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Human interference prevents recovery of infaunal beach communities from hurricane disturbance

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ABSTRACT

Natural disturbances can obliterate established communities, which in resilient environments recover given time. Ecosystem recovery, however, can be altered by human activities. We document this phenomenon in beach habitats along the upper Texas coast that were impacted by Hurricane Ike, which struck the Texas coast in September 2008. Our monthly monitoring of two beaches spanned June 2007 through May 2009, and thus captured pre- and post-hurricane periods. The beach sites differed in their use by humans during the post-hurricane period, with one beach experiencing heavy vehicular driving. At both beach sites, macroinvertebrate population densities decreased, sediment was lost, and sediment grain size increased as a result of the hurricane. Within 3 months, sediment grain size recovered at both sites. At the beach location not experiencing heavy vehicular driving, total sediment and organismal abundance recovered within 9 months. The beach community there comprised taxa that were primary and secondary successional species. At the other beach location, however, recovery was not observed. It is likely that the heavy vehicular driving there interfered with recovery of the beach community. These findings demonstrate that human activities in these beach environments following large natural disturbances strongly influence ecosystem recovery, in this case possibly preventing return to the pre-hurricane ecosystem state.

1. Introduction

Sustainable use of beaches worldwide has increasingly become a priority. Managers, stakeholders, and conservationists working together produce the best practices (van der Meulen and Salman 1996; Micallef and Williams 2002; Jones et al. 2007; Eigenbrod et al. 2009). Many beach practices have been dominantly human centered (James 2000; Ariza et al. 2008; Schlacher et al. 2008b). These create variable consequences resulting in human-induced disturbances upon the ecological community (Godfrey and Godfrey 1980; James 2000; Peterson et al. 2000; Schlacher et al. 2008a; Defeo et al. 2009). The upper Texas coast experiences many types of human-induced disturbances. These include raking, traffic, construction, and beach nourishment. Raking is a technique of seaweed and debris removal from the intertidal zone that influences some beach processes. For example, targeted placement of raked *Sargassum* may influence dune formation and retention, but if done casually could adversely affect beach erosion and benthic communities (Davidson et al. 1991; Gheskiere et al. 2006; Feagin and Williams 2008). Automobile and pedestrian traffic also alters beach communities through accelerated erosion and sand compaction. Traffic on the upper beach causes loss of dunes, while traffic near the water line causes beach erosion (Godfrey and Godfrey 1980). Compaction is more problematic higher on the beach than at the water's edge (Rickard et al. 1994; Moffett et al. 1998). Construction strongly alters beach environments, where seawalls and jetties encourage continued erosion of the beach face, thus loss of intertidal organisms (Griggs 2005; Stutz and Pilkey 2005; Dugan et al. 2008). Finally, beach nourishment, deposition of sediment upon the beach face replacing loss from erosion, was shown to suffocate infaunal organisms on the beach face and when deposited in nearshore sandbars (Bishop et al. 2006; Bolam 2011).

Natural fluctuations in biomass and diversity of macrofauna are common in marine benthic communities (Thistle 1981; Sousa 2001). Some fluctuations occur because of disturbances (Grime 1977; Sousa 2001), which might be characterized as a single event (pulse) or a continuous, chronic condition (press) (Bender

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et al. 1984). Open sandy beaches of the Gulf of Mexico are exposed to pulsed disturbances in the form of seasonal storms (Saloman and Naughton 1977; Jaramillo et al. 1987; Davis et al. 2004; Dreyer et al. 2005). Many scientists are predicting continued and increasing hurricanes for the Caribbean (Henderson-Sellers et al. 1998; Goldenberg et al. 2001; Elsner 2006; Kerr 2006; Sanders and Lea 2008). This increase in storms has the ability to interfere with the beach ecosystem through destabilizing the habitat, altering recruitment, increasing erosion, and human manipulation (Hughes 2000; Galbraith et al.2002; Zhang et al. 2004). Press disturbances such as the landward change in shoreline position because of global sea level rise and increasing subsidence and erosion is expected to continue (Brown and McLachlan 2002; Feagin et al. 2005; IPCC 2007). Human induced press disturbances occur in the form of gradual beach erosion and vehicular driving. While pulse and press disturbances have differing effects on beach communities because they operate over varied time scales, it is likely that there are interaction effects between these disturbance types.

Ecological recovery of coastal beach communities is influenced, in part, by the type and magnitude of disturbance. Following fast moving pulse events such as winter and tropical storms, various water quality parameters took only hours to recover (Davis et al. 2004). But when sediment was removed and benthic communities disrupted, sediment and community recovery took months to years (Boesch et al. 1976; Saloman and Naughton 1977; Jaramillo et al. 1987; Morton et al. 1994; Peterson et al. 2000). Some communities may not recover from disturbances, but instead move to a new steady state/equilibrium. For example, following a large hurricane in New England where the sediment was completely removed, the previous community characterized by 18 taxa dominated by the polychaete *Scolelepis squamata* was replaced by a community including eight newly encountered taxa characterized by polychaetes, *Capitella* sp. and later *S. squamata* (Jaramillo et al. 1987). In this and other studies after a large disturbance, it was observed that abundance and diversity returned within a few years, but species composition took longer, if at all (Miller 1986; Jaramillo et al. 1987; Byrnes et al. 2004).

In this research, we examined recovery of coastal beach benthic communities from a large pulse disturbance, Hurricane Ike, which struck the Texas coast in September 2008. The Texas coast experiences regular tropical storm disturbances at a rate of one every 0.76 years (McGowen et al. 1977). In addition, the Texas coast experiences many press disturbances that include coastal development with accompanying use of beaches as roadways. The passage of Hurricane Ike and varied human use of beaches post-hurricane provided the opportunity to study how pulse and press disturbances interact as they influence recovery of beach communities. We do this here, with examination of pre- and post-hurricane beach geomorphology and macrofaunal community composition and dynamics.

2. Materials and Methods

2.1. Study sites and design

Two coastal Texas beaches were monitored before and after Hurricane Ike from June 2007 through May 2009. Sites were selected based on low to moderate use, site accessibility, and position along the upper Texas coast. Sites, named by the nearest municipality, included Sabine Pass and Surfside Beach (Fig. 1). Geomorphological and biological data were examined to determine the pre-hurricane ecosystem state and the rate of recovery following the hurricane. Each site was surveyed monthly within 10 days of the full moon. Surveys included recordings of beach profiles, beach road presence and width, sediment grain size, and

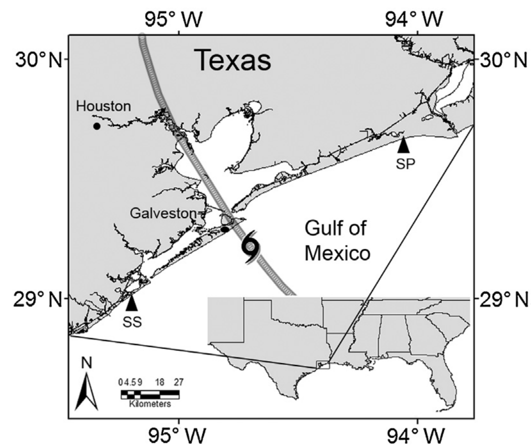

Fig. 1. Study sites. Location of each study site, titled by nearest municipality. SP- Sabine Pass; SS- Surfside Beach.

macrofaunal densities. Beach width was defined as the distance from the benchmark (dune line before Hurricane Ike) to the high tide line. Beach loss was measured as the landward migration of high tide after the hurricane. Beach disturbance was measured as the percent of beach with road tracks.

Two shore normal transects were established at each beach demarked by a stationary object (benchmark) and fixed by GPS coordinates. The benchmark established at each beach at the beginning of the study before Hurricane Ike were reestablished after Hurricane Ike using GPS coordinates, confirming positions with photographs, remaining landmarks and range markers. A beach elevation survey was conducted monthly by site along the "b" transect line with the established benchmark. Surveys ran from the benchmark to the shoreline including 5 m into the intertidal zone. The LaserMark LMH series, laser survey equipment, was used to determine elevation throughout this project. Elevation was normalized to sea level using verified data from local NOAA buoy, Galveston Pleasure Pier, TX Station ID: 8771510 for Sabine Pass site and NOAA buoy, USCG Freeport, TX Station ID: 8772447 for Surfside Beach. North American Vertical Datum 1988 (NAVD '88) mean low low water mark (MLLW) was used in elevation measurements.

2.2. Macrofaunal and sediment collections

Monthly intertidal core samples were collected on each transect every 4 weeks; total of 24 cores per month. Along each transect six intertidal stations were established to ensure the capture of macrofauna across varying zones (Fig. 2). Cylindrical PVC tube measuring 10 cm diameter by 10 cm length (0.00785 m^2) was used for macrofaunal and sediment coring. Total surface area collected monthly was 0.09 m^2 per site or 0.19 m^2 total across the sites. Sediment cores were sieved with a 1.0 mm bucket sieve on site. Fauna and shell hash remaining on the sieve were fixed and preserved with 10% formalin buffered with seawater and pre-stained with Rose Bengal until sorting in the laboratory at Texas A&M University, College Station, Texas. In the laboratory specimens were sorted from shell fraction and debris, then identified and counted. Identified specimens were stored in 95% ethanol. Identification was made to the lowest possible taxonomic level.

Sediment was collected in July 2008, September 2008 and December 2008 from each site to examine sediment grain size. One 10 cm diameter by 10 cm length cylindrical cores was collected at relative sea level (0 m). Sediment was placed in Ziplock bags for transport back to the laboratory. In the laboratory sediments were dried at 35 °C in a Thelco Precision Scientific oven until a constant