Marine Environmental Research 94 (2014) 48–55

Contents lists available at ScienceDirect

Marine Environmental Research

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

Plugging the leak: Barrier island restoration following Hurricane Katrina enhances larval retention and improves salinity regime for oysters in Mobile Bay, Alabama

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ARTICLE INFO

Article history:
Received 3 September 2013
Received in revised form
9 November 2013
Accepted 9 December 2013

Keywords:
Oyster population
Hurricane Katrina
Recovery
Salinity
Larval retention
Mobile Bay

ABSTRACT

Changes in geomorphology of estuaries are common following major perpetuations such as hurricanes and may have profound impacts on biological systems. Hurricane Katrina in 2005 created a new pass, called Katrina Cut, halving Dauphin Island in Mobile Bay, Alabama. Significant decline in oyster population at Cedar Point Reef, the primary oyster harvest grounds in Mobile Bay, had persisted since then until the Cut was artificially closed in 2010. A bio-physical model for hydrodynamics and oyster larval transport was used to evaluate two potential mechanisms responsible for oyster population declines: salinity changes in the context of oyster habitat suitability and retention of oyster larvae. The model results revealed that when open Katrina Cut increased salinity at Cedar Point Reef. During high freshwater discharge, in particular, water exchange through Katrina Cut increased the bottom salinity from <5 psu to well over 15 (sometimes >20) psu during the tropic tides. Elevated salinities are associated with greater predation on oysters and higher disease incidence. The presence of the Katrina Cut also reduced larval retention in the spawning area regardless of tidal or river discharge conditions. We conclude that closing the Cut likely improved conditions for oysters within Mobile Bay and eastern Mississippi Sound and that these improved conditions have contributed to increased oyster landings.

1. Introduction

Large-scale changes in the geomorphology of estuarine landscapes, which may occur from natural forcing (e.g. hurricanes and earthquakes) or anthropogenic intervention (e.g. dredging and dams), may affect the endemic biological community through changes in physical exchange of propagules, sediments or solutes. For organisms with limited mobility (e.g. sessile invertebrates and plants), changes in the physical–chemical environment can have profound effects on local population dynamics. Oysters, sessile invertebrates that serve as ecosystem engineers, are important elements of healthy estuarine and coastal ecosystem (Coen et al., 2007; Powers et al., 2009). Successful recruitment of oysters, like other marine organisms with planktonic larval stage, depends on production of larvae, larval transport and supply, larval settlement, and post-settlement survival to adults, and variations in each of these components has the potential to regulate their populations (Kennedy, 1996; Underwood and Keough, 2001). Spatial and temporal variability in larval supply has been shown to primarily reflect physical processes governing water circulation (e.g. Brown et al., 2005; Kim et al., 2010). Thus, changes in hydrodynamic regime affect circulation patterns that could modify delivery of new recruits. Further, modifications to the physical environment could also affect biological communities if the new environmental conditions exceed the physiological tolerances of species. Here, we used a unique opportunity, the natural formation of an inlet within a once continuous barrier island and the subsequent anthropogenic filling of it, to illustrate how such large-scale changes in the geomorphology of an estuary can have cascading effects to important biological elements of estuarine ecosystems such as oysters.

Hurricanes are high-energy extreme events that have the capacity to drastically alter estuarine and coastal ecosystems. Hurricanes can damage habitats through direct wind or wave action (Livingston et al., 1999; Litaker and Tester, 2003). Storm-induced salinity changes, either a decrease or an increase, can adversely affect sessile benthic organisms. Rapid reductions in salinity due to increased freshwater discharge may reduce abundance and lower species diversity (Boesch et al., 1976; Litaker and Tester, 2003). Increases in salinity due to storm-induced intrusion of ocean water may bring in predators and thus increase oyster mortality

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0141-1136/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marenvres.2013.12.003

(Livingston et al., 2000; Mackenzie, 2006). Oxygen deficits due to increased nutrient loadings may result in massive fish kills (Mallin et al., 1999; Burkholder et al., 2004), but the effects on benthic organisms vary from minor (Burkholder et al., 2004) to severe (Boesch et al., 1976) depending on the severity and duration of hypoxic events. Different hurricanes can cause different impacts depending on the storm characteristics and their interaction with human use of estuarine and coastal systems (Mallin and Corbett, 2006). Many studies have reported relatively rapid recovery from the effects of hurricanes of estuarine and coastal ecosystems, particularly in shallow systems that are frequently disturbed by hurricanes (Livingston et al., 1999; Mallin et al., 2002; Litaker and Tester, 2003; Burkholder et al., 2004; Paperno et al., 2006; Switzer et al., 2006; Williams et al., 2008).

The Mobile Bay system, a shallow estuary in the northern Gulf of Mexico (Fig. 1a), has been frequently disturbed by hurricanes. The system supports one of the few sustainable oyster fisheries in the world (zu Ermgassen et al., 2012). Observations in Mobile Bay and eastern Mississippi Sound, Alabama have shown a persistent gradient in oyster spat settlement decreasing from west to east (Hoese et al., 1972; Saoud et al., 2000; Kim et al., 2010). Significant settlement exists in the southwest side of Mobile Bay and eastern Mississippi Sound and negligible settlement occurs in the middle and east side of the Bay (Fig. 1b). Cedar Point has the largest expanse of oyster reefs, Cedar Point Reef (*CPR* in Fig. 1a) and has been the historic center of the Alabama oyster fishery, contributing over 90% of oyster harvest in Alabama (May, 1971; Gregalis et al., 2008). Hurricane Katrina in 2005 left a seemingly irreversible mark on Dauphin Island, creating a new pass halving the Island (Fig. 2). The new pass at first was expected to be filled in, returning to one island as it had been over the past several hurricanes and storms; however, the pass, called 'Katrina Cut,' had widened (~2 km wide) and deepened (~3 m deep in the center) owing to the swift current, and appeared to be a permanent feature. Of the suspected impacts of the Katrina Cut was drastic decline in oyster population in the *CPR* area. Oyster landings had plummeted in 2007 and 2008, and remained much lower in 2009 and 2010 than previous years (Fig. 3). Local fishermen expressed their strong belief that the Cut was related to this decline. Specifically, it was speculated that Katrina Cut, which formed a direct connection between *CPR* and the northern Gulf of Mexico, might have enhanced flushing (loss) of larvae through the Cut into the Gulf, resulting in the decreased larval supply. Additionally, elevated densities of marine predators (e.g. oyster drills) due to higher salinities as a result of saltwater intrusion from the Gulf through the Cut might have increased post-settlement mortality. While oysters can survive and grow in a wide range of salinities (5–35 psu), oyster populations thrive within a narrow range of 10–20 psu. Higher salinities tend to promote predator density and disease prevalence (Soniat and Brody, 1988; Fodrie et al., 2008). In many estuaries, freshwater events can pulse low salinity waters through oyster reef areas and reduce the populations of predators or incidence of disease (Livingston et al., 2000; Powell et al., 2003; La Peyre et al., 2009).

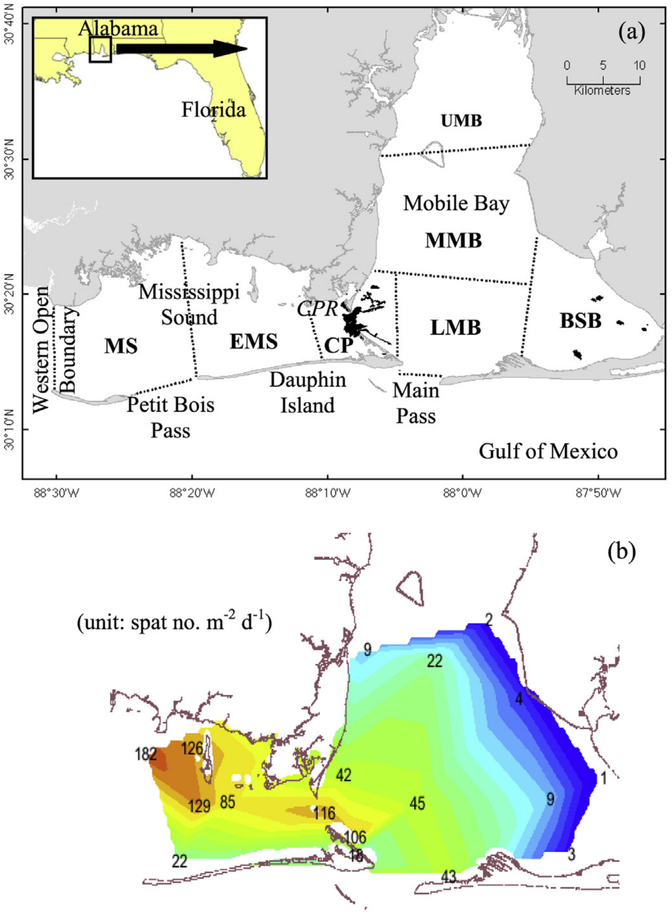

Fig. 1. A map of Mobile Bay and eastern Mississippi Sound (a) and the average oyster spat settlement intensity observed in May–October 2006 (b). In (a), the filled areas indicate existing oyster reefs including Cedar Point Reef complex (*CPR*), and the dashed lines denote boundaries of seven zones, including Mississippi Sound (MS), eastern Mississippi Sound (EMS), Cedar Point (CP), lower Mobile Bay (LMB), middle Mobile Bay (MMB), upper Mobile Bay (UMB), and Bon Secour Bay (BSB).

Salinity in Mobile Bay exhibits great fluctuations in response to freshwater discharge, wind, tide, and intrusion of saline Gulf water, which themselves fluctuate greatly (Kim and Park, 2012), making it difficult to isolate the portion of salinity changes due to the Katrina Cut solely based on field data. It also is inherently difficult to study larval transport and supply solely based on field data. Deterministic bio-physical models that solve the governing equations of continuity, momentum and mass-balance equations have been widely used to study various aspects of larval transport under a variety of forcing conditions (e.g., Churchill et al., 2011; Metaxas and Saunders, 2009; North et al., 2008; Simons et al., 2013). Then, a deterministic bio-physical model for hydrodynamics and oyster larval transport that has already been validated for the study area would become a reasonable alternative to investigate changes in salinity and larval transport. We investigated using an existing model to evaluate the potential mechanism(s) responsible for oyster population declines. We have focused on: 1) changes in salinity due to the Katrina Cut in the context of oyster habitat quality at *CPR*, and 2) changes in larval supply due to the Katrina Cut in the context of larval retention at *CPR*.

2. Methods

2.1. Larval transport model and grid systems

A three-dimensional larval transport model was developed as part of a study to investigate larval transport of the eastern oyster, *Crassostrea virginica*, in Mobile Bay and eastern Mississippi Sound, Alabama. The model accounts for physical transport, biological movement of larvae, and site- and larvae-specific conditions (Kim et al., 2010; Kim and Park, 2012). The model application gave a good reproduction of the observed water level, current velocity, and salinity for both total and subtidal components. The model reasonably reproduced the observed gradients in oyster spat settlement and bivalve larval concentration. Detailed information of the model and its application and validation was reported in Kim