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Insight

Historical Regimes and Social Indicators of Resilience in an Urban System: the Case of Charleston, South Carolina

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ABSTRACT. Employing the adaptive cycle and panarchy in perturbed urban systems can contribute to a better understanding of how these systems respond to broad-scale changes such as war and sea level rise. In this paper we apply a resilience perspective to examine regime shifts in Charleston, South Carolina from a historical perspective. We then look more closely at changes that occurred in Charleston in recent decades, including Hurricane Hugo, and the potential effects of these changes on resilience of the social-ecological system to future shocks. We close with a discussion combining social and ecological perspectives to examine future regime-shift scenarios in the Charleston case and suggest ways to better understand resilience in other coastal urban systems.

Key Words: *Charleston, South Carolina; regime shifts; resilience; sea-level rise; social-ecological systems*

INTRODUCTION

This paper examines resilience within the urban system of Charleston, South Carolina. Disturbances of interest include major upheavals to Charleston's social system, particularly the Civil War and the subsequent dismantling of the plantation-slavery economy and natural disasters such as Hurricane Hugo and the threat of sea level rise. Utilizing the resilience concepts of adaptive cycles and panarchy in perturbed urban systems can contribute to a better understanding of how these systems respond to broad-scale changes. Examining past disturbances and regime shifts aids this process by revealing historical patterns that have shaped current trajectories of system change and growth.

Resilience theory provides a framework for understanding social and demographic changes within an urban system while acknowledging the influence of the ecological system on social structures and functions. For resilience to be useful for studying urban systems, it must move beyond metaphor to something that is measurable. This requires specifying temporal and spatial scales and identifying system configurations and disturbances of interest (Carpenter et al. 2001). Ecological resilience can help explain how urban systems respond to broad-scale changes and identify system characteristics that serve as indicators for future regime shifts.

In ecological resilience, periods of gradual change are punctuated by rapid changes that can result in a significant change to a system's structure and behavior, a process known as regime shift. When a system lacks sufficient resilience, its structures and functions undergo changes that alter its identity (Biggs et al. 2009). Ecological examples include lakes that turn from healthy to eutrophic (e.g., Guttal and Jayaprakash 2008) and commercial fisheries that suffer collapse (e.g., Biggs et al. 2009). In resilient systems, a shock or disturbance creates opportunities for innovation and development. Existing structures and processes recombine into new trajectories while retaining the system's identity. By contrast, even small disturbances can force a system that lacks resilience to switch into a different regime (Folke 2006).

A similar process occurs in social-ecological systems, which comprise the complex sets of interactions among humans and nature at multiple scales (Holling 2001). Human impact on ecosystems can exceed long-term sustainable levels well before the effects become noticeable (Biggs et al. 2009). In some cases, maximum utility of an ecosystem is close to the threshold at which the system collapses: stabilizing feedback keeps the system within its stable state until the stress becomes too great (Scheffer et al. 2002). The consequences of these ecological impacts in turn affect social systems. For example, ecological economists seek to place a quantifiable value on services such as storm protection provided by mangroves and marshes (e.g., Costanza et al. 1997). Encroachment of human development into natural areas can have short-term economic benefits that seem to enhance the social-ecological system's overall resilience. However, a closer examination of functions and feedbacks may indicate that resilience is actually decreasing. The same can also hold true within the social realm, such as an infrastructure project that brings economic opportunity but disrupts existing communities and social networks.

METHODS AND THEORETICAL FRAMEWORK

We use a case study approach to provide insights into urban resilience and the response of an urban system to broad-scale changes. Case study methodology is particularly useful for research that offers an in-depth examination of a specific concept (Feagin et al. 1991). Our case study examines Charleston as a social-ecological system undergoing changes over time. In examining urban resilience, the term social-ecological system can be used to emphasize the artificial and arbitrary nature of delineating social and natural systems

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(Berkes and Folke 2002). We combine resilience theory framework with both a socio-historical perspective and population data to illustrate changes in the city of Charleston and the surrounding metropolitan area over time. Data from the U.S. Census of Population for the years 1890-2000 and Census CD Neighborhood Change 1970-2000 Tract Data are used to describe population characteristics and change.

In addition, we use the online inter-active version of the Sea Level Affecting Marshes Model (SLAMM) Version 2.0 (www.slammview.org/) as developed for the Georgia/South Carolina Region Project to explore potential effects of sea level rise on the Charleston area based on scenarios from the Intergovernmental Panel on Climate Change (IPCC). Two scenarios are used for an area that covers most of the developed land around Charleston Harbor and on the barrier islands of Folly, Sullivan's, and Isle of Palms.

Efforts to measure resilience in social systems often have their origins in ecological resilience theory. Ecological resilience looks at the magnitude of disturbance necessary to change a system's identity in terms of its structure, functions, and feedbacks. It emphasizes nonlinear dynamics, thresholds, and uncertainty (Carpenter et al. 2001, Holling and Gunderson 2002, Walker et al. 2004, Folke 2006, Brand and Jax 2007). Within this theoretical framework, ecosystems are understood to have four phases that taken together make up its adaptive cycle: exploitation (r), conservation (K), release (Ω) and reorganization (α). In the first two phases, known as the front loop, rapid colonization of disturbed areas eventually leads to the slow accumulation and storage of energy and material as system structures and functions become more tightly organized. The back loop consists of the release and reorganization phases. This collapse and renewal can occur in relatively brief periods that bring about major system changes (Carpenter et al. 2001, Holling and Gunderson 2002).

Panarchy describes a nested set of adaptive cycles that occur across spatial and temporal scales. Each adaptive cycle within a panarchy functions at different orders of magnitude and can be characterized as having a fast, medium, or slow speed. The relationships among these temporal and spatial scales in conjunction with the phase of each adaptive cycle give a system its adaptive complexity (Holling et al. 2002*a*). Changes in slow variables combine with large, unique disturbances to create the potential for system collapse (Carpenter et al. 2002).

CHARLESTON AS A SOCIAL-ECOLOGICAL SYSTEM

Previous efforts to apply resilience theory to social science research have developed modified definitions. Adger (2000) defines social resilience as the ability of groups and communities to cope with changes and disturbances brought on by social, political, and environmental factors. Resilience can be a desirable or undesirable characteristic, depending on the system. For example, a dictatorship or polluted water supply can be a highly resilient but undesirable state (Carpenter et al. 2001). In Charleston's case, the plantation system proved highly resilient until the end of the Civil War in 1865. Once slavery was abolished, the regional economy collapsed (Goldin 1973). This led to a regime shift for the city's social-ecological system. Overall, the South lagged behind the rest of the country in terms of metropolitan growth until World War II (Gardner 2001). Charleston did not begin its economic recovery until the federal government dredged the harbor channel and built a Navy Yard in the early 20th century (Fraser 1989).

Settled in 1670, Charleston is an old southern city. Its original boundaries are situated on a peninsula less than two miles across at its widest point. Figure 1 shows city streets in and around the peninsula and their spatial relationship to the area's extensive wetlands. The economic structure of Charleston has always been shaped by its environment, which is characterized by sea islands and coastal marsh. During the Colonial Period, the deep water harbor became a major port for overseas commerce and a center for immigration. The fertile soils of the mainland and barrier islands surrounding the city supported the growth of rice, indigo, and cotton plantations that required slave labor (Nash 1992). The productive marsh and estuary system and the abundance of wild game in both wetlands and uplands supported numerous livelihoods and served as a major food source up until 1900 (Zierden and Reitz 2009).

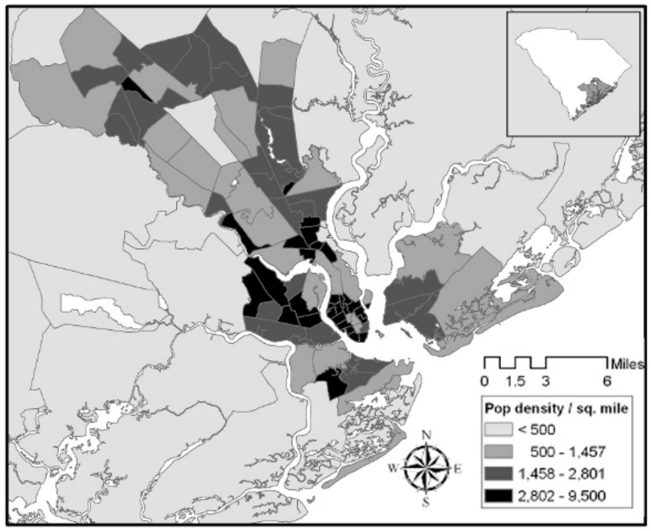
Fig. 1. The Charleston peninsula and surrounding areas showing the extent of road development and wetlands (Sources: South Carolina Department of Natural Resources 2005, U.S. Fish and Wildlife Service 2011).

Charleston was the fifth largest city in the United States in 1800 (Pease and Pease 1985). Its size and importance in the colonial period reflected its key role in the British trade of rice and indigo (Nash 1992, Smith 1987). Following the American Revolution, slow economic variables continued to shape Charleston's social-ecological system, primarily in the demand for cotton by European nations. At the start of the Civil War, the Confederate states made up what would have been the world's fourth largest economy behind England, France, and the nonseceding U.S. states. From 1800 to 1860, cotton grew from 7.1% to 57.5% of all U.S. exports. During the same period, the number of slaves in the U.S. grew from less than one million to nearly four million (Guthrie and Peevely 2010). The Civil War cost $3 billion in 1860 dollars, while the value of all owned slaves in 1860 was $2.7 billion. Emancipation represented a massive redistribution of income as plantation owners lost the value of slaves as property and were forced to invest in worker wages for maintaining large-scale operations (Goldin 1973).

Although Charleston declined precipitously as an urban economic force following the Civil War, its white-dominated social and cultural identity proved far more resilient. This has been attributed to former colonial ties and the aristocratic nature of the Charleston elite (Jahler 1982). Emancipation had brought a major shift in race relations from slave-holding paternalism to competitive segregation. During Reconstruction, blacks and white were forced to define new economic and social relations, a process that brought uncertainty and unrest (Vernon 1978). In terms of the adaptive cycle, this period marked the beginning of a highly disrupted renewal phase. Once federal controls on politics and military were removed in 1877, white southern elites forced blacks out of positions of authority and back into subservient roles (Vernon 1978).

Ecological patterns and processes are part of a continuous, embedded interaction with social and institutional processes (Scoones 1999). As Charleston grew prior to the Civil War, forested areas and wetlands were converted to plantations. Following the city's slow economic recovery in the 20th century, these plantations were converted over time to suburbs and industrial areas. As the city expanded, development continued to encroach on previously undisturbed areas, including tidal marshes and beaches. The natural beauty of the city, the abundance of nearby barrier-island beaches, and its subtropical climate made it a tourist destination and retirement location. In 2000, the Charleston-North Charleston metropolitan area was the 77th largest in the U.S. with a population of 549,033 (U.S. Census Bureau 2001). The landscape had transformed into a metropolitan sprawl extending inland nearly 50 miles. Figure 2 illustrates settlement patterns as represented by population density in the current tri-county Charleston area, i.e., the Charleston-North Charleston Metropolitan Statistical Area (MSA).

Fig. 2. Population density per square mile for census tracts in the Charleston-North Charleston metropolitan statistical area for the year 2000 (Source: U.S. Census Bureau 2001).



REGIME SHIFT

Charleston's social-ecological system experienced a regime shift following the shocks and disturbances of the Civil War and Reconstruction. The switch from Regime 1 (Old South) to Regime 2 (New South) was driven by social variables, namely the opposition to slavery and by extension the plantation system that depended on it. By contrast, we propose that the next regime shift will be driven by ecological variables, namely the consequences of sea level rise.

Salt water marshes and other coastal wetlands provide crucial ecosystem services that are at risk of significant decline in the face of sea level rise. Salt water marshes in the southeastern U.S. have been projected to decline by 20 to 45%, based on simulation models using the IPCC's sea-level-rise scenarios (Craft et al. 2009). As sea levels rise, storm surges from hurricanes and other ocean storms will ride into coastal areas on higher water levels that increase the potential for damage (Scavia et al. 2002). Charleston's boom in coastal development over the last two decades has reduced system resilience against this disturbance.

Table 1 summarizes changes in regime shifts and identifying characteristics for Charleston based on proxy indicators for social resilience (Adger 2000). These indicators include institutional change, economic structure, and demographic change.

Regimes 1 and 2 both experienced changes to their identifying characteristics, i.e., structures, functions, and feedbacks, that

Table 1. System characteristics, adaptive cycles, and regime change in Charleston, South Carolina.

	Regime 1: Old South		Collapse	Regime 2: New South	
Time Period	1670 – 1781	1782 – 1860	1861 – 1900	1901 – 1989	1990 – present
Characteristic	Colony	Plantation system	Civil War and Reconstruction	Growth and preservation	Post-Hugo expansion
Start phase	α to r to K	r to K	Ω to α	r to K	r to K
Structure					
- Institutional	Colonial	Slavery	Federal	Local	Regional
- Economic	Emergence of plantation system	Staple crops: cotton rice, indigo	Plantation decline, end of slave labor	Military bases, container port	Manufacturing, container port
- Demographic	Population growth	Social stratification	Racial conflict	Spatial expansion	Coastal density
Function	Trade / commerce	Trade / commerce	Rebuild economy, infrastructure	Military support, trade, tourism	Tourism, trade, expansion
Feedbacks	Colonial tensions, growing wealth	Economic rigidity, abolitionists	Social upheaval, new laws	Federal spending, population growth	Hugo insurance $, development
Disturbance	Revolution	Secession	War, Earthquake	Hugo	Sea level rise
End phase	Ω to α	Ω	Ω to α	Ω to α	Ω

did not result in a regime shift but did cause a loss of social resilience. These changes correspond with the four stages of the adaptive cycle. Changes in identifying characteristics were preceded by a shock or disturbance that pushed the system into a collapse and renewal phase while allowing the system to retain its basic identity.

Regime shifts generally occur when changes to slow variables cause system collapse. In Regime 1, the slow variables that pushed the system over the threshold involved the federal government and national economy. Changes in these variables forced Charleston's system into collapse at medium and fast variables. National support for abolishing slavery ultimately caused a collapse in the adaptive cycles of the plantation system (medium variable) and crop production and trade (fast variables).

In the Charleston system, the potential collapse of Regime 2 would be driven by sea level rise and responses to it at the state and national levels (slow variables). Whether the social-ecological system shifts to a new regime would be determined in large part by interactions among coastal development and the marsh system (medium variables) and flooding and human activity (fast variables). Reduced resilience in the marsh system and the subsequent reduction in storm-buffering effects would intensify these interactions.

In both Regimes 1 and 2, key characteristics of the system have demonstrated strong resilience in the face of shocks, disturbances, and uncertainty. Most notably these resilient features are the plantation system during Regime 1 and economic growth, i.e., development, tourism, trade, and commerce, during Regime 2. During Regime 1, a change in identifying characteristics occurred during the collapse and renewal stages corresponding to the American Revolution. The Charleston area, like much of the south, maintained its character as an agrarian-based economy built on the plantation system. However, its feedbacks changed as a result of independence. The former colony was now part of a new nation, and the resilience of its plantation system set up an inevitable collision with the rapidly industrializing northern states and the push to abolish slavery (Goldin 1973).

Charleston did not fully begin the growth phase of its Regime 2 adaptive cycle until the Charleston Naval Base was established in the early 1900s. This base became a strong economic engine for the city and grew to become the country's third largest home port for the Navy (Jacobson 2000). At the time of its closing in 1996, the base was Charleston's largest employer, with more than 22,000 workers (Economist 2009).

During Regime 2, we argue that a change in its identifying characteristic occurred in the aftermath of Hurricane Hugo, a category 4 storm with sustained winds of 135 mph (National Research Council 1994). The coastal areas around Charleston experienced a 12- to 20-foot storm surge, which caused extensive damage to homes on outer barrier islands. Insured losses for the Charleston area were approximately $2.3 billion (National Research Council 1994). It is argued here that post-Hugo insurance money and subsequent real estate development fundamentally altered the regime's character, accelerating expansion and reducing resilience. In general, land use intensification allows powerful local interests such as developers, realtors, and bankers to maximize their profits. Coalitions of business elites work together with local politicians and institutions to encourage economic and demographic growth. The current U.S. system of disaster relief fuels this process by injecting capital that is used by these coalitions for not only recovery but aggressive expansion of development (Pais and Elliott 2008).

In both regimes, the resilient characteristics that survived major disturbances made the urban system less resilient to future shocks. The plantation system's resilience following American independence played a major role in the collapse that occurred after the Civil War. Likewise, the city's economic growth and subsequent expansion of development into ecologically vulnerable areas following Hurricane Hugo reduced the social-ecological system's resilience to future storms and sea level rise. Such cases reveal a paradoxical resilience: the very characteristics that survive the shock place the system at greater risk for future regime shift.

IDENTITY AND RESILIENCE SINCE 1900

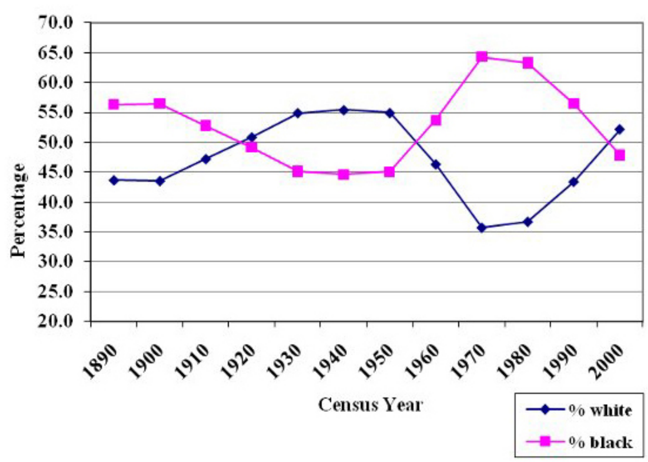
Social networks and cultural identity are often more important than infrastructure to maintaining a city's identity and functions (Campanella 2006). However, Wallace and Wallace (2008) point out that the preservation of housing is critical for socioeconomic resilience in neighborhoods. Charleston experienced a series of blows to its physical structures in the late 1800s. During the Civil War, the city experienced a fire that consumed 540 acres and a siege by Union artillery that lasted 587 days, leaving many residents homeless (Burton 1970). Combined, the two events caused considerable damage to city structures. The 1886 earthquake, estimated at 7.3 on the Richter scale (USGS 2010), caused $6 million in damages to the city's buildings out of a total value of $24 million (Fraser 1989).

The local economic depression following the Civil War lasted into the 20th century and spared Charleston's surviving architecture. By the time the city reached a sufficient economic level to build up its infrastructure in the 1920s, the uniqueness of its stock of historic buildings was apparent. Historic preservation became a major cause for city residents who wanted to reclaim a visible piece of the city's former glory. The emerging preservation movement actively sought to limit the development of new structures (Fraser 1989). To accommodate growth, the city expanded beyond the geographic boundaries of the peninsula, developing outward on the surrounding barrier islands and inland along its major rivers and highways.

To maintain its identity, a system must preserve its familial, social, and religious networks (Berke and Campanella 2006). Charleston's historic preservation efforts would in time become a powerful draw for tourism, which boosted the city's economy. However, the subsequent increase in housing values pushed lower income residents, who were primarily black, out of the expanding historic district (Bures 2001). This move disrupted existing social networks and began changing the character of neighborhoods on the city's downtown peninsula. Charleston's white and black residents had initially lived in mixed neighborhoods, as blacks continued living in former slave housing adjacent to the homes of former slave owners. Over time, neighborhoods became more segregated. Blacks and whites moved into various sections of the expanding metropolitan area in response to changing economic and social conditions.

Figure 3 illustrates changes in the racial structure of the Charleston peninsula from 1890 to 2000. Initially, more blacks than whites lived there (56% vs. 44%). This started to change around 1900 as the Navy moved in. By 1930, the city's racial composition had shifted: more whites (55%) resided in the peninsula than blacks (45%), and it would remain that way through 1950. This coincided with the period when the peninsula's population reached its peak, exceeding 70,000 in 1940 and 1950. However, beginning in 1950, white city residents began migrating out of the peninsula to Charleston's expanding suburbs. By 1970, blacks far exceeded whites on the peninsula (64% to 36%). This corresponds with a time of heightened racial tension involving a hospital workers' strike and city curfews (Fraser 1989).

Fig. 3. Summary of population by race on Charleston's peninsula, 1890-2000 (Source: Cutler et al. 1999, U.S. Census Bureau 2001).



As historic preservation and the resultant gentrification began taking hold in the 1980s and 1990s, the peninsula's racial composition was in flux once again. Charleston had passed the first Historic Zoning Ordinance in the United States in 1931 (Rosen 1997). Backed by federal and local policies, such as the National Historic Preservation Act of 1966 and tax benefits in the late 1970s, preservation-based development served to bring progrowth coalitions together in some cities (Reichl 1997). In Charleston, historic preservation served as a successful strategy for commercial and economic development and contributed to neighborhood change as wealthier homeowners invested in properties once considered low-income housing. By 2000, the peninsula's population had dropped to 33,000 and was 52% white and 48% black, suggesting that gentrification and its consequences were continuing to push out lower-income residents of both races.

Whereas the population of the peninsular city shrank, the surrounding suburbs grew rapidly. Between 1970 and 2000,

Table 2. Population and racial distribution in the Charleston area, 1970-2000.

	1970	1980	1990	2000
Charleston peninsula				
White (%)	35.7	36.3	42.9	50.4
Black (%)	64.3	63.3	56.5	47.8
Other (%)	0.0	0.4	0.5	1.8
Total population	46,503	40,783	36,540	33,318
Charleston remainder				
White (%)	74.6	68.6	66.6	64.2
Black (%)	24.9	30.3	31.8	33.1
Other (%)	0.5	1.1	1.6	2.7
Total population	189,687	226,125	259,093	276,651
Berkeley County				
White (%)	69.3	72.6	72.9	68.5
Black (%)	30.3	24.7	24.2	26.9
Other (%)	0.4	2.7	3.0	4.6
Total population	56,021	94,455	128,182	142,651
Dorchester County				
White (%)	64.4	73.0	75.0	71.6
Black (%)	35.1	25.3	23.1	25.4
Other (%)	0.5	1.7	1.9	3.0
Total population	32,276	58,761	83,060	96,413
Charleston-North Charleston metropolitan statistical area				
White (%)	67.1	67.0	67.9	65.8
Black (%)	32.5	31.5	30.2	31.0
Other (%)	0.4	1.5	1.9	3.2
Total population	324,487	420,124	506,875	549,033

Source: Geolytics 2002.

the population of the Charleston-North Charleston MSA grew 69%, from 324,487 to 549,033 (Table 2). During this time, the ratio of whites to blacks remained constant at roughly 2 to 1. However, the percentage of blacks declined in Berkeley and Dorchester Counties and increased within Charleston County outside of the peninsula. This suggests that blacks moved primarily into older suburbs as the white population pushed into new developments that expanded into neighboring counties.

As the population of the Charleston-North Charleston MSA grew, the area experienced economic growth, and mean family income increased across the metro area. The largest income increases in Berkeley and Dorchester Counties (20.8% and 25%) occurred between 1970 and 1980, indicating the growth of North Charleston and area suburbs. The Charleston peninsula saw its largest income increase (32.1%) between 1980 and 1990, a period when the historic districts expanded and gentrification increased (authors' calculations based on U.S. Census data).

The closing of the Naval Base in 1996 also spurred economic growth by opening new opportunities for diversified businesses in manufacturing, distribution, and technology (Jacobson 2000). This demonstrates an example of an adaptive system undergoing a collapse and reorganization that does not result in regime shift. Job growth in the Charleston region grew 16.5% between 2000 and 2007, more than twice the national average, and household income increased 30% (Economist 2009), fueling population growth. As the Charleston area became a destination, the percentage of the MSA's population born in South Carolina experienced a steady decline, from 63.4% in 1970 to 56.7% in 2000 (see Table 3). Having a high percentage of native residents can indicate that a metropolitan area is incapable of attracting newcomers (Campanella 2006), and we use state of birth as an indirect measure of native concentration. The steepest declines occurred on the Charleston peninsula, because of gentrification, and in Dorchester County, which experienced growth through suburban expansion. The decline of native residents on the peninsula reflects an indirect consequence of the continued success of the historic preservation movement (Bures 2001). Although ties to place are often associated with revitalization (Fried 2000, Brown et al. 2003), the characteristics of revitalized areas often attract new residents from outside the area.

Table 3. Percentage of population born in South Carolina.

	1970	1980	1990	2000
Charleston peninsula	81.3	77.9	72.7	62.4
Charleston County remainder	58.4	59.5	59.0	57.7
Berkeley County	66.4	55.8	52.8	55.3
Dorchester County	72.0	57.8	52.7	53.8
Charleston – North Charleston metropolitan statistical area	63.4	60.2	57.4	56.7

Source: Geolytics 2002.

In the two decades following Hugo, new construction and development projects pushed into coastal areas vulnerable to future storms and sea level rise (Allen and Lu 2003, Van Dolah et al. 2008). The combination of private property and the modern insurance industry essentially guarantees a quick reconstruction of areas lost to natural disaster (Campanella 2006). The Federal Emergency Management Agency's National Flood Insurance Program, which began in 1968, has kept private insurance premiums artificially low by assuming risk for flood damage. However, speedy recovery is not guaranteed for all areas within a social-ecological system, as seen in the aftermath of Hurricane Katrina (Campanella 2006, Lam et al. 2009).

The changes in population size and composition that occurred during these decades reflect the Charleston area's positive economic growth. However, coupled with increased urbanization, this growth may lead to a reduction in attachment to place. This can result in greater detachment from the natural system and the loss of a sufficient baseline for gauging ecological health (Turner et al. 2004). As development expands into natural areas, new residents are less likely to pick up on important signals that indicate a pending regime shift in the ecological system.

IMPLICATIONS FOR FUTURE RESILIENCE

Developers and urban planners tend to view the environment as a static entity that exists in equilibrium, ignoring ecological dynamics (Scoones 1999). For example, among their many functions, marshes act as buffers that protect coastal areas from hurricanes and storm surges (e.g., Loder et al. 2009). Achieving financial returns from piecemeal destruction of marsh habitat can lead to nearly imperceptible changes in slower variables such as the health of the overall marsh system (Holling et al. 2002*b*). The push for residential and commercial development in salt-water marsh systems within the Charleston area illustrates this.

Results of the SLAMM simulations demonstrate the extent to which Charleston is vulnerable to sea level rise and future collapse (Image Matters 2011). Each of three available scenarios shows a major decrease in salt water marsh and ocean beach for the barrier islands and urban areas surrounding the Charleston peninsula (available from authors on request). The lowest scenario, a 0.4 m sea level rise through the year 2100, shows a 51% decline in salt water marsh, a 21% decline in ocean beach, and a 58% increase in open water along tidal rivers. The highest scenario, a 1.0 m sea level rise, shows an 80% decrease in marsh, a 61% decrease in beach, and a 99% increase in open water. Under Category 4 hurricane conditions, these changes would make urban areas as vulnerable to storm surges as Charleston's coastal beaches were during Hurricane Hugo. It should be noted that recent studies find a likelihood for sea level rise above 1 m (Rahmstorf 2007, Nicholls and Cazenave 2010).

Sea level rise poses a tremendous challenge because it occurs at the highest levels of the panarchy, both spatially and temporally. Higher sea levels would bring a fundamental change to slow variables by significantly altering the ecological system over a broad spatial extent and forcing the social system to respond. The resources necessary for protecting against and mitigating the damage from sea level rise would likely drain government resources at local, state, and federal levels. Further, the insurance industry can no longer be counted on to provide the funds necessary for rebuilding private coastal property in the aftermath of natural disasters (Pompe and Rinehart 2008). However, Feagin et al. (2010) note that protecting private property is likely to occur at the expense of wetlands and publicly owned lands as long as property and housing investments are considered profitable.

The disruption of social mechanisms for response to sea level rise at the highest levels of the panarchy would parallel the regime shift that occurred at the end of the Civil War. The plantation system contained a massive amount of the social system's stored energy in the form of human, financial, and social capital, and its dismantling precipitated a regime shift. The contemporary equivalent in terms of stored energy would be the extensive infrastructure and concentrations of private capital located in the areas around Charleston that are most vulnerable to sea level rise.

As discussed by Pais and Elliott (2008), recovery from a major hurricane can take up to 10 years, and the recovery process responds to the destruction of property rather than homes and communities. The authors find that inequality increases during the recovery phase, particularly in the hardest hit areas: the residential elite use their private resources and social capital to rebuild in ways that squeeze out nonelites such as blacks, the elderly, and renters. Sea level rise, however, would likely change this dynamic of elite retrenchment, as resources such as private property insurance and federal flood insurance diminish under the burden of increasing claims (Breslau 2007, Frank 2010). Simultaneously, areas that previously had endured less damage from major hurricanes and served as residential destinations for displaced nonelites would become increasingly vulnerable to future storms because of increased coastal inundation.

CONCLUSION

Charleston represents a case of ongoing urban change that illustrates both maintenance and disruption of the social and physical environments. Resilience in one time period can be achieved at the expense of future resilience (Carpenter et al. 2001). The metaphor of the adaptive cycle can be used to classify systems and order events so that specific questions and testable hypotheses can be formulated to help understand transformations in social-ecological systems (Holling and Gunderson 2002). The collapse of the plantation system, which persisted in the Charleston low country for more than 160 years, occurred quickly. A collapse in Regime 2 structure and function could occur just as quickly under the right combination of shocks and disturbances at different levels in the panarchy. Recognizing the system characteristics that are most vulnerable to these shocks and disturbances is the first step in addressing ways to make the social-ecological system more resilient.

Environmental uncertainties and novel disturbances require social mechanisms that maintain ecosystem resilience and allow for adaptive responses (Carpenter et al. 2002). However, in many urban coastal systems, the slower ecological variables that promote resilience are degraded in favor of faster social variables that promote economic growth. This appears to increase the odds that responses to major disturbances caused by sea level rise would focus on protecting existing infrastructure and other social-system resources rather than finding innovative ways to adapt. In this regard, economic growth and development as currently practiced by many urbanized coastal systems could be considered its own rigidity trap.

Just as economic growth shaped Charleston's population changes in the 20th century, sea level rise appears poised to do the same in the 21st century. Sea level rise makes populations vulnerable to health risks, displacement, and shifting migration streams (Curtis and Schneider 2011). Coastal counties in South Carolina have a high proportion of blacks and elderly, and both groups are projected to be disproportionately affected by sea level rise and storm surges through 2030 (Curtis and Schneider 2011). Wetlands are known to reduce wave heights, and man-made structures such as oyster domes and reef balls can be used in combination with wetlands to enhance coastal protection (Gedan et al. 2011). To avert regime shift, coastal managers would need more information about sea level rise that can be integrated into day-to-day decision making, and that requires a process by which the information produced by scientists is made available in a practical way to managers (Tribbia and Moser 2008). Institutions and social structures that would allow for this are still in their early stages of development. Given the complexity of the social and ecological interactions involved at various spatial and temporal scales, this is no easy task.

RESPONSES TO THIS ARTICLE

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