Ecological Modelling 297 (2015) 154–170

Contents lists available at ScienceDirect

Ecological Modelling

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

The application of oyster and seagrass models to evaluate alternative inflow scenarios related to Everglades restoration

Christopher Buzzelli *, Patricia Gorman, Peter H. Doering, Zhiqiang Chen, Yongshan Wan

South Florida Water Management District, 3301 Gun Club Road, West Palm Beach, FL 33406, United States

A R T I C L E   I N F O

Article history:
Received 2 July 2014
Received in revised form 21 October 2014
Accepted 26 October 2014
Available online 27 November 2014

Keywords:
Everglades
Modeling
Freshwater
Salinity
Seagrass
Oysters

A B S T R A C T

The South Florida landscape is highly engineered featuring ~3380 km of canals, ~1225 water control structures, >70 pumping stations, managed wetlands, densely populated coastal watersheds, and impacted estuaries. Landscape scale agricultural and urban modifications require flood control which sometimes results in the release of excess freshwater that potentially damages estuarine ecology. The Central Everglades Planning Project (CEPP) is a partnership between the U.S. Army Corps of Engineers and the South Florida Water Management District focused on restoring natural patterns of freshwater flow to the Everglades and associated estuaries. One of the primary project goals is to reduce deleterious inflows eastward to the St. Lucie Estuary (SLE) and westward to the Caloosahatchee River Estuary (CRE) by diverting freshwater south from Lake Okeechobee. Performance evaluation of the CEPP relies upon integrated modeling which links the watershed engineering projects to estuarine salinities and biotic responses. The objective of this study was to utilize seagrass and oyster models to evaluate the effectiveness of alternative inflow scenarios. There are three different scenarios: the existing condition base (ECB), the future without proposed CEPP projects (FWO) but with other landscape features that could alter freshwater inflows, and alternative 4R (ALT4R) that incorporates a suite of restoration projects including those associated with the CEPP. Each of these inflow scenarios was used to generate daily salinity time series from 1965 to 2005 at multiple locations in the SLE and CRE which were used to run site-specific seagrass and oyster models. The hydrodynamic and ecological effects of freshwater inflow were greater in the SLE compared to the much larger CRE. Predicted densities of oysters (individuals m^{-2}) and seagrass (shoots m^{-2}) were greater in the wet season (May–Oct) vs. the dry season (Nov–Apr) in both estuaries. Oyster and seagrass densities increased under the ALT4R inflow scenario that mitigated high inflows to the estuaries in the wet season. This result improved environmental conditions while increasing freshwater availability for other parts of the Greater Everglades and the southern estuaries such as Florida Bay and Biscayne Bay.

1. Introduction

The restoration of historical freshwater flow to the Florida Everglades and associated coastal ecosystems represents an unprecedented attempt to restore aquatic ecology at the regional scale (USACE and SFWMD, 1998; Obeysekera et al., 2011; Herbert et al., 2011). The Comprehensive Everglades Restoration Plan (CERP) emerged from the Central and South Florida Project Review Study to return the interior Everglades and estuaries to a more natural state (Table 1; USACE and SFWMD, 1998; NRC, 2012). The CERP is in response to widespread environmental degradation attributed to the long-term transformation of the Everglades landscape once characterized by sheet flow, abundant wetlands, and diverse coastal habitats. The modern landscape is highly engineered featuring ~3380 km of canals, ~1225 water control structures, >70 pumping stations, heavily managed wetlands, densely populated coastal watersheds, and highly impacted estuaries (Ogden et al., 2005; Obeysekera et al., 2011). While the present water management system completed in the 1970s was intended to provide water supply and flood protection for approximately 2 million people, by 2013 there were >8.3 million people inhabiting southeastern Florida. In fact, recent population estimates indicate that ~75% of Floridians reside in the coastal zone (United States Census Bureau, 2010; NOAA, 2013). The long-term landscape scale modifications associated with heightened

* Corresponding author at: Coastal Ecosystems Division, South Florida Water Management District, 3301 Gun Club Road, West Palm Beach, FL 33406, United States. Tel.: +1 561 682 6519; fax: +1 561 682 5556.

E-mail addresses: cbuzzell@SFWMD.gov (C. Buzzelli), pgorman@SFWMD.gov (P. Gorman), pdoering@SFWMD.gov (P.H. Doering), zhichen@SFWMD.gov (Z. Chen), ywan@SFWMD.gov (Y. Wan).

http://dx.doi.org/10.1016/j.ecolmodel.2014.10.029
0304-3800/

Table 1
List of defined acronyms that appear in this study.

Acronym	Definition
CERP	Comprehensive Everglades Restoration Project
CEPP	Central Everglades Planning Project
USACE	United States Army Corps of Engineers
SFWMD	South Florida Water Management District
ECB	Existing Condition Base Inflow Scenario
FWO	Future Without Project Inflow Scenario
ALT4R	Alternative 4R Inflow Scenario
RSM	Regional Simulation Model
SIRL	Southern Indian River Lagoon
CRE	Caloosahatchee River Estuary
SLE	St. Lucie Estuary
EAA	Everglades Agricultural Area
EPA	Everglades Protection Area
CC	Cape Coral (Caloosahatchee River Estuary)
SP	Shell Point (Caloosahatchee River Estuary)
US1	Highway US 1 (St. Lucie Estuary)
BSI	Boy Scout Island (St. Lucie Estuary)

agriculture and urbanization resulted in the loss of Everglades ridge-and-slough wetlands, widespread water quality and habitat degradation, the release of excess freshwater to the sea for flood protection, and damage to coastal aquatic ecology (USACE and SFWMD, 1998).

Elevated freshwater demand associated with high population density has great implications for coastal ecosystems and estuaries (Livingston et al., 1997; Sklar and Browder, 1998; Alber, 2002; Flemer and Champ, 2006). Estuaries such as Biscayne Bay in the southeast adjacent to Miami; Florida Bay at the southern tip of the Florida peninsula adjacent to Everglades National Park; the St. Lucie Estuary (SLE), Loxahatchee Estuary, and Lake Worth Lagoon on the east coast; and the Caloosahatchee River Estuary (CRE) on the west coast have been impacted by freshwater diversions (Table 1; USACE and SFWMD, 1998; Rudnick et al., 2005; Sime, 2005; Barnes, 2005; Browder et al., 2005). While reductions in the quantity of freshwater supply have promoted hyper-saline conditions in portions of Biscayne Bay and Florida Bay high discharge in the wet season (May–Oct) and low discharge in the dry season (Nov–Apr) stress the SLE and CRE, respectively (Doering, 1996; Doering et al., 2002; Lirman and Cropper, 2003; Wilson et al., 2005; Koch et al., 2007). Regulated discharge through the major canals to the east (C-44) and west (C-43) of Lake Okeechobee follows a detailed protocol that is essential to maintain lake water levels and afford flood protection for all inhabitants of South Florida (Obeysekera et al., 2007). However, unnatural patterns of freshwater inflow to the estuaries have greatly altered the composition, distribution, abundance, and status of ecologically valuable oyster and seagrass habitats (Volety et al., 2009; Santos and Lirman, 2011; Herbert et al., 2011).

Oysters provide an excellent indicator of freshwater inflow and salinity distributions in many estuaries (Wilbur, 1992; Beck et al., 2011; Petes et al., 2012; Soniat et al., 2013). This is particularly true for Gulf of Mexico estuaries with historically productive oyster fisheries (Livingston et al., 2000; Powell et al., 2003; Turner, 2006; Buzan et al., 2009; Pollack et al., 2011). Despite the absence of an active fishery and an overall dearth of historical data, the abundance and status of oysters in the SLE and CRE are known to fluctuate with variable salinity (Wilson et al., 2005; Barnes et al., 2007). In particular, depressed and near-zero salinity in the wet season (May–Oct) can be detrimental to oysters in the SLE. This occurred in 2005 when extreme freshwater inflows associated with tropical storm activity decimated existing oyster habitat (Buzzelli et al., 2013a; Parker et al., 2013). Despite these impacts, oyster populations stabilized in subsequent years as live density increased with reduced freshwater inputs (Parker et al., 2013; SFER, 2014). Salinity values of 14–28 have been established as beneficial for oysters in the CRE (Barnes et al., 2007; Volety et al., 2009; Buzzelli et al., 2013c). While salinity is generally more stable in the much larger CRE compared to the SLE, increased salinity in the dry season (Nov–Apr) offers the potential for oyster-specific marine predators and parasites (Livingston et al., 1997; Tolley et al., 2005; Pollack et al., 2011).

Salinity patterns also influence the composition, distribution, and abundance of seagrass habitats in Florida estuaries (Montague and Ley 1993; Livingston et al., 1998; Lirman and Cropper, 2003; Kahn and Durako, 2008; Lirman et al., 2008). Florida seagrass communities can include *Halophila* species (*Halophila johnsonii*, *Halophila* decepiens, *Halophila*engelmanni), *Halodule wrightii* (shoal grass), *Thalassia testudinum* (turtle grass), *Ruppia maritima* (widgeon grass), and *Syringodium filiforme* (manatee grass) each with different tolerances to variable salinity and submarine light (Doering and Chamberlain, 2000; Doering et al., 2002; Lee et al., 2007; Buzzelli et al., 2012). In general, following a large scale salinity disturbance *Halophila* and *H. wrightii* are able to re-colonize impacted areas more rapidly than *S. filiforme* or *T. testudinum* (Lirman et al., 2008; Herbert et al., 2011; Santos and Lirman, 2012). By contrast, episodic depression of salinity associated with tropical storms in 2004 and 2005 led to widespread loss of *S. filiforme* habitat in the Loxahatchee Estuary and southern Indian River Lagoon (SIRL; Ridler et al., 2006; Buzzelli et al., 2012). As opposed to simply releasing freshwater to the sea for flood protection, the capture and southward redistribution of high outflows from Lake Okeechobee should benefit both the Everglades and the associated estuaries.

The Central Everglades Planning Project (CEPP) was introduced as a vehicle to advance engineering projects focused on the restoration of the Everglades (NRC, 2012). This effort includes integrative models that combine hydrology, water chemistry, and ecology to explore the various environmental restoration options (Livingston et al., 2000; Urban, 2006; Obeysekera et al., 2011; NRC, 2012; Soniat et al., 2013). A major thrust of the CEPP is to reduce large regulatory releases to the coastal zone by diverting freshwater from Lake Okeechobee southward towards the Everglades and Florida Bay (USACE and SFWMD, 2013). The reduction in large freshwater discharge to the CRE and SLE in the wet season should stabilize salinity and water quality conditions for essential seagrass and oyster habitats. In order to support the ecological goals of the CEPP, the objective of this study was to utilize seagrass and oyster models established for the CRE and SLE to evaluate the potential effectiveness of alternative inflow scenarios related to Everglades restoration generated by hydrologic models.

2. Methods

2.1. Study sites

The South Florida Water Management District (SFWMD) encompasses 16 counties from the Kissimmee River in Central Florida to the Florida Keys. Lake Okeechobee, the second largest freshwater lake in the continental United States, is located in the center of the SFWMD area where it receives inflows from the Kissimmee River. The outflows from Lake Okeechobee feed the SLE to the east, the CRE to the west, and the Everglades Agricultural and Protection Areas (EAA and EPA, respectively) to the south (Fig. 1). Lake Okeechobee is a critical component for regional flood control in the wet season and water supply in the dry season.

Located in southeastern Florida in Martin and St. Lucie counties, the SLE comprises a major tributary to the SIRL. Historically, the SLE was a freshwater system only occasionally exposed to the coastal ocean through ephemeral passes in the barrier islands. The St. Lucie Inlet was permanently opened in 1892 to provide a connection between the SLE and the coastal ocean. The C-44 canal