Remote Sensing of Environment 208 (2018) 171–188

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Sea surface temperatures and seagrass mortality in Florida Bay: Spatial and temporal patterns discerned from MODIS and AVHRR data

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ARTICLE INFO

Keywords:
SST
AVHRR
MODIS
Landsat-8
Thalassia testudinum
Seagrass mortality
Florida Bay
Hyperthermia
Reflectance

ABSTRACT

Two major episodes of seagrass mortality have occurred in Florida Bay in the past 30 years: The first occurred between 1987 and 1991 and the second began in 2015. In both episodes, dense beds of turtle grass (*Thalassia testudinum*) were decimated. Elevated water temperature and hypersalinity have been implicated as contributing factors in both mortality events. During both die-off events seagrass beds on shallow (Z ≈ 0.3 m) mudbanks in western Florida Bay were disproportionately affected when compared to neighboring seagrass in deeper basins (Z ≈ 1.5 m). A network of *in situ* monitoring stations has measured sea surface temperature and salinity at hourly intervals in 16 basins in Florida Bay from August 2009 to the present day and these data aided in diagnosing the 2015–2016 die-off event. However, very few *in situ* observations of sea surface temperature have been collected on Florida Bay's shallow mudbanks as most are inaccessible by boat. As a result, our understanding of the role of elevated SST in shaping the spatial patterns of seagrass mortality is hindered by the spatial distribution of the *in situ* monitoring data and its record length. Therefore, we turn to remotely sensed SST data to expand our spatial coverage to include the entire Florida Bay ecosystem and to extend the record length to include the 1987–1991 die-off event. 1 km MODIS SST shows that shallow mudbanks were consistently warmer (by up to 6°C) than nearby deeper basins. While water depth is likely the primary driver of spatial variability in SST, Landsat-8 surface reflectance data suggest that shallow seagrass beds could have suffered from the added influence of low surface reflectance, which might have further contributed to their thermal stress. Daily 0.25° AVHRR SST shows that the August maximum SST has increased by 1°C from 1981 to 2016, which is a cause for concern for the future of seagrass in Florida Bay. Correlation of monthly AVHRR SST anomalies with the multivariate ENSO index shows that ENSO can only partially explain the anomalous temperatures. When viewed together, the *in situ* and remotely sensed SST suggests that both extended exposure to anomalously warm temperatures and large, rapid changes in temperature could have contributed to seagrass mortality during both events.

1. Introduction

Seagrasses provide numerous direct and indirect ecosystem services (Orth et al., 2006; Dewsbury et al., 2016; Kearney et al., 2015; Hejnowicz et al., 2015; Ruiz-Frau et al., 2017; Waycott et al., 2009). They act as nurseries for fish and shellfish (Browder et al., 2002; Criales et al., 2015, 2011), food sources for herbivorous organisms including manatees and sea turtles (Kirsch et al., 2002; Valentine and Heck, 1999) and ecosystem engineers (Abdelrhman, 2003; Bryan et al., 2007; Bradley and Houser, 2009; Fonseca et al., 1983; Fonseca and Fisher, 1986; Fonseca and Cahalan, 1992; de Boer, 2007; Hansen and Reidenbach, 2017; Koch and Gust, 1999; Manca et al., 2012), while also supporting recreational and artisanal fisheries (Duarte, 2002; Orth et al., 2006; Waycott et al., 2009). Seagrasses also contribute to carbon sequestration and can be an important blue carbon habitat (Alongi et al., 2016; Duarte and Krause-Jensen, 2017; Fourqurean et al., 2012; Thorhaug et al., 2017). Despite their importance, seagrasses worldwide are threatened by human activities and the effects of climate change (Duarte, 2002; Marbà et al., 2014; Short et al., 2014; Valle et al., 2014), and major losses of seagrass habitat have occurred on every continent.

One potentially lethal impact of climate change for seagrasses is thermal stress due to rising ocean temperatures. Thermal stress is most

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https://doi.org/10.1016/j.rse.2018.02.014
Received 29 June 2017; Received in revised form 4 January 2018; Accepted 12 February 2018

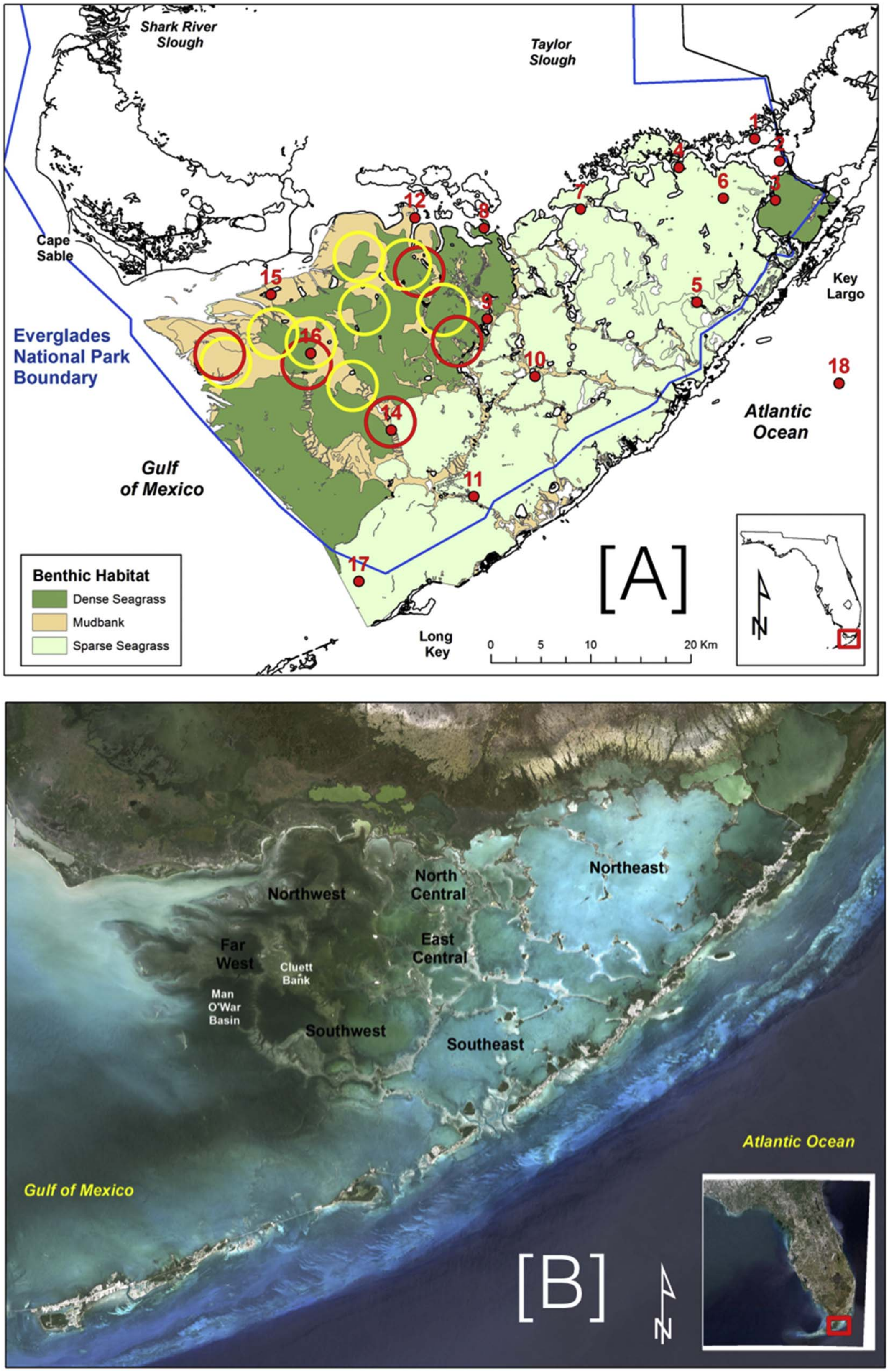

Fig. 1. [A] A map of Florida Bay that highlights dense seagrass beds (dark green), sparse seagrass cover (light green), and mudbanks (brown). Regions that experienced significant die-off in 1987–1991 and 2015–2016 are indicated in red and yellow, respectively. The boundaries of Everglades National Park are shown in blue and place names mentioned in the text are also indicated. The locations of the *in situ* monitoring stations are also shown and use the same numeric order in the first column of Table 1. [B] The geographic regions of Florida Bay and the neighboring Atlantic Ocean and Gulf of Mexico are overlaind, along with Cluett Bank and Man O'War Basin, on a Landsat-8 image of the region. The inset map shows the location of Florida Bay in relation to the rest of the state.