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Hurricane Impacts on Coastal Ecosystems

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Introduction

Hurricanes, typhoons, and other cyclonic disturbances often produce sudden, massive disturbances in estuaries and other coastal ecosystems around the world. Compared with other ecological disturbances, such as prairie and forest fires, tree falls, and coral bleaching events, the effects of hurricanes are usually studied in isolation of each other and rarely as repeated or even ecologically predictable events across an area of sustained hurricane activity. Studies of their effects have rarely contributed to the growing body of theory on ecological disturbance and ecosystem resiliency and they are conspicuously absent from ecological textbooks.

Since 1996, there has been an increase in the frequency of hurricane landfalls in the southeastern United States that is predicted to continue for some years into the future (Goldenberg et al. 2001; Emanuel 2005; Webster et al. 2005). Coupled with the availability of results from many water quality and biological monitoring programs now in place in these coastal systems, the increase in hurricane activity now provides an opportunity to begin the systematic investigation of how a series of hurricanes might produce cumulative and perhaps even irreversible effects on coastal ecosystems. One particular example that is highlighted in this special issue of *Estuaries and Coasts* is the occurrence of four major hurricanes to make landfall in Florida in a two-month period of 2004. In some localities, sequential hurricanes made landfall in close proximity to each other, while in other regions of coastal Florida, the repeated heavy rains associated with the multiple hurricanes had effects that were distinct from the wind and storm surge effects often associated with hurricanes.

This special issue of *Estuaries and Coasts*, which reports investigations of hurricane-mediated disturbances, is an opportunity to describe the individual and cumulative effects of storms on coastal environments and component flora and fauna, to put effects of extreme events in the context of long-term monitoring data sets in multiple estuaries, to examine effects of storms on estuarine management, and to provide the impetus for synthesis and generalization. Although the articles in this issue focus primarily on new findings related to the effects of the 2004 hurricanes on coastal systems, the effects of earlier hurricanes are summarized, and some preliminary reports on effects of the 2005 hurricanes are given.

A prominent theme emerging from these articles is that many ecological components of estuaries and coastal systems, although initially severely altered by individual or multiple hurricanes, were quite resilient to the acute effects of the 2004 season hurricanes, in sharp and striking contrast to the long-term effects on human and social systems. Hydrodynamic effects can be strong, but short-lived (days) (Wilson et al. 2006). Water quality and phytoplankton productivity in Gulf of Mexico estuaries (Hagy et al. 2006; Morrison et al. 2006; Tomasko et al. 2006) demonstrated an initial (days to weeks) response to winds or increased rainfall in the watershed, but effects also were relatively short-lived (months). Fish assemblages also demonstrated initial impacts (days to weeks) but recovered rapidly (days, weeks) following acute hurricane impacts (Greenwood et al. 2006; Paperno et al. 2006; Stevens et al. 2006; Switzer et al. 2006). A study of manatee populations, which had been thought to be affected by previous severe storm events, revealed that individual manatees showed only slight movement from their normal areas of activity in response to passing hurricanes (Langtimm et al. 2006).

The response of submerged aquatic vegetation to hurricanes was more variable. Seagrasses appeared resilient to changes in salinity associated with increased rainfall or tidal surge tied directly to hurricanes (Byron and Heck 2006; Steward et al. 2006) and exhibited only isolated instances of physical impacts from scouring (Steward et al. 2006). In both fresh (Frazer et al. 2006) and marine environments (Ridler et al. 2006) longer-lasting

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changes in SAV community structure occurred in response to hurricane induced changes in salinity, or to physical dislodging of SAV (Lapointe et al. 2006).

Spatial variation in physical damage and recovery from single or multiple hurricanes was evident. Shoreline and dune erosion was severe in some areas but not in others (Sallenger et al. 2006). Wetland soil elevation changes resulting from hurricanes are influenced by a multitude of factors, including shoreline vegetation community structure, and are very difficult to predict (Cahoon 2006). In some areas of coastal Louisiana, large sections of wetlands were lost in extreme events. Physical damage to mangroves and other vegetation varied as the distance from the eye-wall and this determined the rate of defoliation (Milbrandt et al. 2006; Tomasko et al. 2006). Delays in mangrove recolonization may be associated with habitat fragmentation caused by shoreline development (Milbrandt et al. 2006), and mangrove reproduction was reduced by an order of magnitude in the year following direct impacts (Proffitt et al. 2006).

Individual storm characteristics also play a large role in the types and temporal extent of impacts. For example, direction and speed of approach, point of landfall and intensity all influence the magnitude of storm surge and resultant flooding (Weisberg and Zheng 2006) and consequent environmental damage. Storms with significant rainfall appear to have longer-term effects on downstream systems than do faster-moving storms with higher winds (Paerl et al. 2006), and areas with higher levels of anthropogenic land use activity are more susceptible to environmental damage and long-term effects from storms (Mallin and Corbett 2006). Recorded impacts from hurricanes include excessive nutrient loading; algal blooms; elevated biochemical oxygen demand and subsequent hypoxia and anoxia; fish and invertebrate kills; aquatic animal displacements; large scale releases of chemical pollutants and debris; exacerbated spread of exotic species and pathogens; and pollution of water with fecal microbial pathogens (Mallin and Corbett 2006).

Effects of hurricanes and other storm events can slow down, halt or reverse environmental restoration and management strategies in estuarine and coastal systems (Morrison et al. 2006; Paerl et al. 2006). Although storm events cannot be managed, the articles in this issue support development and implementation of research and monitoring strategies to better understand their impacts (Bortone 2006) and help direct more effective management of watersheds and coastlines.

Results and findings of the research reported in this special issue provide a compelling but incomplete picture of some of the impacts of hurricanes on coastal systems, especially in how human systems are affected by the ecological responses and themselves affect the extent of ecological damage. Many questions remain: among agents of ecological disturbance, do hurricanes deserve unique status? Does the combination of wind and rain in such storms leave an identifiable environmental signature? How do storm frequency and intensity interact to change community structure and function? If land use practices, such as coastal development, are affecting the resiliency of estuaries and coasts to extreme disturbances like hurricanes, are researchers and managers collecting sufficient and appropriate data on a relevant spatiotemporal scale to understand and better predict these impacts? To what extent do other anthropogenic effects on coastal systems determine their resiliency to single or multiple hurricane events? How can scientists and managers better place impacts from disturbances into perspective with long-term temporal environmental trends? And, as suggested by observations made following the December 2004 Indian Ocean tsunami (Liu et al. 2005; Adger et al. 2005), does coastal development ultimately determine the vulnerability of human and ecological systems to hurricanes?

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