Science of the Total Environment 554–555 (2016) 276–292

Contents lists available at ScienceDirect

Science of the Total Environment

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

Will a rising sea sink some estuarine wetland ecosystems?

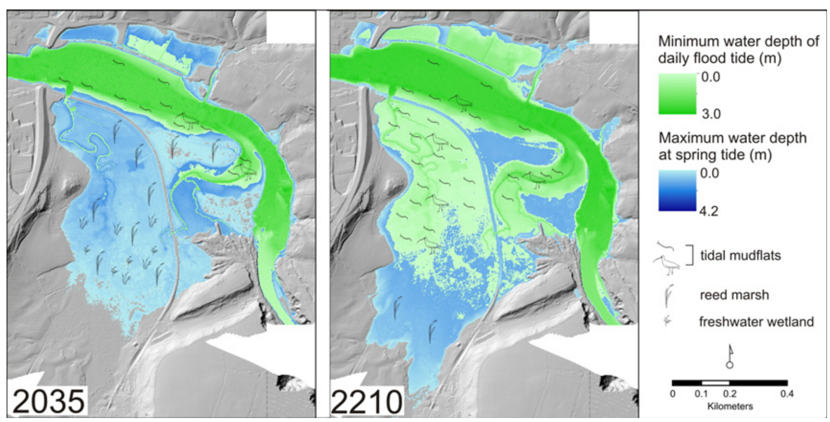
S.E. Grenfell [a,*], R.M. Callaway [b], M.C. Grenfell [c], C.M. Bertelli [b], A.F. Mendzil [d], I. Tew [b]

[a] Department of Geography, Environmental Studies and Tourism, University of the Western Cape, Robert Sobukwe Road, Bellville 7535, South Africa
[b] SEACAMS, Department of Biosciences, Swansea University, Singleton Park, Swansea SA2 8PP, UK
[c] Institute for Water Studies, Department of Earth Science, University of the Western Cape, Robert Sobukwe Road, Bellville 7535, South Africa
[d] SEACAMS, Department of Geography, Swansea University, Singleton Park, Swansea SA2 8PP, UK

HIGHLIGHTS

- We investigate the effect of sea level rise on a tidal wetland ecosystem.
- Wetland sedimentation processes are modelled against the effect of sea level rise.
- Model shows that in 175 years, the wetland is inundated at every flood tide.
- Increased salinity and inundation are associated with decline in species diversity.
- In short term, sea level rise is associated with increased carbon storage.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 25 November 2015
Received in revised form 26 February 2016
Accepted 27 February 2016
Available online 5 March 2016

Editor: Simon Pollard

Keywords:
Coastal wetland
Accretion model
LiDAR
Sea level rise

ABSTRACT

Sea-level rise associated with climate change presents a major challenge to plant diversity and ecosystem service provision in coastal wetlands. In this study, we investigate the effect of sea-level rise on benthos, vegetation, and ecosystem diversity in a tidal wetland in west Wales, the UK. Present relationships between plant communities and environmental variables were investigated through 50 plots at which vegetation (species and coverage), hydrological (surface or groundwater depth, conductivity) and soil (matrix chroma, presence or absence of mottles, organic content, particle size) data were collected. Benthic communities were sampled at intervals along a continuum from saline to freshwater. To ascertain future changes to the wetlands' hydrology, a GIS-based empirical model was developed. Using a LiDAR derived land surface, the relative effect of peat accumulation and rising sea levels were modelled over 200 years to determine how frequently portions of the wetland will be inundated by mean sea level, mean high water spring and mean high water neap conditions. The model takes into account changing extents of peat accumulation as hydrological conditions alter.

Model results show that changes to the wetland hydrology will initially be slow. However, changes in frequency and extent of inundation reach a tipping point 125 to 175 years from 2010 due to the extremely low slope of the wetland. From then onwards, large portions of the wetland become flooded at every flood tide and saltwater intrusion becomes more common. This will result in a reduction in marsh biodiversity with plant communities switching toward less diverse and occasionally monospecific communities that are more salt tolerant.

* Corresponding author.
E-mail address: se.grenfell@gmail.com (S.E. Grenfell).

http://dx.doi.org/10.1016/j.scitotenv.2016.02.196

While the loss of tidal freshwater wetland is in line with global predictions, simulations suggest that in the Teifi marshes the loss will be slow at first, but then rapid. While there will be a decrease in biodiversity, the model indicated that at least for one ecosystem service, carbon storage, there is potential for an increase in the near future.

1. Introduction

Climate change and associated sea level rise is one of the greatest challenges to the continued provision of coastal wetland ecosystem services and biodiversity. Nicholls et al. (1999) estimate that by the 2080's, sea level rise could cause the loss of 22% of the world's coastal wetlands. The spatial impact of rising water levels on coastal wetlands has been the focus of numerous studies (e.g. Rogers et al., 2012; Poulter and Halpin, 2008; and others) which have highlighted the need to allow space for ecosystem migration inland. In many instances though, coastal squeeze will prevent ecosystem migration and the remaining wetland communities will be dramatically altered. In this study we use a two stepped approach to forecast what wetland vegetation communities might be like in a wetland in west Wales as sea level rises. First, we investigate controls on present wetland vegetation communities. Second, we model the effect of sea level rise on inundation levels in the wetland. We combine these analyses to provide a forecast of probable change in the distribution of wetland vegetation communities over the next 200 years.

Predicting change to wetland ecosystems is complex as alterations to the physical environment are mediated by biological interactions, often resulting in an outcome that is not necessarily obvious (Day et al., 2008). Nevertheless, by studying systems in which a single environmental variable has been altered, it may be possible to understand trajectories of change in similar ecosystems while acknowledging the cascading effect that change may have on other environmental variables. Warren and Niering (1993) applied this method to the New England saltmarshes in the US, by contrasting current vegetation with a survey completed in 1947. In our study, we investigate existing environmental gradients within the wetland and use these to evaluate future changes to vegetation communities. This method, employing ergodic reasoning (space for time substitution), provides an alternative where long term data sets are absent.

Likely scenarios were provided by raster based modelling of future inundation levels in the wetland against a background of ongoing organic sediment accumulation. Raster modelling is limited by the resolution of elevation data (e.g. Poulter and Halpin, 2008), but as Rogers et al. (2012) demonstrate, LiDAR elevation data provides a major advance in mapping coastal flooding. In their study, inundation levels were forecast by mapping rising sea levels onto a LiDAR digital elevation model to which an accretion model had been applied. The authors contrasted their work with 'bathtub' modelling (e.g. planar water surface flood inundation modelling, Priestnall et al., 2000), which fails to account for the increase in elevation of coastal wetlands through processes of mineral or organic accretion. More complex models include the effects of compaction and decomposition in addition to sediment accretion and incorporate feedbacks that may alter elevation (e.g. Day et al., 1999).

Using a combination of these methods, several authors have demonstrated the importance of ongoing sedimentation to coastal wetland resilience as sea levels rise. In most instances, research has shown that at IPCC best estimate rates, sedimentation in coastal wetlands is unable to keep pace with sea level rise (e.g. Day et al., 1999; van Wijnen and van Wijnen and Bakker, 2001; Goor et al., 2003; FitzGerald et al., 2008). Even when the feedback between inundation and vegetation growth is modelled, maintaining an equilibrium elevation is impossible in most coastal marshes (Kirwan and Temmerman, 2009). Resilience is particularly low in wetlands where changes in elevation are controlled by peat accumulation rather than clastic sedimentation. For example, in the wetlands of the Albemarle-Pamlico peninsula of North Carolina in the US, vertical accretion rates are considered too low to prevent submergence if sea level rise accelerates (Moorhead and Brinson, 1995).

In contrast, in areas where suspended sediment concentrations are high or increasing, some coastal wetlands may be able to persist (e.g. Temmerman et al., 2004; Reed, 2002; Morris et al., 2002). In San Francisco Bay for instance, marsh accretion as a result of sedimentation and peat formation has been able to compensate for high rates of subsidence and the low rate of sea level rise, maintaining the elevation of the marsh surface above mean high water (Patrick and DeLaune, 1990). A key factor is that the system is not sediment limited. Indeed, it has been suggested that sediment dispersal by natural and/or engineered mechanisms could mitigate coastal wetland loss in some of the World's largest deltas (Nittrouer et al., 2012; Edmonds, 2012).

This study is focussed on a small tidal wetland in west Wales that is located at the present day interface of fresh and salt water. The aim was to understand how inundation frequency and magnitude will alter as sea levels rise, and to evaluate the likely effect on vegetation and benthos communities. There is a regional need for insight into the potential for coastal wetlands to provide habitat and/or maintain their biodiversity such that wetland bird and animal populations can be sustained in the future. To develop this insight, we investigated present day benthos and vegetation along environmental gradients (i.e. wetness and salt tolerance). We then used a raster based model to estimate inundation levels at mean water level as well as at neap and spring tides. The model incorporated an accretion model to account for elevation that was continually created as peat was formed. The model accounted for an increase in peat formation extent as more of the wetland became flooded.

1.1. The Pentood and Rosehill Marshes, Teifi Marsh

The Teifi Marsh is located alongside a tidal estuarine stretch of the Teifi River just upstream of Cardigan town in west Wales, the UK (Fig. 1) and falls within a reserve managed by the Wildlife Trust of South and West Wales. The reserve comprises two marsh areas – the Rosehill Marsh on the eastern side of the abandoned Cardi-Bach railway, and the Pentood marsh on the western side. A meandering stream, the Afon Piliau, drains a small catchment to the southwest (~14 km^2 in size), and flows through the Pentood Marsh into the Teifi River.

The reserve is managed for waterfowl habitat and is grazed by a combination of horses and water buffalo to encourage plant diversity. In addition, some ponds have been dug and are occasionally cleared to maintain patches of open water. The abandoned Cardi-Bach railway compartmentalises the marsh into two systems that vary hydrologically and ecologically (Fig. 1). The Rosehill Marsh, confined on all sides by a combination of the railway, an old slate tip and the Teifi River, is primarily reed bed. It receives some water from discontinuous channel networks that drain the Pentood Marsh and pass under the railway through culverts and also experiences tidally induced flooding from the Teifi River estuary. Contrarily, the Pentood Marsh has a restricted connection to the Teifi River at the junction of the Afon Piliau and the extent of tidally induced flooding is less pronounced than in the Rosehill Marsh.

Prior to the last glaciation, the Teifi River occupied a wide meandering floodplain. During the Last Glacial Maximum, Irish Sea ice reached the west coast of Wales creating ice dammed lakes in coastal river valleys across western Wales. One of the largest was Llyn Teifi (Fletcher and Siddle, 1998). During the glaciation, the lake and the pre-existing course of the Teifi River were gradually filled with glacially-derived sediment.