Remote Sensing of Environment 118 (2012) 176–185

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

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

Post-spill state of the marsh: Remote estimation of the ecological impact of the Gulf of Mexico oil spill on Louisiana Salt Marshes

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ARTICLE INFO

Article history:
Received 26 May 2011
Received in revised form 11 November 2011
Accepted 18 November 2011
Available online 22 December 2011

Keywords:
Gulf of Mexico
LA
Deepwater horizon oil spill
Ecological impact
Salt marsh
Canopy chlorophyll
Above ground biomass
Field spectroscopy
Landsat TM

ABSTRACT

One and a half years after the worst oil spill in U.S. history, we present the first quantitative assessment on the ecological impact of the spill on the salt marsh habitats along the southeastern Louisiana (LA) coast. This research combined satellite and ground data to quantify the impact of the oil and dispersant on the salt marshes in terms of their photosynthetic capacity and physiological status over a large spatial scale. Two of the most important marsh biophysical characteristics, including distribution of canopy chlorophyll content and above ground green biomass, were monitored across the southeastern LA coast during the salt marsh growing season (May–October) of 2009 (pre-spill) and 2010 (post-spill) in order to compare and isolate the spill impacted areas. The initial assessment showed that there was a significant post-spill increase in areas with reduced biomass and canopy chlorophyll (>400 km^2) during the 2010 growing season compared to 50–65 km^2 during the 2009 growing season. Phenological analysis of the post oil-spill data revealed a significant decrease in the magnitude of biomass and canopy chlorophyll during the peak of the 2010 growing season. June was consistently found to be the worst month in terms of salt marsh health across LA over the 2010 phenological cycle followed by the initial signs of recovery along the fringing marsh areas proximal to the shoreline that were first impacted by oil. Interior marsh patches exhibited persistent signs of stress towards the end of the growing season. Extensive reduction in photosynthetic activity was observed during the peak of the growing season, particularly in Plaquemines Parish and St. Bernard Parish. The products generated through this study successfully delineate the critical hotspots of marsh stress so that prioritization of areas needing immediate restoration can be performed.

1. Introduction

Salt marshes are considered to be the most vulnerable coastal environment (vulnerability index of 10 from a 1–10 scale) that can be adversely affected by an oil spill, with the predicted residence times of over 10 years (Gundlach & Hayes, 1978; Pezeshki et al., 2000). Salt marshes generally have more oil-sensitive vegetation than freshwater marshes and the oil impact on vegetation is most significant in highly organic soils of salt marshes (Lin & Mendelssohn, 1996; Pezeshki et al., 2000). The direct and immediate physical impact of an oil spill on wetland vegetation includes the coating of the plant and soil surfaces causing temperature stress, and reduced photosynthesis due to blockage of stomata and transpiration pathways. Petroleum hydrocarbons also adversely affect the ability of salt marsh vegetation to tolerate salinity, which increases the potential of dieback and hampers recovery (Gilfillan et al., 1989). Additional damage can be caused by the resulting cleanup activities such as skimming, oil collection, burning, flushing, use of dispersants, and plant cutting (Allen & Ferek, 1993; Kiesling et al., 1988; Mendelssohn et al., 1990; Owens et al., 1993a, 1993b). To complicate matters further, the effects of oil spills vary with vegetation types and season. For example, previous research shows that, of the more common Gulf Coast vegetation species, *Spartina alterniflora* is more sensitive to oiling than *Juncus roemerianus* (Pezeshki & DeLaune, 1993). Furthermore, flora are more sensitive to oiling during the growing season than during the pre-dormancy or dormant season (Pezeshki et al., 2000). It is advised that summer burns of contaminated marsh patches be avoided if possible (Lindau et al., 1999), because flooding following burning also adversely affects plant growth in many species (Pezeshki et al., 2000). The Deep Water Horizon Macondo MC252 oil spill beginning on April 20, 2010 poured more than 200 million gallons of crude oil in the Gulf waters off southeastern Louisiana (LA), and an

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doi:10.1016/j.rse.2011.11.007

additional 1.8 million gallons of dispersant were added to countervail the effects of the contamination (US DOI, 2010). Since the oil spill and cleanup efforts occurred mainly in the early summer, the critical growing season for *Spartina* and other marsh species, it was expected that a severe, short-term impact of the spill would occur on salt marshes causing changes in plant community composition associated with species' sensitivity to fouling and physical disturbance.

Canopy chlorophyll content (CHL) is one of the most important foliar biochemicals that is related closely to both the productivity and health of vegetation (Curran et al., 1990). Above ground green biomass (GBM) is a direct result of vegetation productivity and another key variable required for analyzing coastal salt marsh status (Curran, 1982; Hardisky et al., 1984). Due to the synoptic view provided by airborne and space-borne sensors, remote sensing has the potential for estimating both CHL and GBM at a regional level. Remote estimations of these characteristics can be performed using transforms of spectral reflectance, referred to as vegetation indices (VIs) (Rouse et al., 1974). Several VIs for estimating CHL and GBM using remotely sensed data have been developed and are proven to provide accurate predictions in different vegetation types (Gitelson & Merzlyak, 1997, 1998; Gitelson et al., 2003a, 2003b; Kogan et al., 2004). The US Geological Survey's (USGS) Landsat satellite holds considerable potential for advancing our capabilities to estimate and monitor the biophysical characteristics of salt marshes across large geographic areas. Landsat provides 16-day coverage of moderate resolution data that are well calibrated, and have relatively high geolocational accuracy (Tucker et al., 2004). The value of Landsat surface reflectance and VI data for various vegetation-related land use/land cover characterization activities such as forest mapping (Pax-Lenney et al., 2001), marsh biomass mapping (Hardisky et al., 1984), phenological monitoring (Fisher et al., 2006), and sub-pixel fractional estimation of vegetation area (Chen et al., 2004) has been well demonstrated.

The overall objective of this study was to quantify the short-term impact of the oil spill on the photosynthetic activity and physiological status of the coastal salt marshes over the large area by combining satellite data with ground experiments. This objective was achieved by analyzing two biophysical characteristics of marsh vegetation including CHL and GBM generated through a remote sensing mapping protocol. The specific objectives included, (1) application of a suite of algorithms combining Landsat 30-m datasets with field data to map CHL and GBM across southeastern LA salt marshes; and (2) compare and quantify the changes observed in CHL and GBM distribution during the salt marsh growing season between 2009 (pre-spill) and 2010 (post-spill) to isolate the spill impact. The products generated through this research will provide restoration decision makers across LA with a practical tool to inform the prioritization of marsh restoration effort to the areas, most affected by the spill.

2. Study area

Salt Marshes cover almost the entire coast of LA (>4500 km^2) (Fig. 1). The habitat is dominated by smooth cord-grass (*Spartina alterniflora*), salt meadow cord-grass (*Spartina patens*), black needlerush (*Juncus roemarianus*), with occasional presence of *Salicornia virginica, Batis maritima* and *Distichlis spicata*. Highly saline and anaerobic nature of the soil allows only selected species to survive, and as such, floral diversity is remarkably low (Weis, 2010) However, salt marshes act as buffers to strong winds and tidal waves in the Gulf of Mexico. In addition, the

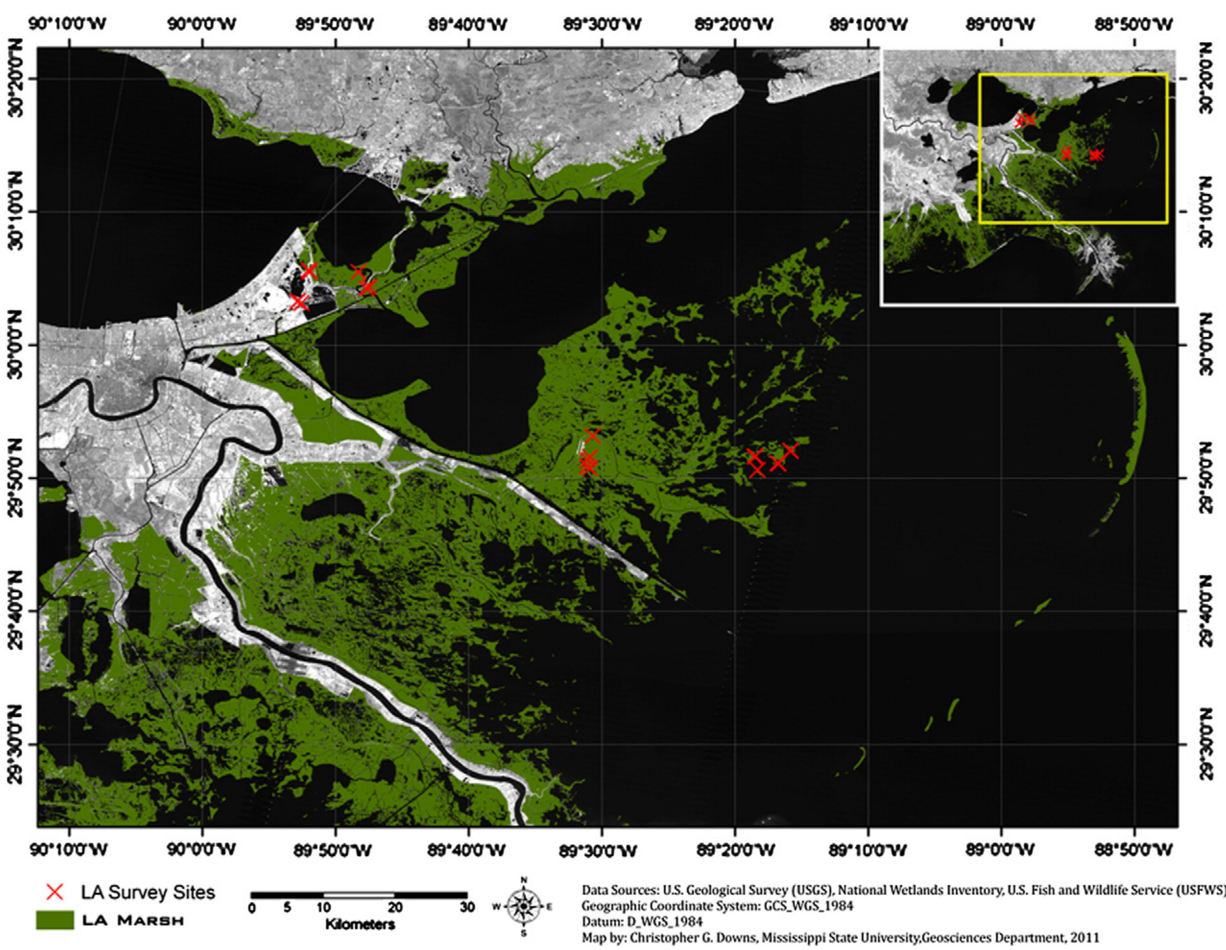

Fig. 1. Map showing study plots in the salt marshes of St. Bernard Parish and Plaquemines Parish, LA.