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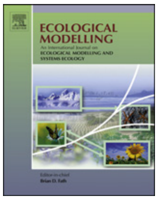

Modelling wetland surface elevation dynamics and its application to forecasting the effects of sea-level rise on estuarine wetlands

Kerrylee Rogers[a,*], Neil Saintilan[b], Craig Copeland[c]

[a] School of Earth and Environmental Science, The University of Wollongong, Wollongong, NSW 2522, Australia
[b] Rivers and Wetlands Unit, New South Wales Office of Environment and Heritage, Department of Premiers and Cabinet, PO Box A290, Sydney South, NSW 1232, Australia
[c] Conservation Action Unit, Industry and Investment New South Wales, 1243 Bruxner Highway, Wollongbar, NSW 2477, Australia

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ABSTRACT

Empirical data derived from a network of surface elevation tables established on the Hunter River, Australia, in 2000 was used to model sediment accretion within estuarine wetlands using factorial analysis of variance. As surface elevation change did not differ significantly from accretion over the 10 year study period in the mangrove and saltmarsh ($p = 0.4104$), the accretion model was regarded as a reliable estimate of elevation change. Using the current rate of sea-level rise ($3.65\,\mathrm{mm\,y^{-1}}$), a rate deemed to be relatively moderate, a landscape elevation model was developed by applying the accretion model to a LiDAR-derived digital elevation model at annual increments to 2050. Based on current rates of sea-level rise and the intertidal elevation that currently supports mangrove and saltmarsh, the landscape elevation model projected a 16% increase in the area within the elevation range suitable to support mangrove and saltmarsh. This contrasts 'bathtub modelling', which projected a 6% decline in wetland extent. Bathtub modelling fails to account for the ability of mangrove and saltmarsh to accommodate sea-level rise through processes of accretion, shrink-swell of sediments and the accumulation of organic material. Results from the landscape elevation model suggest that planning for sea-level rise should be directed towards facilitating wetland adaptation by promoting tidal exchange to mangrove and saltmarsh and providing land for wetland migration.

1. Introduction

As sea levels are projected to continue to rise at an accelerated rate in the 21st century (Meehl et al., 2007) coastal managers are increasingly questioning whether estuarine wetlands are able to maintain their elevation with respect to rising water levels. Models of the response of estuarine wetlands to changes in water level began to appear in 1987 (Krone, 1987) and were largely focussed on mineral sedimentation processes. Since this time, models have become increasingly complex and have begun to simulate organic matter accumulation dynamics as well as processes that may influence wetland surface topography, such as wave energy and tidal currents (see summary provided by Rybczyk and Callaway, 2009). These models have also increased in spatial scale with the application of zero-dimensional models to landscape scale digital elevation models.

In conjunction with the development of these models, research has emerged that indicates that there is often a disparity between the degree of vertical accretion and the degree of elevation gain observed at a wetland. This research largely relies on the use of surface elevation tables (SET) and feldspar marker horizons (MH) to establish that many processes in conjunction with surface accretion can affect soil volume and influence the capacity of wetlands to maintain their elevation with respect to rising water levels (Cahoon et al., 1999). Cahoon (2006a) describes eight processes altering wetland surface elevations: sediment deposition, erosion, compaction, soil shrinkage, root decomposition, root growth, soil swelling and lateral folding of the wetland root mat.

A network of surface elevation tables was established on Kooragang Island, Hunter River, Australia in 2000, providing a 10 year elevation and accretion data set for mangrove and saltmarsh, the longest dataset in the southern hemisphere. The data set provides empirical measures of surface elevation change that incorporates all the mechanisms that influence surface elevation, as opposed to measures of surface accretion alone. Wetland surface elevation models developed using empirical measures of the response of wetland surfaces to changes in water level may accurately predict the response of estuarine wetlands to water level changes, as mechanisms and feedbacks influencing estuarine wetland elevations are inherently incorporated into empirical values. The accuracy of modelling is enhanced when empirical data sets with greater temporal scale are used to derive models of wetland response to water

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[*] Corresponding author. Tel.: +61 417899544; fax: +61 242214250.
E-mail address: kerrylee@uow.edu.au (K. Rogers).

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level changes as there is greater opportunity for mechanisms and feedbacks to be reflected within empirical values.

In this paper we expand and reanalyse a 10 year accretion and elevation data set from Kooragang Island (Howe et al., 2009) to develop a simple model of the response of estuarine wetlands on the Hunter River to water level changes. In this model, rates of mineral sediment accretion and organic matter accumulation are considered functions of relative elevation which in turn is influenced by a range of “drivers”, including climatic drivers such as rainfall; hydrological drivers, such as estuarine water level; and site specific drivers, such as elevation and distance to the channel. This model was applied to a landscape-scale digital elevation model that was developed for the Hunter River floodplain to project the relative elevation of land that may support estuarine wetlands at 2050. While elevation and accretion data derived from SET and MH has been used to develop theoretical models of wetland response to water level changes (Morris et al., 2002; Morris, 2006), and radiometric measures of accretion have been used to develop landscape scale models of wetland response to water level changes (Craft et al., 2009), this is the first application of empirical measures derived using SET and MH techniques to develop a landscape scale model of the response of estuarine wetlands to water level changes.

2. Materials and methods

2.1. Study site

The Hunter River (151°44′E, 32°52′S) is located approximately 120 km north of Sydney, Australia (Fig. 1). It has a length of approximately 300 km and drains a relatively large catchment area of 22,000 km^2. The estuary has a semi-diurnal tidal regime and a tidal range of approximately 1.9 m at the mouth of the river. The Hunter River has been classified as a mature barrier estuary with mangrove and saltmarsh occurring on the fluvial delta and sediment deposition concentrated in a central mud basin (Roy et al., 2001). Kooragang Island is located approximately 10 km from the mouth of the Hunter River and developed from fluvial deposition of sediments at the mouth of the river.

2.2. Surface elevation and vertical accretion

Surface elevation tables (version IV, Cahoon et al., 2002) were used to investigate surface elevation and accretion dynamics on Kooragang Island. SET's enable detection of changes in surface elevation in intertidal and shallow sub-tidal environments and have a confidence interval of 1.4 mm (Cahoon et al., 2002). SET monitoring stations were established in replicated sets of three within the mangrove, saltmarsh and mixed mangrove/saltmarsh communities; a total of nine SETs were established on Kooragang Island. Within each zone, SETs were established within structurally similar vegetation and land elevations. Initial measures were taken on 29 January 2002 and subsequent measures were taken on 4 March 2003, 18 November 2003, 30 August 2005, 18 April 2006, 7 February 2007, 12 July 2007, 22 September 2007, 3 December 2007, 2 February 2008, 1 April 2008, 11 June 2008, 3 August 2009 and 17 May 2010.

In conjunction with each SET monitoring station, three replicate feldspar marker horizons (MH) were established within 0.25 m^2 plots; a total of nine plots were established within each zone, yielding 27 plots on Kooragang Island. MH serve as a marker against which vertical accumulation of sediment and organic material can be determined. Accretion was determined by the difference between the marsh surface and the horizon within mini cores extracted from MH plots. MH plots were established on 29 January 2002 and subsequent measures taken in conjunction with SET measures.

SET values that were not within two standard deviations of the mean for a sample were regarded as outliers and excluded from statistical analyses. These outliers may occur when SET pins are located on an obstruction, such as a pneumatophore or crab hole. The corrected data was used to generate a curve of accumulative mean surface elevation change within each community. Similarly, cumulative mean vertical accretion was generated from replicated MH measures.

Changes in surface elevation and vertical accretion were standardised by conversion to annual rates of surface elevation change and vertical accretion (mm y^{-1}). To determine whether accretion corresponded to surface elevation change univariate repeated measures ANOVA was used to identify statistical differences between rates of surface elevation change and vertical accretion.

Time series absolute elevation data was generated for each SET monitoring station by adjusting elevation data obtained from a Light Detection And Ranging (LiDAR) survey with the corrected time series SET data. The Hunter River LiDAR survey was completed in January 2007 and has a quoted accuracy of ±15 cm (Fugro Spatial Solutions, Pty, Ltd. 2007). More specifically, the elevation of each SET monitoring station at the SET measurement time closest to the LiDAR survey (i.e. 7 February 2007) was based on elevations derived from the LiDAR survey; subsequent corrected SET data for each monitoring station was then added to the LiDAR-derived elevation of each SET monitoring station, while corrected SET data collected prior to 7 February 2007 was subtracted from the LiDAR-derived elevation of each SET monitoring station.

2.3. Water-level model

A model of water-level variability was developed and forecast information derived from the model was applied to the developed empirical model by undertaking time series analysis on monthly maximum and monthly mean water level data obtained from the Tomaree ocean tide gauge using Stepwise Auto-Regressive Integrated Moving Average (ARIMA) models. This technique is relatively simple and accounts for some of the temporal variability in water levels. Other techniques for deriving water level forecasts could also be employed and applied to the empirical model, such as forecasts derived from hydrodynamic models. In addition, a range of climate change scenarios could also be considered by altering water level forecasts accordingly. The Tomaree ocean tide gauge data was selected for inclusion within the model as it provided a relatively reliable ocean level record for the Hunter Region and was not confounded by irregularities that can occur with estuarine water level gauges (Floyd, pers. comm.). Ocean tide gauges in Southeastern Australia that are located outside estuaries and ports, such as the Tomaree gauge, are regarded as relatively tectonically stable (Bryant et al., 1988; Harvey et al., 2001). The Tomaree ocean level record was of sufficient duration (1985–2010) to factor out variations due to the moon's lunar cycle (Turner, 1991).

The Tomaree ocean level data was transformed to normal distribution when necessary. ARIMA analysis was undertaken and auto-regressive and moving average components were included in the analysis when significant at 0.05 confidence level. In a similar manner to Irvine and Eberhardt (1992), models were eliminated when stationarity and invertibility criteria were not met and models were selected for forecasting on the basis of low residual variance, low standard errors of the coefficients and comparison between the observed data and modelled data. The most reliable model for monthly maximum and monthly mean water level was selected for forecasting water levels to 2050.