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Beach ridge sets reflect the late Holocene evolution of the St Lucia estuarine lake system, South Africa

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ABSTRACT

Sets of sandy beach ridges and intervening swales define shoreline sections of the shallow St Lucia wetland system within the iSimangaliso Wetland Park, World Heritage Site in northern KwaZulu-Natal province, South Africa. The sets comprise 3–10 beach ridges, the most prominent being 80–150 m wide and rising 0.5–2 m above the adjacent swales. The highest beach ridge crests elevated 3.2–4.6 m above mean sea level are furthest from the present shoreline and the lowest ridges, rising about 0.5 m above the swales, occur closest to the present mean lake level shoreline. This investigation assesses the genesis of the sandy beach ridges on five strand plain remnants within the estuarine lake. The ridges were topographically surveyed and their ages estimated using optically stimulated luminescence (OSL) dating. OSL dating reveals that the oldest beach ridge formed around 6240 years ago, with a sequence of beach ridges having accumulated during the period ~4000 to 1500 years ago reflecting coeval accretion around the lake. The present mean lake level shoreline was only reached within the past ~600 years. Sedimentation changed from marine-dominated to lacustrine deposition in the estuary during the period of beach ridge accretion. The dated beach ridges, supported by new radiocarbon dates of fixed biological indicators from Holocene intertidal zone settings on the coast, are used with published sea-level curves to set the context of periodic beach ridge accretion in the marine-linked estuarine lake. The dated ridges suggest that episodic regression of the estuarine lake shoreline occurred after a mid-Holocene sea-level highstand. The record of sea-level change is also reflected by the long-term natural shrinking and shallowing of the proto-St Lucia lagoon/estuarine lake in the context of reduced marine influences due to closure of former marine channels by progressive barrier dune accretion. The sequence of coeval beach ridges reflects a pulsed lowering of relative sea-level in the shallowing estuarine lake. Height differences between the coeval ridges at sites around the lake reflect local environmental controls including the range of wind fetch distances across shallow lake compartments, wave height and wind-induced seiche effects.

1. Introduction

The Maputaland coastal plain stretches north from St Lucia estuary into the Maputo Bay area of Mozambique, representing the southern extent of the southeast African coastal plain (Bruton, 1980). The morphology of the Maputaland coastal plain evolved over several million years of dune accretion and remobilization linked to climate change and groundwater table level fluctuations (Grundling, 2004; Porat and Botha, 2008). The variably weathered dune sands, groundwater seepage-fed rivers and lakes, unique vegetation patterns and biodiversity are conserved within the iSimangaliso Wetland Park, a UNESCO World Heritage Site and RAMSAR Wetland of International Importance (Whitfield et al., 2013).

A unique aspect of the coastal lakes within the region is the sets of 3–10 shore-parallel, concentric or slightly oblique sand ridges raised above the margins of St Lucia lake (Orme, 1973, 1974; Hobday, 1979; van Heerden, 1987; Wright, 2002). These low sand ridge and swale patterns form broad strand plains, composite spits or barrier berms isolating tributary streams or wetlands (Figs. 1, 3–7). The asymmetrical ridges have slightly steeper slopes on the lake shoreline side and are elevated 0.5 to ~4.6 m above the present mean lake level shoreline.

Similar beach ridge/swale patterns on strandplains have been described from numerous littoral marine or lacustrine settings where the temporal aspects of beach ridge accretion have been recorded. The strandplains comprising numerous, closely spaced beach ridges around

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the Great Lakes of Canada and USA reflect rapid development of beach ridge sets over timeframes of several decades. Ridges aggrade during lake-level highstands with increased sediment supply and prograde when water levels stabilize lakeward during the fluctuations (Thompson and Baedke, 1995; Johnston et al., 2007). On the Mediterranean coast of Spain, Goy et al. (2003) describe beach ridges spanning the period from the early to late Holocene with high rates of ridge set accretion over decadal periodicities, related to a relative mean sea level that did not exceed +1.3 m. On the Atlantic coast of Spain, Zazo et al. (1994, 2008) dated grouped 'sets' of beach ridges, separated by wide swales that form coastal spits at river mouths where littoral drift associated with storms supplies sediment and spit progradation. Ridge accumulation since the early Holocene (cf. 6900 yr BP) was related to short-term sea-level rise associated with climate change, with accretionary beach ridge set units, comprising numerous beach ridge couplets formed over decadal timeframes, that accumulated during episodes with 1400–300 year cyclicity, separated by periods of swale development (Zazo et al., 2008). In the context of the low wind- and wave energy coastline of Rockingham Bay, north Queensland, Australia, Forsyth et al. (2010) attributed the formation of a sequence of 19 shore-parallel beach ridges rising up to 5.5 m above mean sea level to tropical cyclones that can generate significant wave heights and storm surges. Despite the shoreward-younging succession, falling sea level was regarded as unlikely to have been a principal driver controlling the elevation of ridge crests across the beach ridge plain over the past 5000 years.

The St Lucia ridges conform to the definition of beach ridges (Hesp, 2004) that include swash aligned, swash and storm wave built deposits or ridges formed of sand, pebbles, cobbles and gravel at or above the normal spring high tide level. Beach ridge growth from a submerged longshore bar, spit or emergent points influenced by swash action during the high tide and the possible addition of an aeolian cap are genetic considerations for interpreting beach ridge formation as described by Evans (1942), Tanner (1995) and Hesp (2004).

This investigation into the distribution, morphology, sedimentology and age of the St Lucia estuarine lake beach ridges aims to elucidate their formation and assess their value in defining an environmental and chronological framework for the Holocene development of the estuarine lake. Like many estuaries along the microtidal South African coast which is a high energy, swell-dominated environment (Cooper, 2001) the St Lucia system shows temporal modification from the Last Interglacial, marine embayment (Wright et al., 2000; Wright, 2002) to a probable tide-dominated system during the early Holocene. The change in morphodynamics affecting the proto-St Lucia lagoon follows the modification of a tidal current and prism dominated system to river-dominated sedimentation (Cooper, 1994, 2001).

The key question to be addressed is to what extent the sequence of raised beach ridges represents estuarine shoreline accretion in response to relative sea-level change. Local environmental effects consider include wind fetch, wave action and seiche. The possible influence of climatically driven lake level fluctuation and flooding in response to catchment discharge, alternating with periods of lowered lake level or even desiccation during long droughts, are factors that must also be considered. Estuary and lake shorelines, combined with records of lake bed sedimentation and regional relative sea-level records, hold the potential for constructing a geochronological framework of Holocene environmental change in the system.

OSL dating was undertaken on the sequence of beach ridges in five sites around the estuarine lake shoreline (Fig. 1). The age distribution and relief of the beach ridge sets, supported by new dated sea-level index point, is compared with published Holocene relative sea-level curves for the eastern coast of South Africa (after Ramsay, 1995, 1996, Compton, 2001, 2006, Ramsay and Cooper, 2002, Botha et al., 2013). The depositional context is supported by St Lucia lake sedimentation records (Benallack et al., 2016; Humphries et al., 2016) and the geochronological framework of dune formation pulses against the coastal barrier and sand remobilization on the coastal plain (Porat and Botha, 2008). The interpretation can be evaluated against palaeoenvironmental records from lacustrine settings in the adjacent Mfabeni fen (Baker et al., 2014) and nearby Lake Eteza (Neumann et al., 2010).

The long-term impacts of sea level on the progressively shallowing, compartmentalized lake and the local environmental influences on beach ridge construction within the young, dynamic system is a crucial consideration in the holistic environmental management of the sensitive shoreline environments in this protected ecosystem.

2. Physical environment of the St. Lucia estuarine lake system

The iSimangaliso Wetland Park includes the St Lucia wetland is the largest estuarine system on the African continent (Begg, 1978; Cowan, 1993). Situated on the southern Maputaland coastal plain, the St Lucia wetland complex currently spans a length of ~58 km from 27° 45′S to 28° 23′S. The lake is compartmentalized into the North Lake (including Tewate Bay) with False Bay in the west and South Lake that includes Makakatana Bay or Catalina Bay (Fig. 1). The main water body extends over 42 km from the paludal "northeastern shallows" or "Selley's lakes" to South Lake. False Bay is ~16 km long by 2–4 km wide. The surface area and form of the shallow lakes changes according to water level and spits form constrictions along the shoreline that segment the wetland into several basins particularly during periods of low water level. The estuarine lake is subject to fluctuating water levels and salinities due to variable annual rainfall and inflow from the catchments feeding the lake (Kriel et al., 1966; Taylor, 2006, 2013), groundwater seepage that buffers the lake salinisation effect from evaporation during dry periods (Taylor et al., 2006) and marine inflow influenced by over 80 years of engineered management of the estuary mouth and link to the Mfolozi River.

Long-term lake level monitoring has revealed a fluctuation range from a maximum weekly average of 0.97 m to the minimum average level of −0.43 m relative to the estuary mean level which is +0.25 m relative to mean sea level (msl) (Kriel, 1965; Taylor, 1982a). The Indian Ocean high microtidal or low mesotidal range is at most 2.1 m at equinox spring tide near the estuary mouth (Connell and Porter, 2013) although very limited tidal influence occurs towards the upper section of "The Narrows" channel some 14 km from the sea (Taylor, 1982a; Wright, 1995).

The estuarine lake system has some 347 km of shorelines and is fed by five main rivers, the Mkhuze, Hluhluwe, Mzinene, Nyalazi and Mpate River catchments covering 7575 km^2, which contribute erratic seasonal runoff (Stretch and Maro, 2013). With the exception of the Mpate River, the rivers supply a high load of suspended silt and clay which flocculates when fresh river water mixes with the saline lake water. The shallow system has a large surface area to volume ratio and is sensitive to rainfall gains and evaporation losses (Perissinotto et al., 2013) which displace the lake shoreline laterally over considerable distances within the shallow lake basin. The estuarine lake level can rise by 1 m during floods when the area reaches 417 km^2, shrinking to just 225 km^2 during droughts (Fortuin, 1992) and losing 80% of its surface area during extreme conditions influenced by a combination of estuary mouth closure and the engineered separation of the Mfolozi River.

Prevailing winds with speeds greater than 4 ms^{-1} are predominantly from the northeast and southwest (Schoen et al., 2014) and create circulation patterns characterized by shallow water downwind jets along the shoreline and deeper water counter-flows interlinked by circulatory gyres. Northerly to northeasterly winds dominate the December wind rose while in July there is a bidirectional split between southerly and northerly winds. The southwesterly to southerly winds occur less frequently than the northerly winds but are stronger (Cooper et al., 2012; Stretch et al., 2013). The north-south lake axis parallels the prevailing winds (see wind rose in Fig. 1) which generate circulation and vigorous turbulence in the system. Wind-induced wave