Estuarine, Coastal and Shelf Science 85 (2009) 292–298

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Mangrove expansion and rainfall patterns in Moreton Bay, Southeast Queensland, Australia

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ARTICLE INFO

Article history:
Received 21 May 2009
Accepted 22 August 2009
Available online 29 August 2009

Keywords:
mangroves
salt marshes
intertidal environment
rainfall
change-point
Australia
Moreton Bay

ABSTRACT

Changes in rainfall pattern have been suggested as a mechanism for the landward incursion of mangrove into salt marsh. The aim of the research was to assess the relationship between rainfall patterns and the spatial distribution of mangrove forests at study sites in Moreton Bay, Southeast Queensland, Australia, over a 32-year period from 1972 to 2004. To identify periods of relatively consistent rainfall patterns points at which rainfall patterns changed (change-points) were identified using the non-parametric Pettitt–Mann–Whitney-Statistic and the cumulative sum technique. The change-points were then used to define the temporal periods over which changes to mangrove area were assessed. Both mangrove and salt marsh area were measured by digitizing aerial photographs acquired in 1972, 1990 (the year with the most significant change-point), and 2004. The rates of change in mangrove area pre-1990 (a wetter period) and post-1990 (a drier period) were estimated. A significant positive relationship was demonstrated between rainfall variables and landward mangrove expansion, but not for seaward expansion. We concluded that rainfall variability is one of the principal factors influencing the rate of upslope encroachment of mangrove. However, the rate of expansion may vary from site to site due to site-specific geomorphological and hydrological characteristics and the level of disturbance in the catchment.

1. Introduction

Mangroves are one of the key components of the world's subtropics and tropics inter-tidal zone landscape. The distribution, structure and function of mangrove forests are controlled by environmental factors with varying impacts over different spatial and temporal scales (Duke et al., 1998). At the global scale, temperature limits the distribution of mangrove forest (Alongi, 2002). However at the regional scale, mangrove extent and characteristics may be determined by the cumulative and complex interactions between landscape position, rainfall, hydrology, sea level, sediment dynamics, subsidence, storm driven processes and disturbance by pest or predator (Woodroffe, 1990, 1995; Smith et al., 1994; Field, 1995; Furukawa and Wolanski, 1996; Furukawa et al., 1997; Alongi, 2002, 2008; Cahoon et al., 2003; Whelan et al., 2005; Lara and Cohen, 2006; Gilman et al., 2007; Paling et al., 2008). Changes in any of these factors is likely to affect the spatial patterns and community structure of mangroves.

Mangrove forests are likely to be affected by factors associated with climate change, such as changes in rainfall, temperature, atmospheric CO_2 concentrations, sea level, high water events, cyclones and storms, and ocean circulation patterns (Gilman et al., 2008). Although a rise in mean sea levels may be the most important aspect affecting the spatial distribution of mangroves in the long term (Field, 1995; Gilman, 2004), changes in regional rainfall and catchment runoff may be more significant in the short term (Snedaker, 1995).

Globally, precipitation over land has increased by about 2% since the start of the 20th century, however, this increase has not been either spatially or temporally uniform (Houghton et al., 2001). Changes in rainfall patterns are expected to affect mangrove growth and its spatial distribution (Field, 1995; Ellison, 2000; Gilman et al., 2008). Higher rainfall and runoff would result in reduced salinity, decreased exposure to sulphates and increased sediments and nutrients supply in coastal areas. These factors can lead to increases in diversity, growth rates and productivity in mangrove forests as well as maintaining the sediment elevations by increasing peat production (Snedaker, 1995; Ellison, 2000;

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0272-7714/$ – see front matter
doi:10.1016/j.ecss.2009.08.011

Gilman et al., 2007). Lower rainfall will increase salinity, which will in turn decrease productivity, diversity, growth and seedling survival, thus altering competition between mangrove species. This process may result in reductions in mangrove area with possible increases in the extent of salt flats (Lovelock and Ellison, 2007; Gilman et al., 2008).

Changing patterns of mangrove distribution in eastern Australia are commonly associated with upslope encroachment into the salt marsh, although there may also be seaward expansion due to increased runoff and associated sedimentation (Jupiter et al., 2007). Increase in rainfall has been suggested by McTainsh et al. (1986), Saintilan and Williams (1999), and Saintilan and Wilton (2001) as a mechanism for mangrove incursion into salt marsh. Salt marsh compaction during drought conditions (van Wijnen and Bakker, 2001) may also assist landward mangrove expansion (Rogers et al., 2006). This pattern has also been observed in other parts of the world. For example, McKee (2004) suggested that, in Louisiana, USA, black mangroves may colonise salt marsh, when cordgrass is stressed (e.g. by extreme droughts). Gilman et al. (2008) noted that although rainfall appears to be related to mangrove dynamics, research has only been conducted in a few areas over short timeframes. This paper addresses the issue and adds to the body of research on the relationship between rainfall and mangrove spatial changes by examining multiple sites over longer timeframes.

Monitoring mangrove spatial changes has been limited by the lack of spatial data at a relevant scale and the difficulty of access limiting field survey. Satellite images have a synoptic capability but have not been extensively used for mapping mangrove due to the limited spectral and spatial resolution of conventional imagery (Wang et al., 2004). Such problems may be overcome by the increased spectral resolution of hyper spectral sensors, but the use of this technology is still not cost-effective (D'Iorio et al., 2007) and it is not available over a long enough time frame for long term studies. Thus the use of aerial photos is essential for time series analysis over several decades at the plant community level (Byrd et al., 2004). Due to the advantages offered by the spatial and temporal scale of aerial photos, they are still widely used for mapping mangrove ecosystems (D'Iorio et al., 2007) and provide the most cost-effective approach to accurate habitat mapping in fine scale studies (Manson et al., 2001).

The aim of this research is to investigate the relationship between rainfall patterns and to use historic aerial photographs to identify the spatial distribution of mangrove forests, at multiple sites within a single region, in northern Moreton Bay, Queensland, Australia, over a 32-year period from 1972 to 2004. The specific objectives were to:

1. Analyse rainfall patterns in the study area between 1972 and 2004 to detect any significant change in the pattern (change-points) thereby identifying periods of relatively consistent rainfall patterns;
2. Identify the spatial distribution of mangroves and calculate rates of change; and
3. Identify the relationship between rainfall patterns and mangrove distribution.

2. Methods

2.1. Study area

The study sites encompassed ten locations distributed along 42 km of the coastline of northern Moreton Bay (27°20′ S, 153° 10′ E) between Cabbage Tree Creek and Glass House Creek, south east Queensland, Australia (Fig. 1). Mangroves and salt marshes are the typical inter-tidal vegetation found along Moreton Bay. There are eight species of mangroves present in the bay, covering about 15,000 hectares of inter-tidal wetlands (Manson et al., 2003), and dominated by *Avicennia marina* which comprises 75% of the community (Dowling and Stephens, 2001). Moreton Bay has a subtropical climate and is subject to the effects of El Niño-Southern Oscillation (ENSO), with rainfall and streamflow patterns associated with the different phases of ENSO. Eastern Australia experiences higher rainfall and streamflow, during the cool La Niño phase of ENSO but reduced streamflow during the drier, hotter conditions that prevail during El Niño (Verdon et al., 2004).

All study sites contain substantial stands of mangroves and other wetland vegetation (salt marsh/saltpan), and are classed as 'middle estuary' sites, whereby water extends throughout the majority of the estuary with a moderate amount of water movement from freshwater inflows or tidal exchanges (Environmental Protection Agency, 2007). To identify the relationship between rainfall patterns and mangrove distribution, study sites were selected in areas not directly impacted by human development. Also, they were chosen approximately near to each other in order to minimise the variation in rainfall. The study sites are in the catchments of Cabbage Tree Creek, Bald Hills Creek, Pine River, Hays Inlet, Little Burpengary Creek, Burpengary Creek, Caboolture River, Lagoon Creek, Ningi Creek and Glass House Creek.

2.2. Rainfall pattern analysis

Daily precipitation data between 1972 and 2004 for the study sites and their catchments were obtained from the comprehensive archive of Australian rainfall and climate data produced by the Australian Bureau of Meteorology (BoM). The database has been constructed using observational data collected by BoM, and spatial interpolation algorithms to produce interpolated surfaces on a regular 0.05° grid to provide data at locations where there is no direct observational data, or for a specific time period, when observational records do not span the entire period of interest (Jeffrey et al., 2001). For analysis, the following rainfall indices in the periods before and after change occurred were derived: mean annual rainfall; median annual rainfall; and the proportions of rainy days with $\geq$2, 10 and 25 (mm). The number of rainy days was converted to the proportion of rainy days because, after the change-point was identified, the two time periods had different lengths.

To identify the year(s) of any abrupt changes (change-points) in the pattern of annual rainfall between 1972 and 2004, we employed the method of Hoppe and Kiely (1999) which approximates the non-parametric Pettitt–Mann–Whitney-Test and is robust for continuous data. This test is a version of the non-parametric Mann-Whitney two-sample test (Pettitt, 1979) and considers the time series as two samples, the period before a change and the period after.

The probability for a change-point in a time series was calculated, for each site as well as its catchment, to identify the year with the most significant change-point. To confirm the change-points, detected by the Pettitt–Mann–Whitney-Test, the 'cumulative sum technique' was also used, which is a method to detect changes in the mean value of a time series dataset (Page, 1955; McGilchrist and Woodyer, 1975). Once a change-point was identified, confirmation of the change was obtained by comparing the means of each variable before and after the identified year, using a *t*-test. As well as detecting change-points, the relationships between mangrove changes and the rainfall indices were determined for all sites using simple linear regression.

2.3. Analysis of aerial photos to identify mangrove spatial change

Aerial photos for 1972, 1990 (the most significant change-point identified in terms of rainfall patterns), and 2004 with scales of