Impacts of sea level rise on the biogeochemistry of a coastal floodplain in eastern Australia

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Abstract

The effect of seawater inundation on the biogeochemistry of coastal floodplain soils was examined by subjecting intact soil cores to 0%, 50% or 100% dilutions of synthetic seawater. Soil cores sampled from a natural levee were slightly acidic, non-saline and showed a slight decrease in pH following inundation (eg. 7.41 to 6.73 in the 100% seawater treatment) and limited mobilisation of Fe^{2+} in the overlying waters in all treatments. Soil cores sampled from a scald were acidic, saline with high concentrations of soluble and exchangeable Al. Following inundation, there was a slight decrease in pH and limited mobilisation of Fe^{2+} in the overlying waters. Soil cores sampled from throughout the backswamp on the floodplain were saline, acidic with high concentrations of exchangeable Al. In most of the backswamp soil cores, pH decreased following inundation with seawater, with the greatest decreases occurring with the 50% seawater treatment. Fe^{2+} concentrations generally increased with time in the backswamp soils. These results have implications for surface water quality when these coastal floodplain wetlands are subjected to seawater or brackish water inundation as a result of sea level rise, storm surge or king tides.

Key Words

Climate change, seawater inundation, coastal lowland acid sulfate soil.

Introduction

Sea level has risen approximately 1.2 mm/year over the last 100 years (Hennessy *et al.* 2004) and is predicted to rise up to 80 cm by 2100 relative to 1990 sea levels (IPCC 2007). The number of extreme events related to sea level such as higher sea levels and increased inter-annual variability have also increased in frequency in the same time period (Hennessy *et al.* 2004). Coastal lowland acid sulfate soils (CLASS) are estimated to cover approximately 12-13 million ha globally (Andriesse and van Mensvoort 2006). These areas commonly occur at or below sea level (≈ 0 m Australian Height Datum; AHD) and are highly susceptible to pulses of saline water caused by saltwater intrusion, storm surge, king tides and rising sea levels.

Many Holocene coastal floodplains in eastern Australia contain large, low elevation (0-1 m AHD) backswamp basins which were originally semi-permanent wetlands and natural floodwater storage basins (Tulau 1999). These backswamp basins are frequently underlain by CLASS and sulfidic sediments. Following European settlement of the floodplains in the late 19th century (Tulau 1999), there has been extensive modification of the floodplain through the construction of drainage systems and expansion of agriculture (Johnston *et al.* 2003). This process has enhanced drainage of the floodplains and resulted in oxidation of CLASS and abundant surface accumulation of reactive Fe minerals (Dent 1986). The construction of extensive drainage systems has increased the susceptibility of the floodplain to seawater inundation by increasing connectivity to the estuarine channel.

Previous studies have shown inundation of CLASS can mobilise trace metals, which has implications for water quality in these floodplain wetland environments (Burton *et al.* 2008). However, controlled tidal exchange in degraded tropical floodplains can neutralise acidity and re-establish reductive environments to aid in reclamation of these areas (Johnston *et al.* 2009). The biogeochemical processes which occur at the surface water-soil interface following seawater inundation of CL ASS are complex and will only increase in importance in the future with predicted increases in sea levels. This study aims to determine the surface water-soil interactions over the short term following seawater inundation in coastal floodplain backswamps containing CLASS.

Methods

Field sampling and site description

Intact soil cores were sampled from the floodplain in the Rocky Mouth Creek (RMC) sub-catchment of the Richmond River in the sub-tropical region of eastern Australia. Rocky Mouth Creek is subject to regular tidal movement and joins the Richmond River at Woodburn, approximately 42 km upstream of the river mouth. The floodplain in the RMC sub-catchment is characterised by extensive, well-developed natural levees grading into a large backswamp basin with elevations mostly < 1 m AHD. Cores were sampled from six sites on the floodplain; natural levee (Le), scald (Sc) and four backswamp sites (Bs1, Bs2, Bs3, Bs4). Vegetation was cut to ground level and intact soil cores were sampled with PVC pipe of diameter 0.1 m. The pipes were driven in to the ground to a depth of approximately 0.2 m, capped, sealed and stored at 4°C until analysis.

Sample preparation and laboratory analysis

Soil cores from each site were inundated for 14 days according to one of three treatments; 0, 50 or 100% synthetic seawater diluted in deionised water. Each treatment was undertaken in triplicate with the mean presented. The synthetic seawater consisted of the major cations and anions found in natural seawater (Cavanaugh 1975) with pH ≈ 8 and EC ≈ 46 dS/m. The 50% treatment was prepared by dilution of the 100% seawater solution and 0% treatment was milli –q water. Each core was inundated to a depth of approximately 0.2 m.

Surface water samples were taken via a port located approximately 0.05 m above the soil surface at 0 hrs, 2 hrs, 24 hrs, 48 hrs, 7 d and 14 d. Dissolved oxygen and pH were measured in situ prior to sampling. Samples were analysed for major cations, metals, and aqueous Fe and speciation. Major cations and trace metals were determined on the extracts by ICP-MS. Aqueous Fe speciation was determined using 1, 10-phenanthroline (APHA 2005). Fe^{3+} was determined from the difference between total Fe and Fe^{2+} following reduction with hydroxylammonium chloride.

Bulk soil from each site was also characterised. Soils were oven-dried at 40°C for 48 hours and lightly crushed to pass through a 2 mm sieve. Soil pH, EC and soluble cations were determined on 1:5 soil:water extracts (Rayment and Higginson 1992). Soil organic C and N were determined by high combustion LECO analysis. Exchangeable cations were extracted with 1:5 soil:2M $BaCl_2/NH_4Cl$. Where the $EC_{1:5} \geq 0.3$ dS/m, soluble salts were removed by washing three times with an ethanol/glycerol solution (Rayment and Higginson 1992). Soluble and exchangeable cations were determined by ICP-MS.

Results and discussion

Selected soil characteristics of the sampled cores are shown in Table 1. The Le soils were non-saline, slightly acidic and had the lowest concentrations of SOC, total N and exchangeable Al. The Sc soils were acidic, saline with high concentrations of soluble and exchangeable Al. Soil cores sampled from the backswamp on the floodplain (ie. Bs1-Bs4) were saline, acidic with high concentrations of exchangeable Al.

Table 1. Soil characteristics from each site.

Site	$EC_{1:5}$ (dS/m)	$pH_{1:5}$	SOC (%)	Total N (%)	Soluble Fe (mg/kg)	Soluble Al (mg/kg)	Exchangeable Fe (mg/kg)	Exchangeable Al (mg/kg)
Le	0.12	5.45	4.12	0.39	81.77	69.81	nd	63.21
Sc	0.56	3.83	5.36	0.42	115.95	3959.27	nd	8567.95
Bs1	1.35	3.66	6.34	0.46	10.65	1016.03	nd	8572.84
Bs2	1.16	4.14	7.87	0.61	16.21	152.83	nd	2730.09
Bs3	0.62	4.56	5.72	0.39	2.10	11.72	nd	2607.88
Bs4	0.67	4.40	9.62	0.76	13.46	78.56	nd	3911.86

Note: nd indicates not detected

Following inundation, the surface waters of the Le soils were circumneutral and showed a slight decrease in pH in all treatments (Figure 1). In the Sc soils, pH rapidly became acidic and showed a slight decrease following inundation. The lower pH at the beginning of the inundation period compared to the other soils is due to the dissolution of acidic salts on the surface, as salt efflorescence was present at the time of sampling. pH in Bs1, Bs2 and Bs4 decreased in all treatments following inundation. The initial decrease in pH in the 50% and 100% seawater treatments is likely to be the result of ion exchange of protons and acidic metal cations of the surface sediments following addition of a higher ionic strength solution. However, Bs3 did not show the same pattern after inundation. pH decreased slightly to Day 2, and then increased in all treatments at this site.

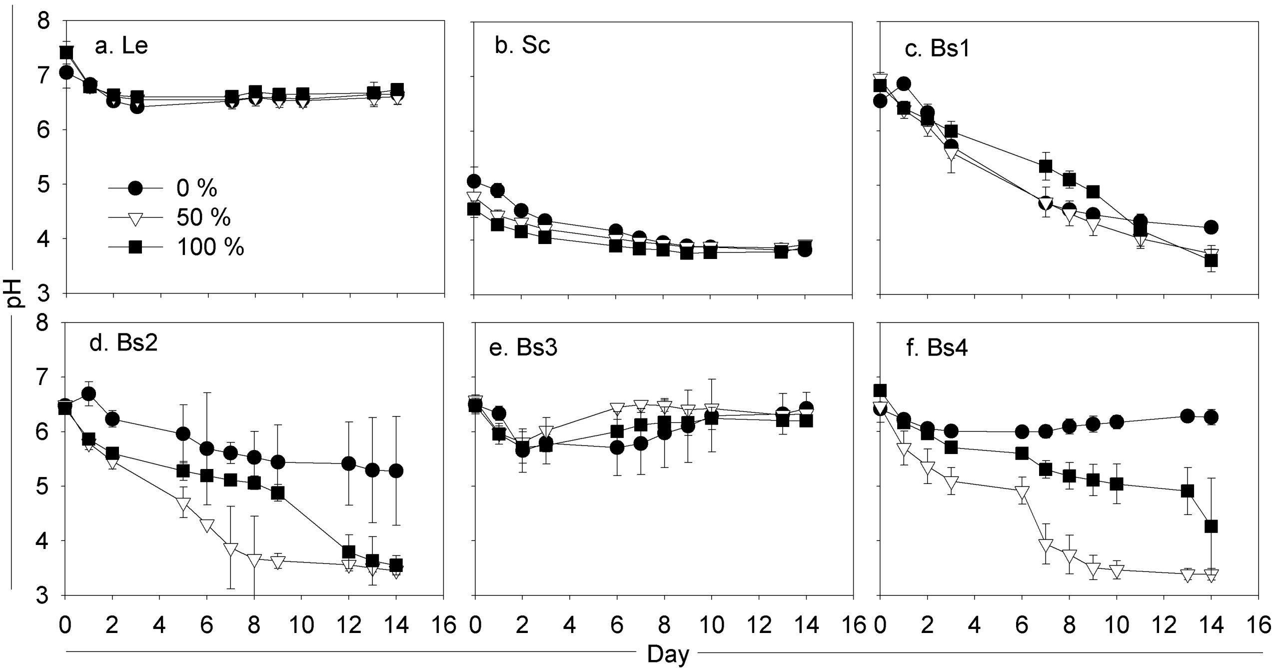

Figure 1. Change in pH over time following inundation with 0%, 50% and 100% seawater in a) Le; b) Sc; c) Bs1; d) Bs2; e) Bs3; and f) Bs4 soils. Vertical bars indicate standard deviation.

When detected, aqueous Fe concentrations were dominated by Fe^{2+} in all treatments at all sites. There was limited mobilisation of Fe^{2+} in the overlying waters of the Le and Sc soils across all treatments following inundation (Figure 2). In the backswamp soils, the highest concentrations of Fe^{2+} were found in 100% seawater treatment. Across all treatments, Fe^{2+} concentrations were highest in the Bs3 soils.

Anoxic conditions were establishing during the inundation period in the Bs3 soils in the 50% and 100% treatments, while the overlying waters from all other sites remained oxic (data not shown). Increasing Fe^{2+} concentrations with time and with increasing salinity in the backswamp soils is most likely the result of reductive mobilisation of metastable Fe-oxide minerals such as schwertmannite (Burton *et al.* 2007). These minerals commonly occur in floodplain backswamp environments in eastern Australia.

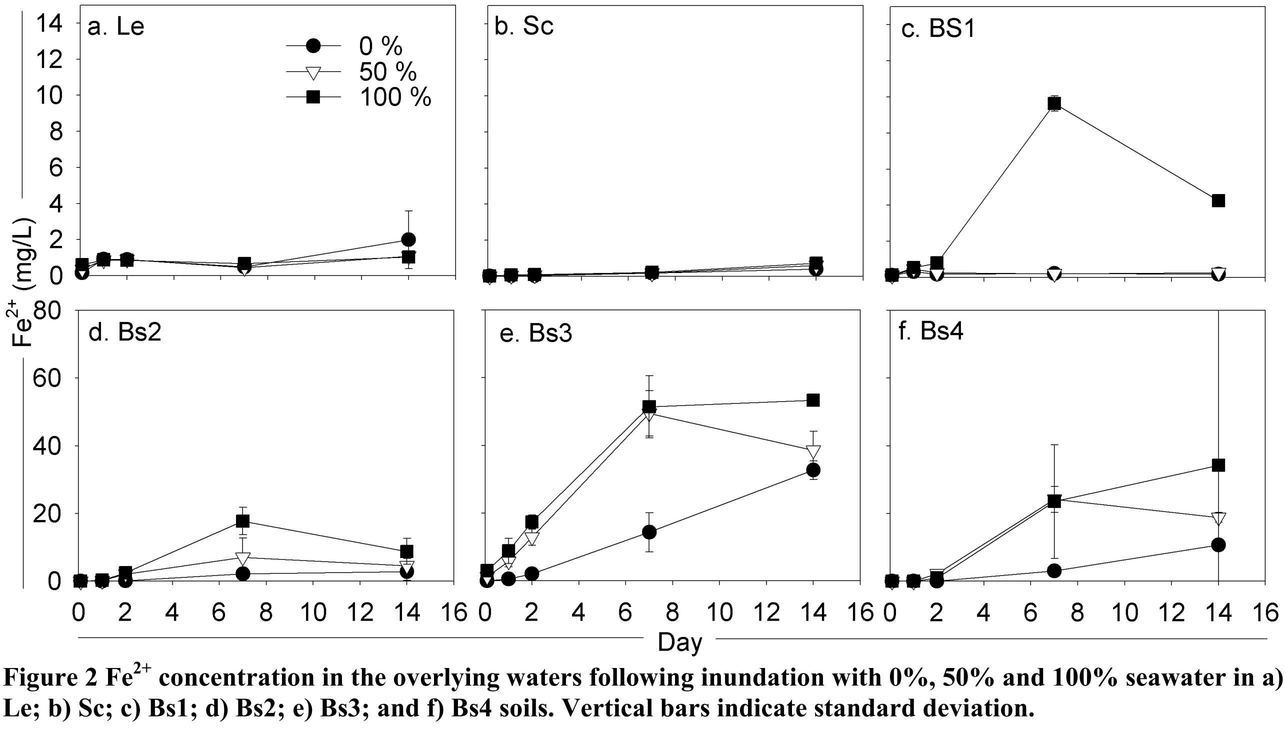

Figure 2 Fe^{2+} concentration in the overlying waters following inundation with 0%, 50% and 100% seawater in a) Le; b) Sc; c) Bs1; d) Bs2; e) Bs3; and f) Bs4 soils. Vertical bars indicate standard deviation.

The decrease in pH in the 50% and 100% seawater treatments has implications for water quality as a consequence of sea level rise. These experimental results suggest that over the short term, inundation with seawater or brackish water can result in a lowering of pH and an increase in concentration and mobility of Fe^{2+} and other trace metals in solution. These experiments were complimented with additional batch experiments, which were used to illuminate key processes occurring in the intact soil cores (Wong *et al.* 2010). In the batch experiments, trace metal concentrations increased and pH decreased with increasing seawater concentration. This is consistent with metal desorption via competitive exchange with marine-derived base cations and hydrolysis of acidic metal cations.

This study shows that seawater inundation of these backswamp basins initiates two distinct, sequential geochemical processes with different kinetics. Both of these processes influence acidity and trace metal behaviour in contrasting ways. It has been assumed that inundation with seawater and the alkalinity contained within will promote proton consuming processes, resulting in an increase in pH. Over longer time periods, prolonged seawater inundation will result in a shift to reducing conditions (eg. Johnston *et al.* 2009). However, experimental results show that a pulse-release of acidity and mobilisation of trace metals will occur in the shorter term during the transition to reducing conditions.

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References

Andriesse W, van Mensvoort MEF (2006) Acid sulfate soils: distribution and extent. In 'Encylopedia of Soil Science'. (Ed. R Lal) pp. 14-19. (CRC Press: Boca Raton, Florida).

APHA (2005) 'Standard methods for the examination of water and waste water.' (American Public Health Association, American Wastewater Association, World Environment Fund: Washington DC, USA).

Burton ED, Bush RT, Sullivan LA, Johnston SG, Hocking RK (2008) Mobility of arsenic and selected metals during re-flooding of iron- and organic-rich acid-sulfate soil. *Chemical Geology* **253**, 64-73.

Burton ED, Bush RT, Sullivan LA, Mitchell DRG (2007) Reductive transformation of iron and sulfur in schwertmannite-rich accumulations associated with acidified coastal lowlands. *Geochimica et Cosmochimica Acta* **71**, 4456-4473.

Cavanaugh GM (1975) 'Formulae and methods VI of the Marine and Biological Laboratory Chemical Room, 6th Edition.' (Marine Biological Laboratory: Woods Hole).

Dent D (1986) 'Acid sulphate soils: a baseline for research and development.' (International Institute for Land Reclamation and Improvement ILRI: Wageningen, The Netherlands).

Hennessy K, Page C, McInnes K, Jones R, Bathols J, Collins D, Jones D (2004) Climate Change in New South Wales. CSIRO, Canberra.

IPCC (2007) Climate Change 2007: Synthesis Report. Intergovernmental Panel on Climate Change.

Johnston SG, Keene AF, Bush RT, Burton ED, Sullivan LA, Smith D, McElnea AE, Martens MA, Wilbraham S (2009) Contemporary pedogenesis of severely degraded tropical acid sulfate soils after introduction of regular tidal inundation. *Geoderma* **149**, 335-346.

Johnston SJ, Kroon F, Slavich P, Cibilic A, Bruce A (2003) Restoring the balance: Guidelines for managing floodgates and drainage systems on coastal floodplains. NSW Agriculture, Wollongbar, Australia.

Rayment GE, Higginson FR (1992) 'Australian Laboratory Handbook of Soil and Water Chemical Methods.' (Inkata Press: Australia).

Tulau MJ (1999) Acid Sulfate Soil Management Priority Areas in the Lower Richmond Floodplain. Department of Land and Water Conservation, Sydney.