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Understanding the creek dynamics and environmental characteristics that determine the distribution of mangrove and salt marsh communities at Nahoon Estuary

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ABSTRACT

The southern distributional limit for mangroves on the east coast of Africa is thought to be at the planted mangrove forest at Nahoon Estuary (33° S) in the Eastern Cape, South Africa. This study investigated the influence of a tidal creek on the intertidal zone and the physical and biological differences between the salt marsh and mangrove forest communities at Nahoon Estuary. Three transects were established across the tidal creek and one transect in each of the following habitats mangrove, mangrove–salt marsh, and the salt marsh area. The tidal creek introduced oxygenated (~6 $mg.l^{-1}$) and saline water with high levels of total suspended solids (120–424 $g.l^{-1}$) into the intertidal zone. In areas where tidal water was retained, algal mats formed over pneumatophores during summer. The vegetation distribution in the mangrove–salt marsh community was significantly affected by elevation, ammonium concentration, and porewater temperature while the salt marsh vegetation distribution was influenced by porewater salinity, sediment, pH and the percentage of sand content. Porewater nitrogen was mostly present as ammonium, and phosphate concentrations were moderate ranging from 1.3 μM in the salt marsh to 3.7 μM in the mangrove community. Mangrove and salt marsh communities are clearly constrained by the physical characteristics of the intertidal area (elevation) and this will ensure that both communities will be maintained at Nahoon Estuary. However with climate change and sea level rise, this may change in the long term with mangroves expanding into elevated areas.

1. Introduction

Mangroves are defined as trees and shrubs that grow in saline coastal habitats (Giri et al., 2011) while salt marsh habitats are defined as stands of salt-tolerant plants such as herbs, grasses, and shrubs that occur in the upper intertidal zone (Adam, 1990). Mangroves characteristically dominate lower elevation zones, where they are frequently inundated by tides, while salt marsh communities occupy the higher elevation zones, which are less commonly flooded (Chapman, 1974, Adam, 2002). On a global scale, mangroves are generally limited to the warmer coastal tropical regions of the world and extend into subtropical and occasionally even temperate regions >33° S (Clarke and Hannon, 1967; Adam, 2002; Stevens et al., 2006; Adame et al., 2010; Morrisey et al., 2010; Giri et al., 2011), while salt marsh are found at most latitudes but are largely replaced by mangrove forests in the tropical latitudes (Chapman, 1960, Chapman, 1975). At the transition zone between temperate and subtropical climate regions salt marsh and mangrove communities can co-exist (Clarke and Hannon, 1967; Steinke, 1995; Adam, 2002; Stevens et al., 2006; Adame et al., 2010; Morrisey et al., 2010). Where these communities co-exist more local conditions such as elevation, sediment characteristics, freshwater, and nutrients influence their distribution and ability to compete. In South Africa, mangroves occur in estuaries from Kosi Bay (KwaZulu–Natal) to Nahoon Estuary (Eastern Cape) where they were planted in 1969 (Steinke, 1972); salt marsh communities are dominant in estuaries further south from Nahoon to the Orange River (Western Cape).

Local parameters such as sediment particle size has a major influence on sediment biogeochemical characteristics such as redox potential, pH and organic and moisture content (Clarke and Kerrigan, 2000) and these in turn will affect the plant community that grows on it. Fine sediments are less permeable than course sediments which have higher infiltration rate of water. Clarke and Kerrigan (2000) found that conductivity, pH, nitrogen, and phosphorus were associated with sediments of different particle size. Mangrove sediments are characterized as being fine grained, poorly drained, saline, anoxic, and rich in organic matter (Lear and Turner, 1977). Fine particles are introduced into mangroves from riverine sources while course marine sediments are washed in through the mouth from the marine environment (Lovelock et al., 2007a). In general, mangroves are low-lying systems with a flat topography. They are thus regularly inundated by tides and

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remain saturated with water even during low tide due to poor drainage (Clarke and Hannon, 1967). As a result of being permanently waterlogged mangrove sediments are anoxic; with oxygen only being present in the surface layers around roots. The physiochemical characteristics of such waterlogged, anoxic soils are different to those of aerated soils. Salt marshes in contrast generally occur at higher elevations than mangroves. Although salt marsh soils can be highly saline, they are generally better drained and are more oxic. The sediment characteristics and nutrient content influence species distribution, as well as long-term growth and survival of plants. How the sediment changes when salt marsh areas are invaded by mangroves will affect a wide range of process as the sediment becomes more anoxic and may affect nutrient availability; this is the main focus of this study.

Soil nutrient availability is variable within and among estuarine ecosystems, including mangrove forests and salt marsh, and these dynamics are mostly unstudied in South Africa. Nutrient concentrations and species can vary spatially along a tidal gradient as well as temporally with seasons depending on the source and rate of cycling in each system (Lovelock et al., 2007a). Micro and macronutrients such as nitrogen, phosphorus, and potassium are essential to a variety of biological and chemical processes, both at the organism level (e.g. somatic growth, reproduction) and on the scale of ecosystems (Nirmal Kumar et al., 2011). Nutrients enter estuarine systems through numerous pathways: upland runoff, precipitation, and tidal input (Nirmal Kumar et al., 2011). Nutrient inputs may increase noticeably following rainfall events, as nutrients are washed from catchments and adjacent areas into the coastal zone. The availability of nutrients within the estuary is further influenced by various biotic factors including microbial activities in the soil, litter production, and rates of decomposition (Prasad and Ramanathan, 2008, Reef et al., 2010, Nirmal Kumar et al., 2011) as well as anthropogenic factors such as sewage runoff.

Nitrogen and phosphorus are two of the major plant nutrients determining plant growth. In mangrove sediments, nitrogen becomes available through microbial fixation of atmospheric nitrogen and through the biological decomposition of organic matter in the soil. In anaerobic soils most nitrogen is available in the form of ammonium ions (Armstrong, 1982). With nutrients being trapped in sediments and often little surface drainage entering from the surrounding environment, mangrove forests depend largely on nutrients from the sediment (released from decomposed organisms) and trapped in sediment porewater (Nirmal Kumar et al., 2011). The movement of nutrients and terrestrial sediment to the landward edges of intertidal range, both from freshwater sources and from the intertidal area, is often facilitated by tidal creeks (Green and Hancock, 2012). Tidal creeks transport oxygenated seawater, unicellular organisms, suspended solids (TSS), dissolved substances, and nutrients into sediments and facilitates the movement of degraded products and organisms from sediments (Santos et al., 2012). Porewater circulation through permeable sediments thus has a major influence on the biogeochemistry of sediments as it influences the porewater composition and the time it resides in sediments. Total suspended solids (TSS) is the concentration ($mg \cdot l^{-1}$) of organic and inorganic matter which is held in the water column by turbulence and alters the water column both physically and chemically.

Very little is known about the nutrient dynamics of Southern African mangrove and salt marsh systems (Emmerson, 2005). A few studies have looked at channel water nutrients in salt-marsh-specific estuaries (Emmerson and Erasmus, 1987; Emmerson, 1989), but have not considered the importance of nutrients in the porewater which is directly available to the plants. This paper specifically aims to determine the role of a tidal creek in the intertidal zone by measuring the adjacent plant communities and the physical parameters of the water entering the intertidal area. Secondly, we aim to determine differences between the physico-chemical conditions in the porewater and sediment of the mangrove and the salt marsh communities. It is important to understand the physiochemical conditions in these sediments as this has a major effect on the vegetative growth response and survival of these vegetation types.

2. Study site

The Nahoon Estuary (32°59′09″ S, 27°57′03″ E) is a permanently open estuary situated in East London and falls within the East London Coastal Nature Reserve in the Eastern Cape Province of South Africa (Fig 1). Nahoon falls into the warm temperate biogeographic region and is 5 km long and the main tributary, the Nahoon River is approximately 70 km in length, with a catchment area between 547 and 625 km^2 (CSIR 2000; Harrison et al., 2001). The Nahoon Estuary is microtidal with an average tidal range of 0.76 m and a coastal spring tide range of 1.6 m (Reddering, 1988), and is historically prone to periodic droughts and floods. Based on the last review, Nahoon was in fair condition and was prioritized at number 70 in the importance rating of estuaries in South Africa (Turpie et al., 2002). This estuary is recognized as the southern limit of the distribution of mangroves in South Africa (Ward and Steinke, 1982). The annual precipitation varies between 200 and 600 mm and most rainfall occurs during the spring and summer months. During this study, approximately 249 mm was received in summer while only 122 mm fell during the winter season. The annual temperatures ranged from a minimum of 4.6 °C to a maximum of 31.1 °C during the study (South African Weather Services 2012). The Nahoon River is a ‘drowned river valley’ since it is surrounded by steep cliffs or slopes which occur along certain lengths of the river. The steep cliffs which reach up to 105 m high in places, limit the access to the estuary and to some floodplain areas (Mega, 2013). The tidal creek at Nahoon Estuary is small and narrow in comparison to other creeks in South Africa.

3. Materials and methods

To determine the influence of the creek on the biological characteristics of the intertidal zone at Nahoon Estuary, water samples were taken at the mouth of the creek over a half tidal cycle and compared to that in the main channel in September 2013. Total suspended solids expressed as ($mg\ l^{-1}$) was measured by filtering 250 ml of water samples through pre-dried GFC filters (at 103 – 105 °C). The residue retained on the filter were dried in an oven at 103–105 °C until the weight of the filter no longer changed. The increase in weight of the filter represented the total suspended solids (Trott and Alongi, 2000). Dissolved oxygen (mg/L^{-1}), pH, temperature and redox was directly measured in the water column using a YSI ProPlus Multimeter. Three transects were then setup along the creek from the lower to the upper parts of the creek. These are labeled A, B, and C. Along each transect (0–5 m, 5–10 m, and >15 m), sediment was collected (3 replicates per depth, $n = 18$ per transect) at the surface and extracted from 20 cm depth to determine the sediment organic and moisture content, redox potential, particle size. The sediment redox potential was measured within 24 hours of collecting the sediment, and pH, moisture content and organic matter were measured within 48 hours. The hydrometer method was used to determine sediment particle size (Gee and Bauder, 1986). The proportions of sand, silt, and clay were then calculated. Redox potential was measured *in situ* with a multiprobe (a HANNA redox/pH meter (HANNA Instruments) and a platinum–gold tipped electrode).The pH of the sediment was measured using a multiprobe (a HANNA redox/pH meter (HANNA Instruments) and a platinum-gold tipped electrode). Moisture content (Black, 1965), organic matter content (Briggs, 1977) and electrical conductivity (The Non-Affiliated Soil Analyses Working Committee, 1990) of the soil was measured in a laboratory according to methods cited.

To determine differences between the physico-chemical conditions in the porewater and sediment; transects were setup perpendicular to the main channel in the mangrove, mangrove–salt marsh and the salt marsh communities. The mangrove community (Fig. 1—Transect

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