repair costs, which were found to be racially discriminatory in a 2010 federal ruling, have resulted in tension between residents and land management agencies that has hampered alternative land use and comprehensive landscape management of abandoned properties (Gotham and Campanella 2011, Gotham 2012, Gotham and Greenberg 2014).

Though the City of New Orleans has recently initiated more aggressive management of abandoned properties, the City does not manage abandoned lots that remain in private ownership or lots that are being transferred to state and municipal agencies. Fearing opposition or legal action by owners, NORA and City of New Orleans maintenance crews only mow publicly owned abandoned lots, creating a patchwork of maintained grasslands surrounded by emergent vegetation frequently comprised of invasive trees and shrubs such as Chinese tallow (Fig. 4). New Orleans Redevelopment Authority and the City of New Orleans are currently working to gain legal clearance to maintain vegetation on privately held abandoned lots in the city. New Orleans Redevelopment Authority also has had some success with granting land rights to individuals and institutions pursuing alternative land use projects such as urban farming, stormwater management, and tree planting. While these projects generate experimental spaces for devising laudable landscape management practices on abandoned lands, they have not yet been implemented at a scale large enough to influence broader vegetation dynamics in the study area.

Comparison across other neighborhoods further illustrates that post-Katrina recovery and landscape management programs have fostered disparate trajectories of recovery. For example, there is greater unmanaged emergent vegetation and abandonment in Gentilly than other non-basin neighborhoods. Gentilly also exhibits the lowest density of trees with the smallest dbh and lowest basal area, as well as the highest percent of herbaceous cover and mean herbaceous richness. In part, this reflects differences in affluence and coping capacity, but it also reflects discriminatory redevelopment policies based on housing market dynamics (Gotham and Campanella 2011, Gotham 2012, Gotham and Greenberg 2014). As in Gentilly, overall population density in Lakeview dropped between 2000 and 2010, but abandoned properties in Lakeview were quickly sold to new owners or adjacent landowners through the "lot next door" and related initiatives and thus were rapidly put back into private-residential management. Consistent with this, our findings indicate that vegetation is better maintained in Lakeview than in Gentilly. Vegetation is also better maintained in the affluent Uptown and Lakeshore neighborhoods, as evidenced by the importance of mature ornamental and native trees and the prevalence of commercial turfgrasses.

Ecosystem services and disservices

While models and quantitative approaches can be useful for exploring the distribution of ecosystem services and disservices in urban landscapes (Dobbs et al. 2011), striking contrasts in our study area allow for well-supported qualitative discussion of socioecological dynamics and notions of environmental justice. For example, our results indicate that lower-income neighborhoods with higher Black residency harbor more opportunistic and invasive species, which in part reflects unmanaged emergent vegetation on abandoned lands. Because invasive-dominated emergent vegetation often provides fewer ecosystem services for residents—and in some cases represents more of an environmental hazard than an asset (Locke and Baine 2014)—such vegetation can be considered an emerging issue of environmental justice, where asymmetries in public and private investment in landscape management result in unequal benefits and hazards between neighborhoods and social groups (Ernstson 2013, Safransky 2014).

Though "re-greening" of urban landscapes has been widely promoted as beneficial (Bowler et al. 2010), it constitutes a public health and land management dilemma in post-Katrina New Orleans (Gulachenski et al. 2016 Rael et al. 2016). Unmanaged vegetation on abandoned lots in lower-income neighborhoods with higher Black residency has spurred public safety and public health concerns. Longtime residents report that unmaintained vegetation shelters rats as well as other commensal and feral animals of concern. Patterns of commensal rodent abundance support perceptions that abandonment is a public health concern, particularly in lower-income neighborhoods (Gulachenski et al. 2016, Rael et al. 2016). Landscape mosaics of maintained and overgrown lots also have become popular locations for illegal dumping and other illicit activities. Ironically, maintained vacant properties have become popular sites for illegal dumping, as they provide hidden but highly accessible sites (Fig. 2) to offload unwanted materials (e.g., construction debris, tires, garbage, stolen vehicles).

Framing of public discourse according to the wisdom of rebuilding a community prone to flood hazards (Rich 2012, Depillis 2013, Campanella 2015) can further foster feedbacks that reinforce ecosystem disservices by hampering redevelopment efforts, capital investment, and population recovery. For example, overgrown vegetation on abandoned lots continues to be portrayed as evidence of "nature reclaiming civilization" and land management as a "race between nature and man" (Rich 2012). Not only does this risk conflation of abandonment with economic inviability (Depillis 2013, Campanella 2015), but it also naturalizes and even romanticizes policy-driven socioecological disparities (cf. Ernstson 2013, Gandy 2013, Millington 2015), and encourages "disaster" tourism (Gotham and Lewis 2015) that capitalizes on "post-apocalyptic voyeurism" of decaying infrastructure (Wooten 2012). Not surprisingly, this has drawn the ire of neighborhood activists who have long argued that neighborhoods such as the Upper and Lower 9th Wards have experienced systematic urban disinvestment (Landphair 2007, Gotham and Campanella 2011, Gotham and Lewis 2015). It also has spurred criticism by residents who are battling social stigmas that discourage repopulation and redevelopment. According to one neighborhood activist who has devoted years to implementing alternative land uses on abandoned properties in the Lower 9th Ward, "[f]or every vegetation-covered lot, there is a story, and much of the story is hard working people trying to make the historic Lower 9th Ward whole again" (Mwendo 2012). Rather than seeking explanations in "nature vs. civilization" dichotomies, this reflects a more socioecological reading of vegetation outcomes that this study has also underscored.

Opportunities to advance ecosystem services and environmental justice

In this study, we have explored the conjoined effect of disturbance and socioculturally mediated patterns of land abandonment in driving vegetation dynamics following a catastrophic disaster. Our findings suggest that like more traditional recovery strategies (e.g., restoration of public utilities and other services), proactive landscape management is critical for anchoring and sustaining neighborhood recovery following catastrophic disasters. Placing a high priority on vegetation maintenance following a major humanitarian disaster may seem misguided, but our findings indicate that early intervention and maintenance by public agencies can deliver long-term benefits for recovering communities.

Progress is being made to improve response capacity through innovative approaches to landscape management. New Orleans Redevelopment Authority and other city agencies are working to improve access to abandoned lots for regular maintenance. The City also has recently secured federal funds to implement large-scale "green infrastructure" projects on public lands. For example, funding from the U.S. Department of Housing and Urban Development (HUD) is supporting the Gentilly Resilience District, which is expected to break ground in 2017. This initiative and several other federally funded projects in the Gentilly neighborhood aim to use vacant and abandoned lands to capture stormwater, enhance groundwater infiltration, and provide public green space—in short, to produce ecosystem services through environmental management. Successful implementation of the Gentilly project might serve to encourage similar projects on abandoned lands across the city. Caution must be taken, however, to avoid challenges such as those that emerged following Hurricane Katrina. Preventing recolonization by opportunistic species, for example, will require sustained maintenance, especially in areas with concentrations of abandoned lands. It will also be necessary to overcome public skepticism toward environmentally oriented redevelopment programs considering the intense controversy and condemnation of green infrastructure plans proposed during the immediate aftermath of the storm (Campanella 2015, Gotham and Lewis 2015).

Conclusions

Uneven socioecological conditions have emerged across New Orleans in the decade since Hurricane Katrina. Though New Orleans has regained nearly 80% of its pre-storm population, with many neighborhoods at ≥100% pre-Katrina residency (University of New Orleans 2013), the extent of recovery and associated economic and environmental benefits are not uniformly distributed among social groups or neighborhoods. Despite efforts to control overgrowth and promote alternative use of abandoned properties, public and private interventions have yet to mitigate the overall spatial distribution of ecosystem services and disservices associated with urban vegetation across the city. With evidence of Katrina's winds and floodwaters becoming increasingly less apparent in some areas, many consider New Orleans to be a resilient city, but the landscapes that have emerged in the Bienvenue Basin serve as a counterpoint of enduring and potentially escalating deficits in infrastructure delivery, public service provisioning, and environmental management. Post-disaster cities present ecologically, politically, and ethically complex environments that demand explanations grounded in multiple forms of data and interdisciplinary approaches to analysis. For knowledge of resilience, socioecological dynamics, and ecosystem services and disservices to meaningfully inform policy and public debate, it must be discussed in close relation to environmental justice, or else resilience programs may fail to address the social and economic relations undergirding the very environmental conditions they aim to transform.

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Literature Cited

Alberti, M., and J. M. Marzluff. 2004. Ecological resilience in urban ecosystems: linking urban patterns to human and ecological functions. Urban Ecosystems 7:241–265.

Allen, C., D. A. Newman, and H. W. Winters. 2004. Grasses of Louisiana. Allen's Native Ventures, Pitkin, Louisiana, USA.

Baró, F., L. Chaparro, E. Gómez-Baggethun, J. Langemeyer, D. J. Nowak, and J. Terradas. 2014. Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. Ambio 43:466–479.

Berland, A., K. Schwarz, D. L. Herrmann, and M. E. Hopton. 2015. How environmental justice patterns are shaped by place: terrain and tree canopy in Cincinnati, Ohio, USA. Cities and the Environment (CATE) 8:1.

Blackman, A., and A. Palma. 2002. Scrap tires in Ciudad Juárez and El Paso: ranking the risks. Journal of Environment & Development 11:247–266.

Bowler, D. E., L. Buyung-Ali, T. M. Knight, and A. S. Pullin. 2010. Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landscape and Urban Planning 97:147–155.

Brookings Institution. 2005. New Orleans after the storm: lessons from the past, a plan for the future. Metropolitan Policy Program. https://www.brookings.edu/wp-content/uploads/2016/06/20051012_NewOrleans.pdf

Brownlow, A. 2006. An archaeology of fear and environmental change in Philadelphia. Geoforum 37: 227–245.

Campanella, R. 2008. Bienville's dilemma. University of Lafayette Press, Lafayette, Louisiana, USA.

Campanella, R. 2015. The great footprint debate. The New Orleans Times-Picayune. http://www.nola.com/katrina/index.ssf/2015/05/footprint_gentrification_katri.html

Chambers, J. Q., J. I. Fisher, H. Zeng, E. L. Chapman, D. B. Baker, and G. C. Hurtt. 2007. Hurricane Katrina's carbon footprint on US Gulf Coast forests. Science 318:1107.

Chapman, E. L., J. Q. Chambers, K. F. Ribbeck, D. B. Baker, M. A. Tobler, H. Zeng, and D. A. White. 2008. Hurricane Katrina impacts on forest trees of Louisiana's Pearl River basin. Forest Ecology and Management 256:883–889.

Colwell, R. K., C. X. Mao, and J. Chang. 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85: 2717–2727.

Colwell, R. K. 2005. EstimateS: Statistical estimation of species richness and shared species from samples.

Conway, T. M., T. Shakeel, and J. Atallah. 2011. Community groups and urban forestry activity: Drivers of uneven canopy cover? Landscape and Urban Planning 101:321–329.

Curtis, J. T., and R. P. McIntosh. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology 72:476–496.

Data Center. 2015. The New Orleans index at ten: measuring greater New Orleans' Progress Towards Prosperity. http://www.datacenterresearch.org/reports_analysis/new-orleans-index-at-ten/

Depillis, L. 2013. If you rebuild it, they might not come: Brad Pitt's beautiful houses are a drag on New Orleans. The New Republic. https://newrepublic.com/article/112620/brad-pitts-make-it-right-houses-drag-new-orleans

Dewar, M., and J. M. Thomas, editors. 2012. The city after abandonment. University of Pennsylvania Press, Philadelphia, Pennsylvania, USA.

Dobbs, C., F. J. Escobedo, and W. C. Zipperer. 2011. A framework for developing urban forest ecosystem services and goods indicators. Landscape and Urban Planning 99:196–206.

Douglas, I. 2012. Urban ecology and urban ecosystems: understanding the links to human health and well-being. Current Opinion in Environmental Sustainability 4:385–392.

Ernstson, H. 2013. The social production of ecosystem services: a framework for studying environmental justice and ecological complexity in urbanized landscapes. Landscape and Urban Planning 109:7–17.

Ernstson, H., S. E. van der Leeuw, C. L. Redman, D. J. Meffert, G. Davis, C. Alfsen, and T. Elmqvist. 2010. Urban transitions: on urban resilience and human-dominated ecosystems. Ambio 39:531–545.

Escobedo, F. J., T. Kroeger, and J. E. Wagner. 2011. Urban forests and pollution mitigation: analyzing ecosystem services and disservices. Environmental Pollution 159:2078–2087.

Evans, J. P. 2011. Resilience, ecology and adaptation in the experimental city. Transactions of the Institute of British Geographers 36:223–237.

Gandy, M. 2013. Marginalia: aesthetics, ecology, and urban wastelands. Annals of the Association of American Geographers 103:1301–1316.

Gaston, K. J. 2005. Biodiversity and extinction: species and people. Progress in Physical Geography 29: 239–247.

Gómez-Baggethun, E., Å. Gren, D. N. Barton, J. Langemeyer, T. McPhearson, P. O'Farrell, E. Andersson, Z. Hamstead, and P. Kremer. 2013. Urban ecosystem services. Pages 175–251 *in* T. Elmqvist, M. Fragkias, J. Goodness, B. Güneralp, P. J. Marcotullio, R. I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto, and C. Wilkinson, editors. Cities and biodiversity outlook: urbanization, biodiversity and ecosystem services: challenges and opportunities. Springer, Dordrecht, The Netherlands.

Gotham, K. F. 2012. Disaster Inc: privatization and post-Katrina rebuilding in New Orleans. Perspectives on Politics 10:633–646.

Gotham, K. F., M. J. Blum, and R. Campanella. 2014. Toward a new normal: trauma, diversity, and the New Orleans Urban Long-Term Research Area Exploratory (ULTRA-Ex) Project. Cities and the Environment (CATE) 7:4.

Gotham, K. F., and R. Campanella. 2011. Coupled vulnerability and resilience: the dynamics of cross-scale interactions in post-Katrina New Orleans. Ecology and Society 16:12. https://doi.org/10.5751/ES-04292-160312

Gotham, K. F., and M. Greenberg. 2014. Crisis cities: disaster and redevelopment in New York and New Orleans. Oxford University Press, Oxford, UK.

Gotham, K. F., and J. A. Lewis. 2015. Green tourism and the ambiguities of sustainability discourse: the case of New Orleans's Lower Ninth Ward. International Journal of Social Ecology and Sustainable Development (IJSESD) 6:57–73.

Grimm, N. B., S. T. Pickett, R. L. Hale, and M. L. Cadenasso. 2017. Does the ecological concept of disturbance have utility in urban social–ecological–technological systems? Ecosystem Health and Sustainability 3:1–18.

Grove, J. M., M. L. Cadenasso, W. R. Burck, S. T. A. Pickett, K. Schwarz, J. O'Neil-Dunne, and M. Wilson. 2009. Data and methods comparing social structure and vegetation structure of urban neighborhoods in Baltimore, Maryland. Society and Natural Resources 19:117–136.

Grove, J. M., D. Locke, and J. M. O'Neil-Dunne. 2014. An ecology of prestige in New York City: examining the relationships among population density, socio-economic status, group identity, and residential canopy cover. Environmental Management 54: 402–419.

Gulachenski, A., B. Ghersi Chavez, A. E. Lesen, and M. J. Blum. 2016. Abandonment, ecological assembly and public health risks in counter-urbanizing cities. Sustainability 8:491.

Haase, D. 2008. Urban ecology of shrinking cities: An unrecognized opportunity? Nature and Culture 3:1–8.

Haase, D. 2013. Shrinking cities, biodiversity and ecosystem services. Pages 253–274 *in* Urbanization, biodiversity and ecosystem services: challenges and opportunities. Springer, Dordrecht, The Netherlands.

Haase, D., N. Frantzeskaki, and T. Elmqvist. 2014. Ecosystem services in urban landscapes: practical applications and governance implications. Ambio 43:407–412.

Hamer, S. A., T. L. Goldberg, U. D. Kitron, J. D. Brawn, T. K. Anderson, S. R. Loss, E. D. Walker, and G. L. Hamer. 2012. Wild birds and urban ecology of ticks and tick-borne pathogens, Chicago, Illinois, USA, 2005–2010. Emerging Infectious Diseases 18: 1589–1595.

Heynen, N. C. 2003. The scalar production of injustice within the urban forest. Antipode 35:980–998.

Heynen, N., H. A. Perkins, and P. Roy. 2006. The political ecology of uneven urban green space the impact of political economy on race and ethnicity in producing environmental inequality in Milwaukee. Urban Affairs Review 42:3–25.

Hobbs, R. J., E. Higgs, and J. A. Harris. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24:599–605.

Hope, D., C. Gries, W. X. Zhu, W. F. Fagan, C. L. Redman, N. B. Grimm, A. L. Nelson, C. Martin, and A. Kinzig. 2003. Socioeconomics drive urban plant diversity. Proceedings of the National Academy of Sciences USA 100:8788–8792.

Howard, J. J. 2012. Hurricane Katrina impact on a leveed bottomland hardwood forest in Louisiana. American Midland Naturalist 168:56–69.

Jansson, M., H. Fors, T. Lindgren, and B. Wiström. 2013. Perceived personal safety in relation to urban woodland vegetation: a review. Urban Forestry & Urban Greening 12:127–133.

Jha, A. K., T. W. Miner, and Z. Stanton-Geddes. 2013. Building urban resilience: principles, tools, and practice. World Bank Publications, Washington, D.C., USA.

Jorgensen, A., and A. Anthopoulou. 2007. Enjoyment and fear in urban woodlands: Does age make a difference? Urban Forestry & Urban Greening 6:267–278.

Kinzig, A. P., P. Warren, C. Martin, D. Hope, and M. Katti. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. Ecology and Society 10:23.

Kirkman, L. K., C. L. Brown, and D. J. Leopold. 2007. Native trees of the southeast. Timber Press, Portland, Oregon, USA.

Kontogianni, A., G. W. Luck, and M. Skourtos. 2010. Valuing ecosystem services on the basis of service-providing units: a potential approach to address the 'endpoint problem' and improve stated preference methods. Ecological Economics 69:1479–1487.

Koskela, H., and R. Pain. 2000. Revisiting fear and place: women's fear of attack and the built environment. Geoforum 31:269–280.

Kupfer, J. A., A. T. Myers, S. E. McLane, and G. N. Melton. 2008. Patterns of forest damage in a southern Mississippi landscape caused by Hurricane Katrina. Ecosystems 11:45–60.

Lachmund, J. 2013. Greening Berlin: the co-production of science, politics, and urban nature. MIT Press, Cambridge, Massachusetts, USA.

Landphair, J. 2007. "The Forgotten People of New Orleans": community, vulnerability, and the Lower Ninth Ward. Journal of American History 94:837.

Langner, M., and W. Endlicher. 2007. Shrinking cities: effects on urban ecology and challenges for urban development. Peter Lang New York, New York, New York, USA.

Lewis, J. 2015. Deltaic dilemmas: ecologies of infrastructure in New Orleans. Dissertation. Stockholm University, Stockholm, Sweden.

Locke, D. H., and G. Baine. 2014. The good, the bad, and the interested: how historical demographics explain present-day tree canopy, vacant lot and tree request spatial variability in New Haven, CT. Urban Ecosystems 18:391–409.

Lyytimäki, J., L. K. Petersen, B. Normander, and P. Bezák. 2008. Nature as a nuisance? Ecosystem services and disservices to urban lifestyle. Environmental Sciences 5:161–172.

Lyytimäki, J., and M. Sipilä. 2009. Hopping on one leg: the challenge of ecosystem disservices for urban green management. Urban Forestry & Urban Greening 8:309–315.

Martin, C. A., P. S. Warren, and A. P. Kinzig. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. Landscape and Urban Planning 69:355–368.

Mathey, J., and D. Rink. 2010. Urban wastelands—A chance for biodiversity in cities? Pages 406–424 *in* N. Müller, P. Werner, and J. G. Kelcey, editors. Urban biodiversity and design. Wiley-Blackwell, Oxford, UK. https://doi.org/10.1002/9781444318654.ch21

Millar, R. B., and M. J. Anderson. 2004. Remedies for pseudoreplication. Fisheries Research 70: 397–407.

Miller, J. H., and K. V. Miller. 2005. Forest plants of the southeast and their wildlife uses. University of Georgia Press, Athens, Georgia, USA.

Millington, N. 2015. From urban scar to park in the sky: terrain vague, urban design, and the remaking of New York City's High Line Park. Environment and Planning A 47:2324–2338.

Muratet, A., N. Machon, F. Jiguet, J. Moret, and E. Porcher. 2007. The role of urban structures in the distribution of wasteland flora in the Greater Paris area, France. Ecosystems 10:661–671.

Mwendo, J. 2012. "Jungleland", really? A Lower 9th Ward response. Lower 9th Ward Center for Sustainable Engagement and Development, New Orleans, Louisiana, USA. http://blog.sustainthenine.org/2012/05/jungleland-really-a-lower-9th-ward-response.html

Nowak, D. J., D. E. Crane, J. C. Stevens, R. E. Hoehn, J. T. Walton, and J. Bond. 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture & Urban Forestry 34:347–358.

Nowak, D. J., and J. F. Dwyer. 2007. Understanding the benefits and costs of urban forest ecosystems. Pages 25–46 *in* J. Kuser, editor. Urban and community forestry in the Northeast. Springer, Dordrecht, The Netherlands.

Nowak, D. J., and E. J. Greenfield. 2012. Tree and impervious cover change in US cities. Urban Forestry & Urban Greening 11:21–30.

O'Meara, G. F., L. F. Evans Jr., A. D. Gettman, and J. P. Cuda. 1995. Spread of *Aedes albopictus* and decline of *Ae. aegypti* (Diptera: Culicidae) in Florida. Journal of Medical Entomology 32:554–562.

Perkins, H. A., N. Heynen, and J. Wilson. 2004. Inequitable access to urban reforestation: the impact of urban political economy on housing tenure and urban forests. Cities 21:291–299.

Pham, T.-T.-H., P. Apparicio, A.-M. Séguin, S. Landry, and M. Gagnon. 2012. Spatial distribution of vegetation in Montreal: An uneven distribution or environmental inequity? Landscape and Urban Planning 107:214–224.

Plumlee, G. S., G. P. Meeker, J. K. Lovelace, R. J. Rosenbauer, P. J. Lamothe, E. T. Furlong, and C. R. Demas. 2006. USGS environmental characterization of flood sediments left in the New Orleans area after Hurricanes Katrina and Rita, 2005. Progress Report No. 2006-1023. https://pubs.er.usgs.gov/publication/ofr20061023

Rael, R., A. Peterson, B. Ghersi Chavez, J. Childs, and M. J. Blum. 2016. Disturbance, reassembly and disease risk in socioecological systems. EcoHealth 13:450–455.

Ramette, A. 2007. Multivariate analyses in microbial ecology. FEMS Microbiology Ecology 62:142–160.

Rapport, D. H., H. A. Regier, and T. C. Hutchinson. 1985. Ecosystems behavior under stress. The American Naturalist 125:617–640.

Rega-Brodsky, C. C., and C. H. Nilon. 2016. Vacant lots as a habitat resource: nesting success and body condition of songbirds. Ecosphere 7. https://doi.org/10.1002/ecs2.1578

Rich, N. 2012. Jungleland: The Lower Ninth Ward in New Orleans gives new meaning to 'urban growth'. The New York Times Magazine. http://www.nytimes.com/2012/03/25/magazine/the-lower-ninth-ward-new-orleans.html?action=click&contentCollection=Magazine&module=RelatedCoverage&region=EndOfArticle&pgtype=article

Riley, C. B., D. A. Herms, and M. M. Gardiner. 2017. Exotic trees contribute to urban forest diversity and ecosystem services in inner-city Cleveland, OH. Urban Forestry & Urban Greening, *in press*.

Rojas-Caldelas, R. I., and E. C. Zambrano. 2008. Urban observatories opportunities for environmental monitoring: solid wastes. Waste Management 28: S40–S44.

Safransky, S. 2014. Greening the urban frontier: race, property, and resettlement in Detroit. Geoforum 56:237–248.

Schetke, S., and D. Haase. 2008. Multi-criteria assessment of socio-environmental aspects in shrinking cities: experiences from Eastern Germany. Environmental Impact Assessment Review 28:483–503.

Schummer, M. L., H. M. Hagy, K. S. Fleming, J. C. Cheshier, and J. T. Callicutt. 2011. A guide to moist-soil wetland plants of the Mississippi Alluvial Valley. University Press of Mississippi, Jackson, Mississippi, USA.

Schwarz, K., M. Fragkias, C. G. Boone, W. Zhou, M. McHale, J. M. Grove, J. O'Neil-Dunne, J. P. McFadden, G. L. Buckley, and D. Childers. 2015. Trees grow on money: urban tree canopy cover and environmental justice. PLoS ONE 10:e0122051. https://doi.org/10.1371/journal.pone.0122051

Seed, R. B., R. Bea, R. Abdelmalak, A. Athanasopoulos-Zekkos, G. Boutwell, J.-L. Briaud, C. Cheung, D. Cobos-Roa, L. Ehrensing, and A. Govindasamy. 2008. New Orleans and hurricane Katrina. I: Introduction, overview, and the east flank. Journal of Geotechnical and Geoenvironmental Engineering 134:701–717.

Stanturf, J. A., S. L. Goodrick, and K. W. Outcalt. 2007. Disturbance and coastal forests: a strategic approach to forest management in hurricane impact zones. Forest Ecology and Management 250:119–135.

Sukopp, H. 1971. Beitrage zur Okologie von Chenopodium botrys L.: 1, Verbreitung und Vergesellschaftung. Verhandlungen des Botanischen Vereins für die Provinz Brandenburg 108:3–25.

Talarchek, G. M. 1990. The urban forest of New Orleans: an exploratory analysis of relationships. Urban Geography 11:65–86.

Tyler, S., and M. Moench. 2012. A framework for urban climate resilience. Climate and Development 4:311–326.

University of New Orleans. 2013. Metropolitan report: economic indicators for the New Orleans area. Division of Business and Economic Research, New Orleans, Louisiana, USA.

U.S. Department of Agriculture Forest Service. 2016. iTree protocol: tools for assessing and managing community forests. http://www.itreetools.org/

U.S. Department of Housing and Urban Development (HUD). 2016. Green infrastructure and the Sustainable Communities Initiative. Office of Economic Resilience Office of Community Planning and Development. hud.gov/resilience

Von Döhren, P., and D. Haase. 2015. Ecosystem disservices research: a review of the state of the art with a focus on cities. Ecological Indicators 52:490–497.

Wallace, D., and R. Wallace. 2008. Urban systems during disasters: factors for resilience. Ecology and Society 13:18.

Wang, F., and Y. J. Xu. 2009. Hurricane Katrina-induced forest damage in relation to ecological factors at landscape scale. Environmental Monitoring and Assessment 156:491–507.

Wooten, T. 2012. Jungleland or grassroots recovery? The Lower Ninth Ward as a symbol of hope. Beacon Broadside. http://www.beaconbroadside.com/broadside/2012/03/jungleland-or-grassroots-recovery.html

Zipperer, W. C. 2002. Species composition and structure of regenerated and remnant forest patches within an urban landscape. Urban Ecosystems 6:271–290.

Supporting Information

Additional Supporting Information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/ecs2.1922/full