Geomorphology 321 (2018) 72–86

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Catastrophic storm impact and gradual recovery on the Mississippi-Alabama barrier islands, 2005–2010: Changes in vegetated and total land area, and relationships of post-storm ecological communities with surface elevation

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ARTICLE INFO

Article history:
Received 19 December 2017
Received in revised form 8 August 2018
Accepted 13 August 2018
Available online 16 August 2018

Keywords:
Gulf of Mexico
Hurricanes
Barrier island
Microtopography

ABSTRACT

One of the most destructive tropical cyclones ever to strike the U.S., Hurricane Katrina made landfall along the Mississippi coast on 29th August 2005. The Mississippi-Alabama (MS-AL) barrier islands were subjected to storm breaching, area reduction, and vegetation loss caused by a number of parameters including salt spray, saltwater flooding, mechanical damage (e.g., ablation of bark from tree trunks), removal of plants and their soil substrate by scouring, burial under sand, and a 10-month, post-storm period of low rainfall. Repeated acquisitions of remotely-sensed data served as an essential tool in quantifying vegetated and total land area before and after the storm, and post-storm ecological community type and topographic elevation. Vegetated land area continued to decline on some islands in the first year following the storm. However, by November 2007, only 2.2 years after the storm, total vegetated land area had recovered to 72, 96, 77, 93, and 82%, and total subaerial land area to 97, 94, 33, 100, and 104%, of pre-Katrina values on Cat, W. Ship, E. Ship, Horn, and Petit Bois islands by natural re-growth and sediment accretion, respectively. Comparing ecological community-type maps that were developed from field and remotely-sensed data with LiDAR-derived digital elevation models determined that year 2010 ecological community type changed distinctively at the decimeter scale as mean surface elevation ranged from 0.1 m to 1.2 m. Storm-related changes in ecological community type included subtidal to supratidal sand flat, low marsh to wet or dry herbland, and woodland to wet herbland/shrubland.

1. Introduction

As generally low-elevation landforms composed almost entirely of sand, barrier islands are highly sensitive indicators of global climatic change and sea level rise (Pilkey, 2003). Indeed, the existence of some islands may be threatened in the present century by an expectedly greater frequency and intensity of tropical cyclones (Knutson et al., 2010), effects of relative sea-level rise (eustatic plus local subsidence), and human influences on sediment availability (e.g., Morton, 2008). After a storm, the level of island reconstruction by natural processes depends on sediment availability (Leatherman, 1979; Hesp, 2002; Psuty, 2004) and the stabilizing influence of vegetation (Hesp, 1991; Snyder and Boss, 2002; Feagin et al., 2015). The latter depends strongly on species adaptations to sediment erosion, movement, and deposition (Moreno-Casasola and Espejel, 1986; Hesp, 2002; Stallins and Parker, 2003; Stallins, 2005; Feagin et al., 2015), salt spray, low nutrient availability, and flooding (Oosting, 1954; Hesp, 1991; Carter and Young, 1993; Shao et al., 1996). For example, dunes allow the formation of more stable backdune plant communities because they reduce overwash and the windborne transport of sand and salt spray toward the island interior (Hayden et al., 1995; Stallins, 2005). In particular, saltwater flooding greatly affects the distribution of woody plant species because it inhibits seed germination and is often lethal (Lantz et al., 2015).

On 29th August 2005, the Mississippi-Alabama (MS-AL) barrier islands in the northern Gulf of Mexico, including Cat, W. Ship, E. Ship, Horn, W. Petit Bois (formerly named Sand Island), Petit Bois, and Dauphin islands (Fig. 1), were impacted severely by Hurricane Katrina (NOAA, National Hurricane Center, https://www.nhc.noaa.gov/data/tcr). The eye of the storm passed 50–150 km west of the islands,

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https://doi.org/10.1016/j.geomorph.2018.08.020
0169-555X/

Fig. 1. Landsat 5 Thematic Mapper (TM5) natural color image of the MS-AL barrier islands and mainland coast acquired on 16th September 2005, approximately two weeks after the 29th August 2005 Mississippi landfall of Hurricane Katrina. By acting as sediment traps, ship navigation channels (solid white lines) extending from Mobile Bay and west of Petit Bois and W. Ship islands have increasingly reduced the volume of westward-directed net longshore sediment transport since the late 19th century (Morton, 2008). Erosional conversion of most of the Chandeleur Islands, Louisiana to sandy shoals (Otvos and Carter, 2013; Moore et al., 2014; Otvos, 2018a, in press) rendered them barely visible at bottom-left in the image. The dashed vertical white line on Dauphin Island indicates longitude 88.2° W, the eastern limit of the study area.

producing storm tide depths which ranged generally from 9 m on the westernmost islands (Cat and W. Ship islands) to 3.5 m on Dauphin Island (Fritz et al., 2007, 2008), with a maximum of 12 m on W. Ship Island (Morton, 2010). Maximum 1-min average wind speeds ranged from 200 km h^{-1} on Cat Island to 140 km h^{-1} on Dauphin Island (Powell and Reinhold, 2007). Island geomorphic features were substantially altered (Feagin and Williams, 2008; Morton, 2008, 2010; Otvos and Carter, 2008; Lucas and Carter, 2013; Jones, 2015; Eisemann et al., 2018), while vegetation was decimated by wind, salt spray, erosion, sand overwash, saltwater flooding and several months of low rainfall following the storm (Hughes, 2008; Otvos and Carter, 2008; Lucas and Carter, 2013). Decadal-scale variability in the MS-AL barrier chain, and land area changes caused by Katrina in the context of long-term trends, were addressed earlier (e.g., Morton, 2008; Otvos and Carter, 2008; Jones, 2015).

From the time of Hurricane Katrina's impact through summer 2010, when boulder placement reconnected central Dauphin Island with the developed eastern portion of the island, vegetation and geomorphic features on the MS-AL barriers west of longitude 88.2° W had undergone only naturally-occurring changes. These included limited erosion by Hurricane Gustav, which made landfall on 1st September 2008 near Cocodrie, Louisiana, approximately 150–200 km west of the MS islands and 230 km west of Dauphin Island, exposing the MS-AL islands to tropical-storm force winds (Doran et al., 2009; NOAA, National Hurricane Center, https://www.nhc.noaa.gov/data/tcr). Frequent acquisitions of remotely-sensed data by government and commercial organizations facilitated quantitative assessment of vegetation reestablishment and habitat change on the islands (Lucas and Carter, 2013). In combination with remotely-sensed data, ground observations from a 2010–2011 field survey (Carter et al., 2016) were incorporated to address post-Katrina changes in vegetation and geomorphic features, and decadal-scale resilience of the islands to relative sea-level rise, sediment deprivation, and storms (Anderson et al., 2016; Funderburk et al., 2016; Jeter Jr. and Carter, 2016). These studies considered either one large island (Cat or Horn Island) or two small islands (E. Ship and W. Petit Bois islands) at remote-sensing spatial resolutions as fine as 1 m ground sample distance (GSD), or ground pixel size. Their results indicated a strong dependence of plant survival and ecological community-type development on microtopographic (<1 m) variations in surface elevation.

In contrast with the earlier studies of the impacts of Hurricane Katrina on island vegetation, the present study was more extensive geographically, addressing the entire uninhabited portion of the MS-AL barrier chain from Cat Island eastward to western and central Dauphin Island. Repeated acquisitions of remotely-sensed data served as an essential tool in identifying and mapping vegetated and total land area, ecological community type, geomorphic features and topographic elevation. Data were combined among the MS islands to describe the relationship between ecological community type and decimeter-scale surface elevation in the MS portion of the barrier chain at a 10 m GSD. Multispectral image data acquired prior to and following Hurricane Katrina in 2004–2005 and 2005–2010, respectively, were classified to produce maps of general land cover (total vegetation, unvegetated or sparsely-vegetated sand, and lagoons and ponds). This enabled quantification of land cover for image acquisition dates that occurred prior to the storm, approximately one and two weeks after landfall, and periodically within the subsequent five post-Katrina years. RADAR, LiDAR, and multispectral image data acquired in 2010 were used to map ecological community types and assess their relationship with surface elevation across the MS portion of the barrier chain. Specific objectives included: 1) determination of total land and total vegetated land area at a GSD of ~2 m to 4 m; 2) mapping the 2010 distribution of ecological community types at 10 m GSD, and 3) comparison of ecological community type with surface elevation at 10 m GSD on the MS portion of the barrier chain.

2. Study area

The ~105 km-long MS-AL barrier island chain marks the southern limit of the Mississippi Sound. Mean elevation of the MS islands,