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Research article

Effects of sea-level rise and freshwater management on long-term water levels and water quality in the Florida Coastal Everglades

Shimelis B. Dessu [a, b, d, *], René M. Price [a, b, d], Tiffany G. Troxler [a, c, d], John S. Kominoski [a, c, d]

[a] Southeast Environmental Research Center (SERC), Florida International University, Miami, FL 33199, USA
[b] Department of Earth and Environment, Florida International University, Miami, FL 33199, USA
[c] Department of Biological Sciences, Florida International University, Miami, FL 33199, USA
[d] Sea Level Solutions Center, Florida International University, Miami, FL 33139, USA

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A B S T R A C T

Since the 1880s, hydrological modification of the Greater Florida Everglades has reduced water levels and flows in Everglades National Park (ENP). The Comprehensive Everglades Restoration Program (CERP) began in 2000 to restore pre-drainage flows and preserve the natural landscape of the Everglades. However, sea-level rise (SLR) was not considered in the development of CERP. We used long-term data (2001–2016) from the Florida Coastal Everglades-Long Term Ecological Research Program to quantify and model the spatial dynamics of water levels, salinity, and nutrients in response to changes in climate, freshwater management and SLR in the Shark River Slough (SRS), ENP. Results indicate that fresh-to-marine head difference (FMHD) was the single most important factor affecting marine-to-freshwater hydrologic connectivity and transport of salinity and phosphorous upstream from the Gulf of Mexico. Sea-level has increasingly exceeded ground surface elevation at the most downstream freshwater site in SRS, thereby reducing the FMHD. We showed a higher impact of SLR in the dry season when there was practically no freshwater inflow to raise FMHD. We also demonstrated effectiveness of inflow depends more on the monthly distribution than the total annual volume. Hence, the impact per unit volume of inflow is significantly higher in the dry season in preventing high salinity and marine-derived nutrient levels. We advocate that FMHD needs to be factored into water management decisions to reduce adverse and likely irreversible effects of SLR throughout the Everglades landscape.

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1. Introduction

The position of coastal wetlands between marine and terrestrial environments makes them particularly vulnerable to the combined presses of sea-level rise (SLR) and human disturbance (White and Kaplan, 2017). Everglades National Park (ENP) (Fig. 1) is above all susceptible to a projected SLR of 1–2 m by 2100 (Haigh et al., 2014), as much of the landscape is less than 1.5 m above mean sea level (Titus and Richman, 2001). Furthermore, hydrological modification of the Greater Everglades watershed which began in the 1880s and continues today has reduced water levels and flows in ENP significantly from its pre-development, natural condition (McVoy et al., 2011; Sklar et al., 2005). The combination of rising sea level with the reduction in fresh water levels has increased salt water intrusion into the coastal estuaries of ENP and its underlying aquifer allowing for salt-tolerant communities such as mangroves to overtake formerly freshwater areas (Karamperidou et al., 2013; Krauss et al., 2011; Ross et al., 2000; Saha et al., 2012). An acceleration in SLR is expected to increase coastal erosion, potentially replacing coastal wetlands with non-vegetated open water areas (Ellison, 1993; Ross et al., 2000; Todd et al., 2012; Trenberth et al., 2014; Wanless et al., 1994; White and Kaplan, 2017). Over 48×10^6 megatons of C in the form of old grown mangroves and associated soils is at risk of being lost from ENP (Jerath et al., 2016).

Efforts are underway to restore freshwater flows and levels to ENP through the Comprehensive Everglades Restoration Plan (CERP). The CERP was authorized by the US Congress in 2000 to provide flood protection and water supply for the residences of south Florida while retaining adequate water to sustain the

* Corresponding author. Institute of Water and Environment, Florida International University, Miami, FL 33199, USA.
E-mail addresses: sbehailu@gmail.com, sdessu@fiu.edu (S.B. Dessu).

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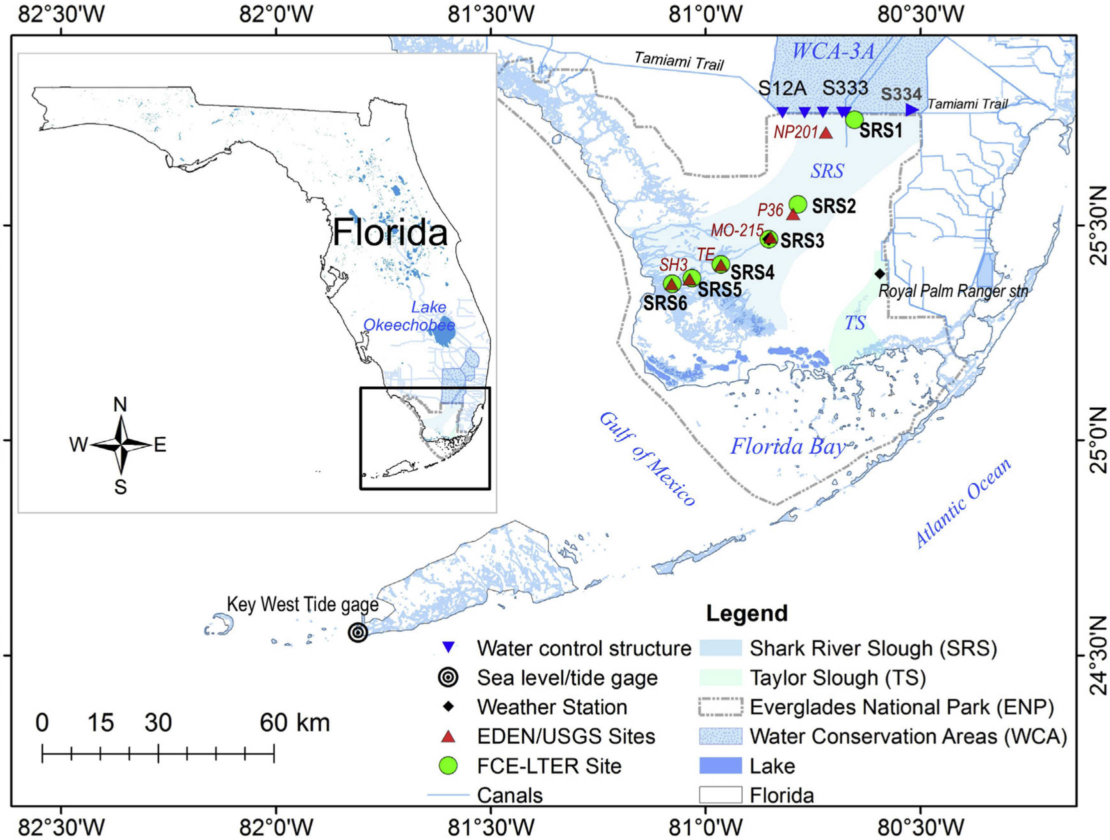

Fig. 1. Location map of the Florida Coastal Everglades Long Term Ecological Research (FCE-LTER) Program and other agencies hydrologic and water quality monitoring sites, in the Shark River Slough (SRS) of Everglades National Park, Florida.

Everglades ecosystem. The eco-hydrological conditions of portions of ENP have been monitored via the Florida Coastal Everglades Long Term Ecological Research (FCE-LTER) Program since 2000 (the same year that CERP was enacted) to address the hypothesis that increased freshwater flows and water levels are needed to reduce the migration of saltwater into freshwater marshes (Childers et al., 2006b; Krauss et al., 2011). To date there are 17 years of hydrologic and water chemistry data available through the FCE-LTER Program. The FCE-LTER sites are located along the two main drainages in Everglades National Park: Shark River Slough (SRS) and Taylor Slough (Fig. 1). Of the two sloughs, SRS is the largest, flowing from Tamiami Trail to the Gulf of Mexico, and is the focus of this paper. SRS remains the largest preserved portion of the "River of Grass" containing freshwater sloughs and marshes of sawgrass (*Cladium jamaicense*) and calcareous benthic microbial mats (periphyton) in the north (SRS-1 to SRS3) transitioning to mangrove forests (SRS4 to SRS6) toward the coast (Ewe et al., 2006).

Previous hydrologic studies of SRS were conducted to evaluate the long-term relationships between freshwater input, salinity, nutrient transport, and climate indices (Childers et al., 2006a; Rudnick et al., 1999; Todd et al., 2012), as well as water balance parameters with salt water intrusion (Saha et al., 2012). Collectively, those studies analyzed data through 2008. Since then, ENP has experienced hydrologic disturbances such as droughts in 2011 and 2015 (http://droughtmonitor.unl.edu/MapsAndData/Graph.aspx) and an accelerated rate of SLR (Wdowinski et al., 2016). However, to date, there has been no study to link both the long-term and recent hydrological and sea level trends with corresponding salinity and nutrient responses in the Everglades.

The aim of this paper is to determine how hydrologic parameters (water levels, salinity, and nutrients) in the SRS responded to upstream (freshwater management) and downstream (SLR) presses over a 16-year period (2001–2016) of varying climate (rainfall and evapotranspiration). The specific objectives of the study were to: 1) quantify changes in water level and water quality to SLR and freshwater drivers, and 2) isolate the impact of freshwater inflows to counteract the increasing press of SLR. We utilized data scaling (z-score), linear regression, and percent exceedance analysis to separate the contribution of freshwater inputs vs SLR on water levels and water quality. Results of the study will help put the hydrologic conditions of the ecologically critical SRS in a context of how freshwater flows as managed through CERP can overcome SLR.

2. Methods

2.1. Study sites

Freshwater input to the ENP comes from direct rainfall and inflow from regional rainfall upstream of the ENP. Rainfall from the greater Everglades was stored in reservoirs (known as water conservation areas 3A, WCA-3A) and discharged to SRS. Freshwater inflow from WCA-3A to SRS is managed by the operation of water control structures, the S12s (A-D), the S333 and S334, located along the northern edge of the SRS (Fig. 1).

This study focused on the six SRS (SRS1-6) sites of the FCE-LTER (Fig. 1). Site SRS1 had a history of changing location. SRS1a was first established at the outlet of S12C in Dec. 2000 and then moved east (SRS1b) close to series of culverts controlled by S333 in July 2005 and finally moved (SRS1d) west between the previous two sites and