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Original research article

Spatio-temporal changes of a mangrove–saltmarsh ecotone in the northeastern coast of Florida, USA

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HIGHLIGHTS

- We found mangrove expansion/contraction near their northern range limit.
- Significant effect of climate variables on habitat areal extent.
- Cyclical spatio-temporal dynamism over a 71-year period.
- Reversals in habitat dominance may point to complex biotic–abiotic interactions.
- Results may contribute to management/conservation strategies under climate change.

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ABSTRACT

General circulation models predict warming trends and changes in temperature and precipitation patterns that have the potential to alter the structure and function of coastal habitats. The purpose of this study was to quantify the expansion and contraction of mangroves and saltmarsh habitats and assess the impact of climate on these landscape changes. The study was conducted in a mangrove/saltmarsh ecotone in Flagler County, FL, near the northern range limit of mangroves along the Atlantic coast of North America. We used time series of historical aerial photography and high-resolution multispectral satellite imagery from 1942 to 2013 to quantify changes in the extent of mangrove and saltmarsh vegetation and compared these changes to climate variables of temperature and precipitation, temperature–seasonality, as well as historical sea-level data. Results showed increases in mangrove extent of 89% between 1942 and 1952, and a continuous increase from 1995 to 2013. Largest decrease in saltmarsh extent occurred between 1942 and 1952 (-136%) and between 2008 and 2013 (-81%). We found significant effects of precipitation, temperature, seasonality, and time on mangrove and saltmarsh areal extent. The statistical effect of sea-level was rather small, but we speculate that it might have ecological impacts on these two coastal ecosystems. Results also showed a cyclical dynamism as well as a reversal in habitat dominance, which may be the result of complex interactions between plant habitats and several environmental drivers of change such as species interactions, and hydrological changes induced by sea-level rise, in addition to temperature and precipitation effects. Our results on mangrove/saltmarsh expansion and contraction may contribute to the improvement of management and conservation strategies for coastal ecosystems being impacted by climate change.

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1. Introduction

Mangrove forests dominate coastal wetlands throughout the world's tropics and subtropics and provide many important ecosystem services. For example, mangroves provide a buffer against erosion and storm damage, provide critical habitats, support fisheries, and sequester five times the amount of carbon as upland tropical forests (Ellison, 2008; Das and Vincent, 2009; Siikamaki et al., 2012). Various responses to global climate change have been predicted for mangrove forests over large scales. One of those responses is a projected poleward expansion by at least 2 degrees of latitude (Record et al., 2013; Osland et al., 2013). An important regional trend shows that warming increases the spatial variability of precipitation, thus contributing to a reduction in rainfall in the subtropics and an increase at higher latitudes and the tropics (Christensen et al., 2007). A 25% increase in precipitation rates is predicted by 2050, with an uneven spatial distribution (Knutson and Tuleya, 1999; Walsh and Ryan, 2000; Houghton et al., 2001). Since 1880, the Earth has warmed 0.6–0.8 °C (Houghton et al., 2001) and is projected to warm between 2–4 °C by 2100 mostly due to human activity (IPCC Intergovernmental Panel on Climate Change et al., 2007). These projected changes in temperature and rainfall are expected to result in shifts in the distribution and abundance of many organisms. Both temperature and rainfall are known to influence the distributions of mangrove species (Duke et al., 1998; Lovelock and Ellison, 2007). Low temperatures restrict the latitudinal extent of mangroves, and high rainfall generally results in greater diversity of species (Krauss et al., 2008). However, questions remain as to how increasing temperatures and rainfall will affect these patterns at different spatial scales. Other variables affecting coastal vegetation include sea temperatures and sea level rise. Mangroves are not expected to be adversely impacted by the projected increases in sea temperature, but will probably face their greatest challenge with increases in sea-level rise (Ellison, 1994; Field, 1995; Gitay et al., 2002; Gilman et al., 2008; Lisboa Cohen et al., 2015).

The effects of changes in precipitation on mangrove forests may vary. For example, decreased precipitation results in increased salinity, which results in lowered mangrove productivity, growth, and seedling survival, and may change species composition favoring more salt tolerant species (Lovelock and Ellison, 2007). It may also result in decreased mangrove area and diversity and increased conversion of landward zone into barren hypersaline flats (Snedaker, 1995). Increased precipitation may increase mangrove area, diversity, and growth (Field, 1995) and may allow mangroves to migrate into and replace salt marsh vegetation (Harty, 2004). Increased precipitation will also increase run-off, erosion, and silt deposition in the inshore environment (Lovelock and Ellison, 2007), which will increase turbidity and reduce primary productivity of coastal systems (Rodney and Mcleod, 2008). The effects of increasing air temperature on mangroves forests also vary. For example, increased air temperature can decrease leaf formation (Saenger and Moverly, 1985), photosynthesis rates (Andrews et al., 1984; Clough, 1984; Cheeseman, 1994; Cheeseman et al., 1997), and seedling establishment (UNESCO, 1992; Krauss et al., 2008). Furthermore, temperature increases may allow mangroves to expand beyond their current poleward range limits. For example, Cavanaugh et al. (2014) found that a decrease in the frequency of extreme cold events has enabled large-scale mangrove expansions past their historical (1942–1980) range limit along the northeast coast of Florida.

We hypothesize that the abundance (i.e., areal extent) of mangroves near their range limit in Florida varies in response to changes in air temperature and rainfall, and secondarily to other environmental variables like sea-level changes. To test this hypothesis we chose a study site at the northernmost reach of mangrove establishment along the Atlantic coast and concentrated on the effect of three environmental variables on habitat extent: we characterized the relationships between spatial and temporal change of mangrove/saltmarsh areal extent and air temperature, rainfall, and sea-level. We used a time series of very high spatial resolution imagery that included: historical aerial black and white photography, orthophotography, and multispectral satellite imagery from QuickBird and the WorldView-2 sensors. We used the normalized difference vegetation index (NDVI) (Tucker, 1979) as a mapping tool to assist in image classification, to separate vegetated from non-vegetated areas, and to quantify the spatial and temporal distributional dynamics of mangrove and saltmarsh ecosystems at the research site. In this study we addressed the following questions:

1. How has the spatial distribution and abundance of mangrove and saltmarsh at the ecotonal research site varied over the past 7 decades?
2. Are changes in mangrove/saltmarsh habitat areal extent correlated with changes in air temperature and precipitation?
3. Are changes in mangrove/saltmarsh habitat areal extent correlated with changes in sea-level?

2. Materials and methods

2.1. Study area

Our study site was located on Anastasia Island just north of Matanzas Inlet, hereafter referred to as North Matanzas (NMAT), which is located within the southern section of Guano-Dolomite-Matanzas National Estuarine Research Reserve (GTMNERR), Flagler County, FL (29°73′N, 81°24′W) (Fig. 1). This area is near the northern range limit of mangroves in Florida. The mangrove/saltmarsh ecotone in this study area is composed of *Avicennia germinans* L. (black mangrove), scattered *Rhizosphere mangle* (red mangrove) in the low intertidal, and a number of short-statured herbaceous saltmarsh wetland species including: *Spartina alterniflora* (smooth corgdgrass) and *S. bakeri* (sand cordgrass) in the low intertidal and *Distichlis spicata* (saltgrass), *Salicornia virginica* (glasswort), *Batis maritima* (saltwort) and *Sueda* spp (seablite) in the high intertidal.