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Review Article

Restoration of Lake St Lucia, the largest estuary in South Africa: historical perceptions, exploitation, management and recent policies

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Restoration of estuarine function to the Lake St Lucia system, the largest estuary in South Africa, was initiated in 2010. Significant change began with the reversal of a mouth management policy that was adopted in 1952 and maintained for the next 60 years, focusing on the separation of a major tributary, the uMfolozi River, from the rest of the estuary. This represented the loss of an essential source of fresh water, as well as the natural driving force in the breaching of the sand bar that develops across the mouth during low river flow periods. The desiccation of the estuary between 2003 and 2012 was unprecedented despite historical dry cycles during the past century. The devastating regional and national effects of this situation were instrumental in driving a reconsideration of the historic management policy. This paper focuses on the interactions between people and the estuary over the past century, management policies and actions, and the catastrophic loss of the largest estuary on the subcontinent. This was followed by a reassessment of management policies based on intensive studies and workshops, examining alternatives to historic policies, and extensive consultations with a plethora of interest groups that culminated in changing policy and the implementation of restoration actions.

Keywords: St Lucia lake, estuarine restoration, cyclones, sedimentation, estuarine fisheries, KwaZulu-Natal, iSimangaliso World Heritage Site

Introduction

A proposal for restoration of any ecosystem or particular environment presupposes that the system has been in some way anthropogenically degraded, whether deliberately, accidentally or even through well-intentioned management actions. Active restoration in turn implies a recognition, based on valid criteria, of an unnatural degraded state, the loss of a natural resource and the level of significance of such a loss on a regional, national and even global scale.

Lake St Lucia constitutes the central core component of the iSimangaliso World Heritage Site (IWHS) on the north-east coast of South Africa in the province of KwaZulu-Natal (KZN). It was the first such site in the country. The management responsibility for the Lake St Lucia Estuary Nature Reserve, originally fell under the provincial Natal Parks, Game and Fish Preservation Board (NPGFPB), subsequently the Natal Parks Board (NPB) and then Ezemvelo KZN Wildlife (EKZNW). Responsibility for the IWHS was finally conferred by government edict to the iSimangaliso Authority (the Authority), the management body established under the World Heritage Convention Act regulations. EKZNW retained the ecological management role along with their mandate as custodians of biodiversity in the province.

The Lake St Lucia estuary has historically supported the largest population of hippopotamus *Hippopotamus amphibius* (Taylor 2013a) and crocodiles *Crocodylus niloticus* (Combrink et al. 2013) in the country and is recognised as a Ramsar Site on the basis of its exceptional aquatic and wading bird habitat (Turpie et al. 2013). It has been a prime nursery habitat for estuarine-associated marine fish (Cyrus 2013), penaeid prawns (Forbes and Forbes 2013) and the mangrove crab *Scylla serrata* (Hill 1979). The historically unprecedented conversion of >80% of this estuarine habitat to a salt pan in the first decade of this century was the ultimate driving factor in the development of a programme to investigate how this situation might have have arisen and to develop possible remediation measures.

This review outlines the historical background, beginning in the first decade of the 20th century, and the past and future geomorphological processes that will ultimately determine the fate of this system. The circumstances driving the historic separate mouth policy and the efforts to maintain it are described along with the exploitation of the system's natural resources, the effects of a major cyclone and the circumstances and processes that finally resulted in the reversal of a 60-year-old environmental management policy. Where possible, conditions at the time of writing are summarised. It should be recognised that the broader restoration programme included major terrestrial components of the IWHS, although these are not dealt with

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in this review which focuses on the estuary as a central component of the IWHS.

This review paper focuses on the interactions between humans and the estuary, rather than the volume of published scientific literature (Whitfield and Baliwe 2013), which provided the information used in this review.

Geological history of the system

The position of the Lake St Lucia Estuary on the South African coast is shown in Figure 1. In a highly simplified sense, the present ecologically significant aspects of the geomorphological history of the system began after the last glacial period approximately 18 000 years BP, after which sea level showed a net rise from c. 100 m below present, stabilizing at the current level (Botha et al. 2013) approximately 5 000 years BP. During the glacial period, river scour generated a channel 40 m below the current bed level running north-east from Hell's Gates towards Leven Point and Leven Canyon (Figures 1 and 2), which has been argued to be a past link of the lake system with the sea (Sydow and van Heerden 1988). Subsequent closure of this link, coupled with the low lying local topography, which would have attenuated and reduced any scouring events potentially generated by the four northern riverine inputs, *viz.* the uMkhuze, uMzinene, iNyalazi and Hluhluwe, would have enhanced sediment deposition in the lake components of the system (Figure 2).

Figures quoted by Botha et al. (2013) refer to a possible maximum water area of 912 km^2, with an additional 253 km^2 in the current lower uMfolozi flood plain (Figure 2) giving a total area of 1 165 km^2. This water area has been reduced by sediment input over the past c. 5 000 years to c. 350 km^2 at a very crudely estimated net loss rate of 0.16 km^2 per annum. Botha et al. (2013) quote widely varying provincial catchment erosion rates in modern times of 12–30 times greater than geologically long-term rates. Depending on which are used, these would have the system being converted to a wetland within 150 to 2 000 years, presumably also depending on the effects of climate change and sea level rise. Note that Figures 1 and 2 include the boundary of the Estuarine Functional Zone (EFZ) defined as the 5 m above mean sea level contour.

The loss of the strong marine link referred to above (Sydow and van Heerden 1988) would arguably have changed the geological evolution of the St Lucia system and resulted in the reduction of estuarine functioning in terms of marine influence and migratory biotic components. This function was, however, maintained by the presence of the low-lying area to the south of the lake component, through a channel now referred to as the Narrows, which allowed a link with the uMfolozi River (Figure 2). This rendered the river an integral part of the Lake St Lucia Estuary, because it critically maintained an intermittently open link with the sea through the coastal dune cordon by virtue of its catchment size and flow magnitude. A comparable closure process occurred in the case of Lake Sibaya (Allanson et al. 1966) north of the St Lucia system (Figure 1). Based on the invertebrate and teleost fauna, this now fresh water coastal lake can arguably more accurately be considered a relict estuary. Riverine inflow is minimal and accordingly, following closure c. 3 000 years BP, there was no mechanism available to breach the bar and sand accumulation allowed the development of the current high, forested dune cordon.

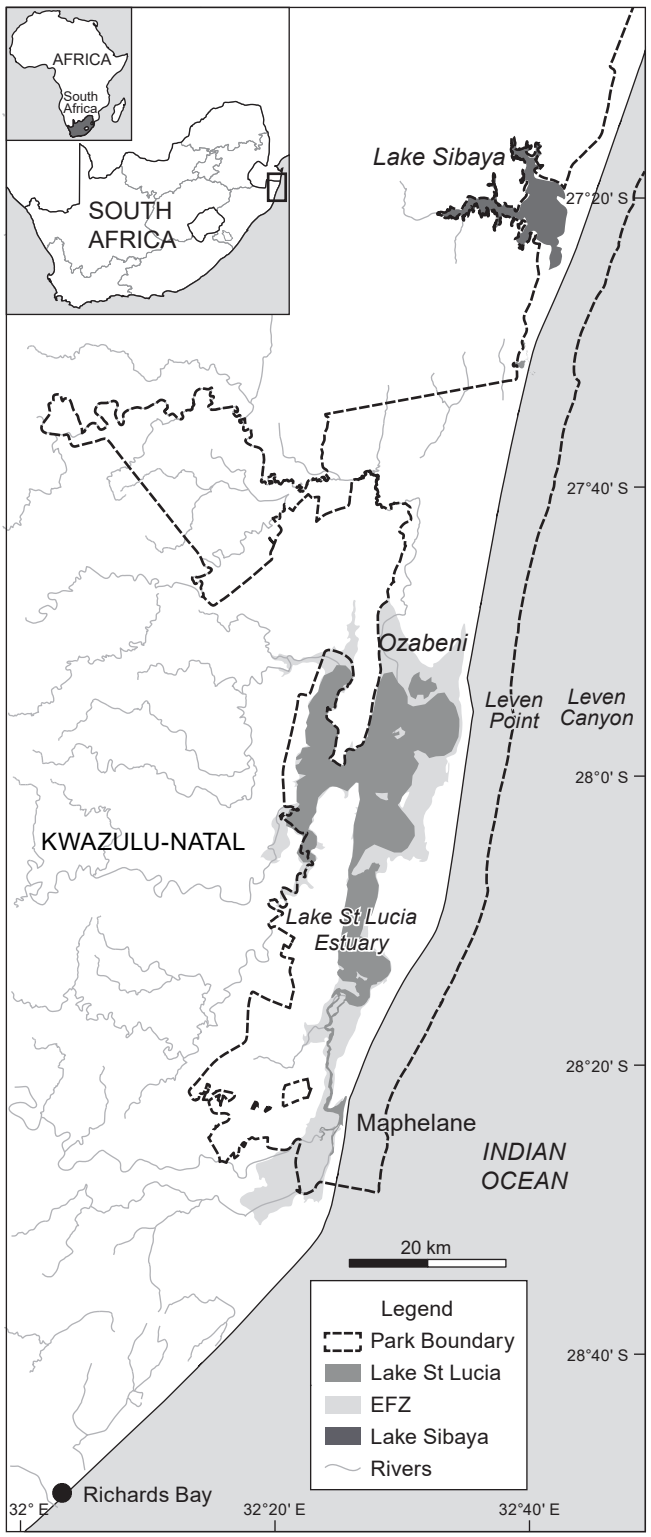

Figure 1: Position of Lake St Lucia Estuary on the north-east coast of South Africa with the major coastal landmarks

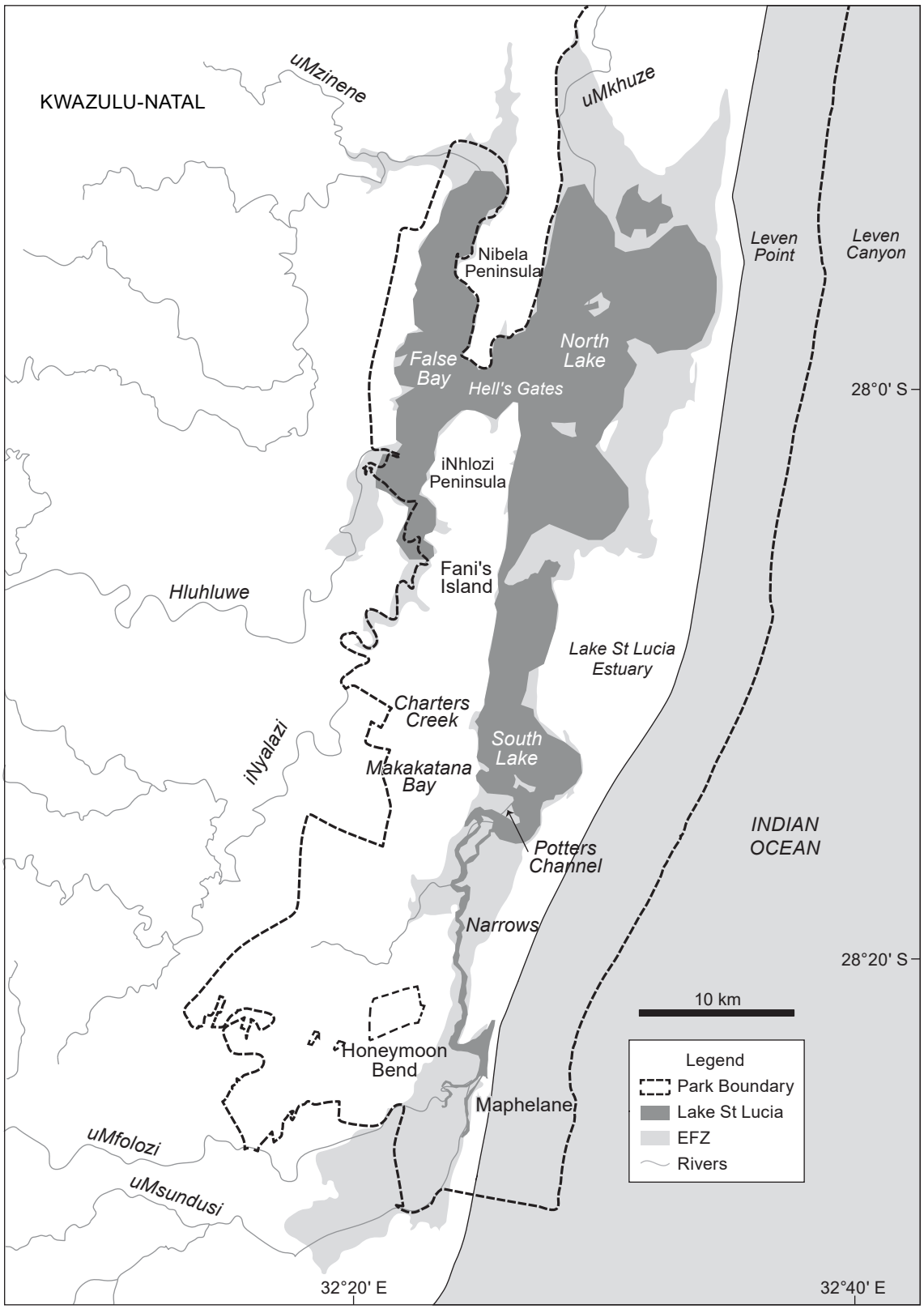

Figure 2: The Lake St Lucia Estuary showing the different components and tributary rivers. The pale grey shading indicates the area below the 5 m above mean sea level contour, conventionally referred to as the Estuarine Functional Zone (EFZ) and demarcating the maximum area subject to inundation during closed-mouth conditions

Human activities, management and policies

History and hunting

Human activities in northern KwaZulu-Natal and the current IWHS provide good examples of the first in a series of changing zeitgeists. A wide-ranging survey of activities beginning with Stone Age man and ending with scientific surveys is provided by Bruton et al. (1980). The original people occupying these areas would have had some environmental impact, but much lower population densities and less technology would have limited these effects. The arrival of European settlers was associated with indiscriminate hunting in the late 1800s, which resulted in legislation to regulate this activity in the 1890s (Porter 2013). It was recognised that areas where no hunting was allowed were required to allow game populations to recover. These efforts began in 1895 and continued in the following decades to include the St Lucia Bird Sanctuary that covered the lake and the eastern shores. These represent the oldest game reserves on the African continent.

The discovery in 1890 that trypanosomiasis was transmitted by the blood sucking tsetse fly *Glossina* sp., which was naturally dependent on wild animals, generated a demand that game be exterminated in order to control the fly. This resulted in a policy of mass extermination of game in areas under the control of the Veterinary Department, including the reserves that were de-proclaimed to carry out the eradication, with the exception of Hluhluwe Game Reserve (Porter 2013). Eventually public concern over the slaughter of the game and the fate of the reserves resulted in the slow reproclamation of reserves although not always in their original form. It is highly significant that a major activity undertaken by the iSimangaliso Authority was to reestablish all the game species that had historically occurred in areas under their control. This process has operated over the past 20 years and it is anticipated to end with the planned introduction of eland *Tragelaphus oryx,* although to date no schedule for the latter has been set.

Flood plains and sugar

The uMfolozi floodplain (Figure 2) was opened up for sugar cane farming in either 1911 (Taylor 2013b) or 1927 (Porter 2013). The former date is the more likely, because Taylor (2013b) refers to major floods in 1918 and 1925 that damaged the cane fields. The area under cane has progressively expanded to now cover c. 9 000 ha. This development required major physical modifications of the flood plain, the installation of drainage canals and the construction of levees that confine the flows to the stabilised uMfolozi and uMsunduzi River courses. The current system incorporates a bypass built into the uMfolozi levees that allows a proportion of high flows to be diverted southwards to the Msunduzi River (Figures 2 and 3).

Mouth dynamics, separation and sediments

Possibly the first focused investigation of the mouth area was carried out by Crofts (1905) during his survey of possible harbour sites, with St Lucia being rejected because of system shallowness. Crofts' survey map confirmed that under natural conditions the uMfolozi River and the St Lucia Narrows (Figures 2 and 3) shared a common mouth and

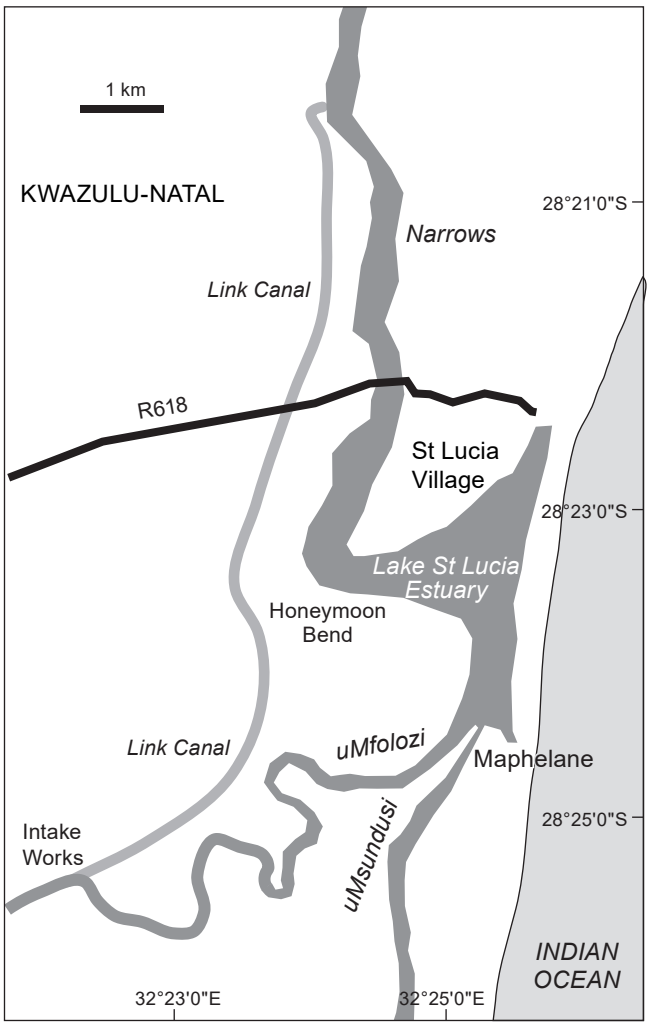

Figure 3: The Lower Narrows and common mouth area of the Lake St Lucia Estuary, uMfolozi and uMsunduzi rivers showing the position of the intake works on the uMfolozi River and the dredged Link Canal between the intake works and the junction with the Narrows. The R618 is the only road access to St Lucia village

thereby became interacting components of the same greater system. An open mouth did not occupy a permanent position on the beach between Maphelane (Figures 2 and 3) and the high ground on the northern bank, but tended to migrate northwards under the influence of wave action and longshore sediment drift. Following closure, which would be followed by rising water levels upstream of the bar, natural breaching could occur anywhere along the 2.5 km stretch of beach, depending on the position of lower lying areas on the bar or the focus of flood impacts arising from the uMfolozi River.

An obvious question arising from the above points regarding mouth migration and closure is the issue of the length of time that the mouth remained open or closed. Mouth closure and artificial breaching constitutes a major management issue and results in sustained local pressure to breach the bar, because an open mouth is seen as a panacea for fishing problems and the alleviation of flooding

of cane fields or banana plantations. The latter were established in the lower reaches of the uMfolozi flood plain inside the IWHS boundaries (Figure 2) during the separate mouth policy regime.

In the situation of very scanty records prior to the 1930s, which simply recorded an open or closed condition, it is nevertheless possible to draw some conclusions based on the biota of the system. The likelihood of past biologically significant periods of closure is indicated by two factors. The first is the historical vegetation survey (Kriel Commission 1966), which indicated a very limited mangrove area, in the context of the size of the estuary, near Honeymoon Bend (Figures 2 and 3). Mangroves occupy an intertidal environment and do not survive for any length of time in estuaries that have a regular closing and back-flooding regime. Exceptionally high tides or flood conditions can transport mangrove propagules to supra-tidal levels where they may germinate and survive. Such a situation is however not indicative of a permanent tidal habitat. The current relatively extensive occurrence of mangroves in the Narrows and lower uMfolozi River can be attributed to the adequate maintenance, from a mangrove tree perspective, of a tidal environment during artificially maintained open mouth conditions.

The second indication of regular and/or extended closure is the absence of any records of the burrowing crustacean *Upogebia (Gebia) africana*, which occurs in estuaries to the north and south of St Lucia. *U. africana* has a marine larval phase and is typically absent from predominantly closed systems where mouth closure disrupts both emigration from the estuary to the sea and return immigration of larvae. The actual recorded disappearance of a species with a similar life style during extensive closed-mouth conditions is provided by the ocypodid crab *Paratylodiplax blephariskios,* which was the major component of the invertebrate macrobenthos in the Narrows and the subject of several papers (Owen et al. 2000: Owen and Forbes 1997, 2002). This species disappeared from the Narrows after 2003, following an extended period of mouth closure. The dependence of the crab on a marine larval phase has been demonstrated by Papadopolous et al. (2002). Admittedly these details do not demonstrate conclusive duration times, but allowing for below average rainfall periods of three to possibly five years, it could arguably be expected that these would correspond with periods of closure, whereas a similar argument could be extended to estimate open mouth durations.

Rising water levels behind the bar would have progressively flooded lower lying areas on the uMfolozi flood plain, including any cultivated areas. This would have generated pressure to artificially breach the bar, an activity that appears to have developed in the 1930s, and would have become more frequently required, because cultivation extended further into progressively lower lying areas on the flood plain.

The assumption then developed that the canalised uMfolozi River flood plain had lost a sediment absorption capacity because of the removal and draining of wetlands for sugar cane cultivation. The combination of a closed common mouth and a link between the uMfolozi and the lower Narrows would therefore result in sediments eroded from the uMfolozi catchment being deposited in the mouth area and lower Narrows of the Lake St Lucia estuary. It is significant that multiple studies have indicated increased catchment anthropogenic erosion rates virtually throughout the country so there was arguably justification for concern.

The above concerns generated the separate mouth policy in the early 1950s, which in practice resulted in ongoing engineering activity over the next 60 years. These arose from the behaviour of the uMfolozi mouth and the realisation that estuarine function in the St Lucia system depended on at least periodic links with the sea, in order to allow migration of estuarine dependent migrant marine fish and invertebrates, such as the penaeid prawns.

The uMfolozi mouth problem, as far as the separate mouth policy was concerned, arose from the fact that it tended to migrate northwards due to the wave approach angle, erosion of the north bank of the mouth during both flood and ebb tides and longshore sand drift. This meant that it would naturally relink with the Lake St Lucia Estuary at the lower Narrows, and if the mouth then closed the perceived sediment problem would reappear. In order to prevent such an occurrence, repeated breaching of the bar at its southern end was carried out and dredge spoil and earth moving equipment were used to construct barriers between the uMfolozi River and the Lake St Lucia Estuary.

The separate mouth policy required substantial and repeated breaching of the sand bar, which appears to have first occurred in 1932, and then consistently from the early 1950s through to November 2011. At that time a directive from the Department of Water Affairs and Sanitation (DWS) arising from a request by the farmers on the floodplain, required the Autthority to carry out a breach because of back-flooding into the cane fields. Significantly this was the last artificial breach to occur.

The still unending perception of a sediment problem 50 years after it was originally raised is summarised in the following recent statement regarding sediments in the mouth and lower Narrows, ‘the fine component, i.e. the clay and silt, is much more evident to the public. Hence the perception is that the uMfolozi sediment was much more important than the marine sediments. Conceptually, the sediments of the mouth area were periodically flushed from the system during a mega-flood, or even more so during a breaching event. The situation where the uMfolozi diverts naturally into St Lucia will occur more frequently than in the past and, because it is unlikely that the public will tolerate a large rise in the water level behind the beach berm, so artificial breaching at a specified level is inevitable’ (Taylor 2013b).

These perceptions, which had been significant in generating repeated breaching and the separate mouth policy of 1952, set the system on a trajectory towards the unprecedented drying up of the lake component in the first decade of this century, the collapse of the Tugela Bank prawn fishery (Forbes and Forbes 2013) and the inferred decline of estuarine dependent marine fish species along the northern KZN coast, which could be extrapolated from the study on tropical stumpnose *Rhabdosargus sarba* (Mann and Pradervand 2007). It also set the Authority, in ultimate charge of the IWHS, on a legal path *via* the High Court in Durban culminating in a successful case at the South African Supreme Court of Appeal in Bloemfontein

where the claimed right of the farmers to artificially breach the sand bar at the mouth in order to prevent back-flooding of the sugar cane fields was finally rejected. This rendered illegal an activity that had been customary for decades and to a large extent still occurs in temporarily closed estuaries along the KZN coastline.

A significant component of the dredging and breaching activities was the co-operation between the St Lucia conservation and management authorities, whether the NPGFB, the NPB or EKZNW, whose mandate throughout this history was the maintenance of biodiversity in the province, and the uMfolozi Co-operative Sugar Producers (UCOSP) who were in charge of the management of the infra-structure on the uMfolozi flood plain, i.e. roads, tracks and drainage canals. The separate mouth policy allowed UCOSP to effectively manage the isolated uMfolozi mouth to the benefit of the cane farms, because any closure of the mouth and subsequent back flow into the cane fields could be rapidly dealt with by breaching of the bar.

Over time, breaching became progressively more critical and frequent because of subsidence in the lower reaches of the flood plain (van Heerden 2011) arising from the drainage programme and the drying out of the floodplain soils. One way valves were installed in the drainage canals to prevent the ingress of tidally driven water with the result that the drainage system in the lower reaches of the flood plain only functioned when there was a combination of an isolated open uMfolozi mouth and low tide conditions.

If the mouth remained open its northward migration would begin and ultimately the whole management process would be repeated. Little thought appeared to have been given to the reality that the mouth management policy as then enacted would require physical intervention in perpetuity. A further significant upshot of the 50-year duration of the separate mouth policy was that a perception developed over time that the uMfolozi River was not actually a highly significant and functional component of the St Lucia estuarine system. This misconception generated significant problems in relation to environmental flow determinations for the St Lucia system because of a tendency to treat the uMfolozi as a separate entity (DWAF 2004).

The Kriel Commission – does the system have a problem?

The Kriel Commission of 1964 to 1966 was convened to assess 'the alleged threat to animal and plant life in St Lucia Lake'. This encyclopaedic document was produced at the time by a panel of seven acknowledged authorities in their respective fields, including zoology, botany, engineering, agriculture and nature conservation, and culminated in a set of recommendations to address the 'alleged threats'. Porter (2013) bemoaned the fact that none of the recommendations was implemented and in fact, in the case of forestry, a recommendation for reduced activity was actually followed by expansion that was 'aggressively implemented after 1968'. It is a remarkable irony that recommendations by the Commission, including clear demarcation and fencing of the Conservation Area, ultimate removal of forestry plantations, improved visitor facilities and restocking with historically occurring game such that the 'St Lucia Lake area should represent a vignette of the original wild life of Zululand' would take more than 50 years before being implemented by the iSimangaliso Authority.

St Lucia and the South African Defence Force (SADF)

In retrospect, a highly unusual situation in an ostensibly protected area arose in 1968, when the then SADF developed a missile testing base on the northern end of the iNhlozi Peninsula overlooking Hell's Gates (Figure 2), from which missiles were fired in a north-easterly direction, landing either in the lake or what is now the Ozabeni area (Figure 1). People had previously been evicted from this area, but it is not clear whether this was part of the missile programme or whether it was simply a case of the use of a conveniently depopulated area. The base was little used after 2000 and the iNhlozi peninsula was subsequently incorporated into the IWHS.

The engineering era

The period between the early 50s and Cyclone Domoina in 1984, which will be discussed later, was one of major engineering in the mouth area, the 20 km of the Narrows between the mouth and South Lake and the dredging of a Link Canal between the southern Narrows and the uMfolozi River (Figures 2 and 3). This period can only be described as an era when finances were available and there was the implicit assumption that the system was understood and could be physically managed and maintained in some sort of ideal condition, or at least within tolerable limits for the estuarine biota. The management action involved extensive dredging operations, initially in the mouth area, but these were subsequently extended to include the entire Narrows as far as Makakatana Bay, where the final piece of dredging involved the excavation of Potter's Channel through an area of dry land (Figure 2). Dredge spoil was deposited on the banks where it formed levees, covered intertidal areas, modified drainage patterns and changed salinity conditions in fringing wetlands.

A management committee in the late 1950s (Taylor 2013b) considered two questions. Would the isolated St Lucia mouth remain open without the influence of the uMfolozi River? Secondly, without the uMfolozi input, would the salinity in the lake during low rainfall periods rise to a level harmful to the biota? The answer to the first question was unequivocally 'no', whereas the second was initially answered by the work of Boltt (1975) who showed that the salinities in North Lake and False Bay (Figure 2) during a period of low rainfall in the late 1960s rose above the tolerance levels of most macrobenthic invertebrates, which appeared to be a salinity of c. 50. The final conclusive answer to the second question occurred in the first decade of this century when for the first time in recorded history the lakes component of the system effectively dried up and salinities, where it was possible to access and sample any remaining water bodies, reached 300 in places.

The contrast between the situation encountered by Boltt (1975), when the system held water, and the situation between 2003 and 2010, when the lakes dried up, can be explained by the mouth management and separate mouth policies. Both were periods of below average rainfall, in the latter case characterised as 'severe droughts' (Bate and

Smailes 2008, Bate and Taylor 2008). By the late 1960s, the isolated St Lucia mouth was being maintained in an open state by a combination of retaining walls, dolosse and active dredging to remove incoming marine sediments. This allowed sea water to enter the system and maintain water levels in the lake that compensated for water lost through evaporation. This generated a reversed salinity gradient between 1969 and 1971, with salinities of c. 50 in South Lake rising to 80 to 90, in North Lake and False Bay (Boltt 1975) (Figure 2). Further increases in salinity were reversed by above average rainfall in the mid-1970s, which generated oligohaline water conditions in some parts of the lake system.

Prior to the increased rainfall in the mid-1970s and during the then unprecedented high salinity levels, particularly in North Lake and False Bay, attention shifted towards the uMkhuze River as a source of fresh water that would obviously mitigate the situation in North Lake (Figure 2). Salinities during this period remained at tolerable levels in the Narrows and South Lake because of the continual inflow of seawater via the then stabilised and open mouth. One approach to the salinity 'problem' appeared to view the uMkhuze swamps and pans adjacent to the lower uMkhuze river as competitors with the lake for a fresh water supply. Arising out of this was the idea that water in the uMkhuze River could be short-circuited into North Lake. In the apparent absence of knowledge of gradients in the area and the potential effects of water flows during average or above average flow levels, a 13.5 km channel was excavated in 1971 (Taylor 2013b) and rapidly became the focus of erosion, exacerbated by a further upstream, excavated channel on agricultural land, with the ultimate effect of irreversibly draining at least one pan and part of the swamps. Repeated attempts at rehabilitation of these areas have not been successful.

In contrast to the above, the mouth situation between 2003 and 2010 was completely different, with the training walls and dolosse at the mouth having been removed by the Domoina floods of 1984 and the mouth being predominantly closed. In the absence of any substantial input from the northern tributaries to the lakes during this dry period, and the isolation of the uMfolozi River from the St Lucia Estuary, there was little freshwater input and the lakes predictably dried up.

The requirement for a consistent supply of fresh water to the system had been recognised following the first hypersaline period in the late 1960s, as described above and, apart from the artificial uMkhuze channel, various options were considered with the choice eventually settling on a Link Canal that would bring water from the uMfolozi River. Planning began in 1975 and involved an intake works on the uMfolozi 9 km upstream from the mouth (Figure 3). It was designed to accept an inflow during intermediate river flows and to shut off during floods when it was assumed that the water would have an unacceptably high silt load. A 12 km channel from the uMfolozi River was then dredged and entered the Narrows 8 km from the mouth, although the intention was that the canal would later be extended to Makakatana Bay (Taylor 2013b) (Figures 2 and 3). A further intention was that a stilling basin would be constructed as part of the Canal immediately downstream of the intake works in order to prevent or at least slow the transport of sediments into the Narrows.

The Link Canal was successfully dredged, starting from two points on the Narrows above and below the R618 access road virtually to the intake works, but at this point boulder beds were discovered in the proposed stilling basin area and the operation ground to a halt. No consideration appeared to have been given to the question as to how any silt settling in the stilling basin would be dealt with and the operation was effectively terminated by the cyclone Domoina floods of January 1984 that totally submerged the intake works. These events also terminated a year-long monitoring programme that had been initiated at the junction of the Narrows and the Link Canal (Figure 3) in January 1983 to provide reference and background information on possible impacts of the uMfolozi water on the Narrows environment. The proposed extension to Makakatana Bay was never completed and the anticipated role of the Link Canal in restoring a fresh water supply to the Lake St Lucia system never materialised.

Cyclones - what about the future?

Cyclone Domoina, which struck the system in January 1984, followed by Cyclone Imboa a few weeks later, provided a nodal point in the history of the system and the attitudes towards physical management. Damage was effectively suffered by man-made infrastructure and equipment rather than the natural system, as shown by the loss of Reno mattresses used for bank stabilisation below Honeymoon Bend, as well as the removal of roads and hard structures as far as the mouth, and the loss of a dredger. The floods also effectively put an end to any consideration of the proposal for a marina in the area between St Lucia village and the Maphelane campsite (Figure 3).

The cyclone had other management implications in that it forced a greater appreciation of the magnitude of natural events and the essentially short term nature of any anthropogenic, physical environmental modification that could be summarily removed by events, such as cyclones. Ultimately this realisation appeared to diminish and the urge to manage reappeared although in a reduced fashion from that which characterised the 1950s and 1960s.

The forecasts for a future cyclone regime are equivocal. According to Malherbe et al. (2013) the projection for the latter half of the 21st century is for a decrease in cyclones in the southwest Indian Ocean, as well as a northward shift in landfall positions over the south-east African region. In contrast, according to Aramuge et al. (2014) cyclones off Madagascar and Mozambique are becoming more frequent and more intense, with greater southerly penetration. The most recent work (Fitchett 2018) argues that Category 5 tropical cyclones, the strongest category of storms, have only recently emerged in the south Indian Ocean and have increased in frequency since 1989. A very real possibility of greater southward extension of cyclones exists because of the measured poleward migration of sea surface isotherms. The arguments put forward in the latter two papers would arguably be borne out by the recent wide spread devastation wrought by Cyclones Idai and Kenneth in early 2019 in Mozambique, Zimbabwe and Malawi.

Dune mining

Prospecting by the mining company Richards Bay Minerals in the dune cordon between St Lucia village and the Leven Point area (Figure 2) in the early 1970s indicated further deposits of the heavy minerals, which the company had already been mining during the previous decades in the dunes south of St Lucia between Richards Bay and Maphelane (Figure 1). In 1989, the company applied for a mining licence. The real impact of the mining operation in terms of the nature and appearance of an operational area, as well as the movement of the large trucks used in the transport of the raw ore to smelters, would have been highly apparent from the existing mining activities to the south of Maphelane. The potential day and night movement of large trucks from the proposed mining area, past St Lucia village and on to the Richards Bay smelters obviously presented major traffic and environmental issues. In addition, dune mining, as performed by the above company, is a highly water intensive operation and concern was strongly expressed regarding implications for the estuary.

After intensive lobbying for several years by a variety of concerned individuals under the banner of the Save St Lucia Campaign, with an emphasis on major petitions regarding St Lucia's 'sense of place' for people of the country, a Cabinet decision to disallow mining was taken in March 1996 (Porter 2013). A comparable threat is again arising with the application to mine the Buffer Zone between the northern boundary of the Richards Bay Minerals lease and the southern boundary of the iSimangaliso WP.

Exploitation of natural resources

Penaeid prawns and the bait fishery

The bait prawn fishery of the St Lucia system, based predominantly on the white or Tugela prawn *Penaeus indicus*, followed in much smaller numbers by the tiger prawn *P. monodon* and speckled prawn *Metapenaeus monoceros*, was historically an integral component of the recreational and economic structure of St Lucia village (Forbes and Forbes 2013). The fishery was operated by the NPB from c. 1952 until its closure in 1996. It was apparently preceded by small scale commercial operations before World War 2, but subsequently taken over by the NPB, which allowed a level of control, because no private collection was allowed. Poaching has however been a permanent feature arising out of the high value of this resource. The official fishery was predicated on the fact that St Lucia was for decades a prime national recreational fishing destination and fishing and associated activities dominated the village activities.

The significance and management of the prawn fishery was, however, lost to management. Effort was limited to three aluminium dinghies, as described by Forbes and Forbes (2013) and 25–30 hp outboard engines pulling 'gate nets'. Treatment of the catch was rudimentary, resulting in a poor-quality end product, but demand remained because anecdotal custom maintained that in order to catch fish in the St Lucia system, St Lucia prawns are desired for bait. Supervision of the overall operation was low on the management importance scale, often being given to the newest recruit to the station and it was no surprise that a management decision to stop the fishery was taken in the mid-1990s (Anon 1996) and summarised in the following statement: 'Shrimping has been low for a number of years and staff decided at the meeting to stop the shrimping operation. It was felt that there is not enough information available regarding what effect the shrimping operation has had on this resource.' The quote appears to relate to concern for the shrimping impact on the stock and constitutes a surprising statement from a conservation mandated organisation that operated the fishery for more than 50 years. Studies by Mann (1995a) on the bait fishery bycatch of juvenile fish between August 1992 and September 1993 found that the bycatch averaged 4.64 ± 6.22% of the total catch by mass and concluded that 'prawn trawling (is) not believed to be a major threat to the fish populations in the St Lucia system'. Bycatch in any fishery is however always a controversial issue and it is arguable that this was a factor in the abandonment of the bait fishery.

Fisheries

Recreational fishing has historically been limited to a demarcated area covering approximately the southern one third of the Narrows, South Lake from Makakatana Bay to Fani's Island and then north in a strip fringing the eastern shore of the iNhlozi peninsula through to the whole of False Bay (Mann et al. 2002; Cyrus 2013) (Figure 2) The historical image and significance of the St Lucia system and St Lucia village as a fisher's paradise and the importance of angling in the village economy was well illustrated by van der Elst (1978) in his review of the sport fishery over the years 1956 to 1976. This coincided with a period of major engineering activity involving consolidation of the separate mouth policy, stabilisation of what became the St Lucia mouth and dredging of the Narrows as far as Makakatana Bay (Figure 2). It also covered the first recorded hypersaline period in the late 1960s and early 1970s (Boltt 1975) when salinities in North Lake and False Bay (Figure 2) exceeded the tolerance levels of the benthic macroinvertebrate fauna.

The van der Elst (1978) analysis described a period of increasing angling pressure, particularly between 1966 and 1976, when annual visitor nights increased six-fold from 50 000 to 300 000 and annual prawn bait sales increased 10-fold from c. R6 000 to R60 000. The first kilometre of the then isolated St Lucia mouth with its concrete walls on the north bank was the most easily accessed section of the Narrows and also the entry and exit point for any migratory fish, as well as opportunistic marine species including sharks. The attraction of this section as far back as the 1940s when anglers annually caught 'tons of fish' was emphasised by van der Elst (1978) and further emphasised by the direct observation that 'up to 400 anglers were recorded over a distance of 500 metres'.

The analysis also refers to 'experienced shark anglers having recently concentrated their efforts at St Lucia in view of the paucity of large sharks elsewhere along the Natal coast'. From a timing point of view this latter situation coincided with the cessation of whaling off the KZN coast and the attraction of large sharks to the city of Durban whaling station south of St Lucia, as well as a steep decline in the catch of sharks per net, over the period 1966 to 1975 (Branch and Branch 1981). Shark nets had been extensively deployed along the KZN coast following attacks

on bathers. In any other situation, the decline in catch per unit effort (CPUE) would have been an immediate indication of a collapsing fishery. In this case it would have been seen as a successful method of minimising contacts between bathers and sharks. Shark nets have never been installed off the St Lucia beaches.

The above analysis of the St Lucia sport fishery was followed some 25 years later by Mann et al. (2002). The older study was based on a 21-year catch analysis of data generated during fishing competitions from 1956 to 1976 and recorded by the Natal Coast Anglers Union. These allowed CPUE data to be collected and used for quantitative catch analyses. The more recent study followed some 10 years later and was based largely on catch card data collected between 1986 and 1999, supplemented by information on boat outings using trailer counts at slipways, numbers of boats entering campsite gates, hire boat outings at St Lucia village and direct interviews with anglers. The earlier study produced 14 species of elasmobranchs and 45 teleosts, whereas the subsequent study produced eight elasmobranchs and 55 teleost species. In combination the two studies produced 17 elasmobranchs and c. 64 teleost species.

The above two papers, despite having been produced nearly 25 years apart with a gap of nearly 10 years between the end of the one data set and the start of the next, as well as very different techniques in terms of data collection, indicated a similar species composition in the catches. These were dominated by dusky kob *Argyrosomus japonicus,* grunter *Pomadasys* spp., (predominantly spotted grunter *P. commersonnii*), perch *Acanthopagrus vagus,* stumpnose *Rhabdosargus* spp. (mainly tropical stumpnose *R. sarba*), springer *Elops machnata* and mini-kob *Johnius dorsalis.* Between 1986 and 1999, dusky kob and grunter constituted 50% of the catch by number and 82% by mass. It is worthwhile noting however that these are all recreational target species taken on rod and line.

Based on gill net sampling during 1969 and 1970 (van der Elst 1978), during which 20 taxa were collected, the most common species was spotted grunter *P. commersonii* followed by unidentified Mugilidae, both of which were double the mass of the third species, the dusky kob *Argyrosomus japonicus,* and four to five times more common than the remaining 17 species. Recreational catches therefore allowed an assessment of the status of those species that take a bait, but gave no indication of the broader picture of the fish species in the system, a situation reflecting the main interests of the average visitor to St Lucia at the time.

Both the above studies produced some catch trends in the major species taken. Between 1956 and 1976, the total teleost catch per 100 angling hours averaged c. 50 kg. The average annual individual mass of spotted grunter *P. commersonnii* dropped from c. 1.8 to 0.8 kg, although there was no corresponding trend in the CPUE. Average perch *A. vagus* mass declined over the same period from an annual average of c. 0.8 to 0.4 kg. The CPUE (catch per 100 angling hours) between 1956 and 1963 was between six and 40 in all years (except for 1958), but less than three between 1964 and 1977. Tropical stumpnose *R. sarba* average annual mass per fish dropped from c.1.5 to 0.7 kg and the CPUE from 10 to 13 to less than three. In contrast the average annual mass per dusky kob *A. japonicus* increased from c. 1.5 to 3 kg although there was no trend in the CPUE.

It is an intriguing point that the van der Elst (1978) data were based on information obtained from angling competitions in a proclaimed nature reserve. The later study, described below, although still fishery orientated, collected data in a very different manner. It is tempting to conclude that this reflects again a changing attitude to what constitutes ethical behaviour in a protected area when it comes to exploitation of natural resources. Perhaps the next step is to provide complete protection for this valuable estuary-associated fish nursery area, an action that will improve the contribution made by the estuary coupled with the MPA to the coastal resources along the entire south-east African coast.

The review by Mann et al. (2002) recorded a CPUE for the whole system between 1986 and 1999 of 0.28 kg angler h^{-1}, which approximates to 28 kg 100 angling h^{-1}, the metric used by van der Elst (1978), who recorded 50 kg 100 angling h^{-1}. It is tempting to draw conclusions of declining stocks, but there is also the possibility of the relative skill of competition anglers versus occasional visitors. CPUE increased during lower salinity (<10) periods between 1987 and 1991 and again between 1995 and 1999. Overall CPUE declined for dusky kob *A. japonicus* and spotted grunter *P. commersonnii*, but increased for estuarine perch *A. vagus*, tropical stumpnose *R. sarba* and springer *E. machnata.*

In contrast to the earlier fisheries review, where the topic was not mentioned, there was an expressed concern regarding overfishing and stock collapse by Mann et al. (2002). The latter review incorporated the results of interviews with anglers, during which it was established that more than 90% of interviewees agreed with size limits, closed seasons and closed areas although the figure supporting bag limits dropped to 83%. More or less inevitably, 85% said fishing had deteriorated because of mouth closure, overfishing and trawling. In view of the national collapse of dusky kob *A. japonicus* stocks, as well as the targeting of this species in the St Lucia system, the review also counselled caution in relation to any expansion of facilities or developments that might increase fishing pressure.

Anecdotal evidence (A.T. Forbes unpublished) indicated that any relationship between accommodation used and fishing pressure could be tenuous because it was not unknown for short-term anglers to overnight on their boats because daily bag limits were based on 24-hour periods between midnight to the next midnight. Consequently, fish caught before midnight could be added to these taken after midnight and the angler would therefore benefit from a two-day limit, although only fishing for possibly 12 hours.

Both van der Elst (1978) and Mann et al. (2002) referred to a Natal Town and Regional Planning document (van Zyl 1973) expressing concern for the economic future of St Lucia village due to its ‘mono-recreational attraction’, i.e. fishing, which was based on the correlation between accommodation utilised and the productivity of the fishery. Seemingly the local tourist industry ‘suffered severe

setbacks' 'during periods of mouth closure or hypersalinity' when the village became 'a virtual ghost town'. In support of the contribution by angling to the St Lucia village economy, Mann et al. (2002) quoted figures of 583 270 occupied bed nights at St Lucia during 1991 and an estimated 15 000 anglers annually. Visitors paid R1.5 million for the use of KZN Wildlife accommodation in 1991, and c. R16.9 million to private accommodation providers, of which R8.3 million were derived from anglers.

A degree of farsightedness was, however, exhibited in a later review (Mann et al. 2002) in that there is reference to a 'diversification of available activities' and 'the proclamation of the Greater St Lucia Wetland Park as a World Heritage Site and a likely change in the visitor profile with a greater number of international tourists whose interests will probably be in viewing the landscapes and biodiversity of the area rather than angling *per se*'.

At the time of writing virtually all the above information regarding historical recreational fishing activity amounted to no more than nostalgic recollections. In 2003, the combination of a succession of dry years, the closed mouth and the long-standing removal of the uMfolozi River as a freshwater source resulted in the unprecedented drying up of the lake component of the estuary with the total loss of the fish resource. The relinkage of the uMfolozi River with the Lake St Lucia Estuary in 2012 restored a water supply to the system and provided a habitat for hippopotamus and crocodiles, but did not restore full estuarine function. A limited and tenuous open mouth period between September 2012 and October 2014 allowed a low level of exchange between the sea and the estuary, but closure since October 2014 has resulted in an almost complete absence of marine migrants and the dominance of the fish community by two freshwater fish species, the sharp-tooth catfish *Clarias gariepinus* and Mozambique tilapia *Oreochromis mossambicus.*

Gill netting

Illegal gill netting has been a feature of the system for the last 60 years, despite long standing control attempts. An estimated annual average of 8 000 m of nets was recovered by anti-netting patrols between 1987 and 1992 and the catch in 1992 was estimated at between 91 and 135 tonnes (Mann 1995b). As a result it was suggested, possibly naively, that a legalised subsistence gill net fishery should be implemented. This was set up in 1995, but initial monitoring suggested that the unexpectedly high proportion of recreational species typically caught by rod and line anglers could lead to conflict between the two user groups (Mann 1996). In a subsequent review Mann (2003) concluded that the objective of developing a sustainable subsistence fishery for the benefit of rural communities had morphed into a commercial enterprise where the objective was to maximise the profits of the fishery. Concerns for the sustainability of the resource resulted in a recommendation that the fishery be terminated and it was subsequently closed down. The closure was, however, only on paper and personal observations during 2017 to 2019 indicated that gill netting was still occurring in the lower and upper Narrows in areas not visited by tour boats, as well as in North Lake off the Nibela peninsula (Figure 2).

World Heritage Site status

Initiatives to have the Greater St Lucia Wetland Park (GSLWP) obtain World Heritage Site (WHS) status began during the years when the threat of dune mining on the Eastern Shores was being resisted. WHS status requires various criteria to be met and the GSLWP met three of these, which meant it was well qualified to obtain full status. This it did in 1999, becoming the first WHS in the country. The three criteria were that the system would have to demonstrate 'superlative natural phenomena and scenic beauty', 'ongoing ecological and physical processes' and the presence of 'biodiversity and threatened species'.

A highly significant point in the above context was that the estuary with its natural cycling from a fresh water to a marine dominated system, depending on the rainfall pattern, formed the central core of the WHS. It consequently became an imperative that this component of the GSLWP be afforded the utmost protection and that it also become a prime target of the restoration programme. It is worth noting that conditions in any estuarine system are significantly determined by events in catchment areas well beyond the typical estuarine boundaries, by marine processes and the vagaries of weather conditions, all of which are either impossible or very difficult to control or regulate.

A corollary of the granting of WHS status in 1999 was the gazetted establishment of the iSimangaliso Wetland Park as a WHS under the World Heritage Convention Act of 1999 and the concomitant establishment of the Authority as the institution responsible for the management of the IWHS. Ezemvelo KZN Wildlife, formerly the Natal Parks Board and before that the Natal Parks Game and Fish Preservation Board, became responsible for the day-to-day conservation management under the overall control of the Authority. This was formalised by an agreement in May 2002 (Porter 2013).

Development of a restoration programme

By March 2003, lake levels were dropping and water in False Bay (Figure 2) had reached marine salinity levels. By December 2003, the surface area of the lakes component of the estuary had been reduced by 75%. Salinities at Charters Creek (Figure 2) ranged between 70 and 130. Rain in the summer of 2003–2004 provided temporary relief, but by September/November 2004, salinities were above 100; by July 2006 the lake surface had been reduced to 10% and by September 2006, the lakes were dry and the mouth closed. The statement by Cyrus et al. (2011) that South Africa's 'largest estuarine lake (was) in crisis' was an apt description and the need for drastic action became obvious.

The desiccation of the lake had resulted in massive fish kills and there was a regional impact of a collapsed marine prawn fishery and a drastic reduction in the recruitment of juvenile estuarine-associated marine fish to the offshore populations, as described earlier. The estuary's significance as an aquatic bird habitat and its Ramsar, as well as WHS status, were all jeopardised.

A St Lucia workshop supported by the Water Research Commission was convened during May 2010 to consider the role and significance of the uMfolozi component in the functioning of the estuary and what information might be required prior to any relinking of the uMfolozi with the Lake St Lucia Estuary (Bate et al. 2011). The

original intended focus on the uMfolozi component of the St Lucia system morphed into an analysis of the role of the uMfolozi and featured, amongst other aspects, a breakdown of the influence of the uMfolozi on the water balance and hydrodynamics of the system (Lawrie et al. 2011), a contribution by representatives of the local sugar industry (Knox et al. 2011) and management concepts for the uMfolozi flood plain (van Heerden 2011). A summary of the proceedings (Forbes 2011) emphasised the priority, as determined by consensus at the meeting, for 'immediate implementation' of restorative measures.

A further workshop was convened in February 2011, attended by estuarine ecologists from across the country, in order to assess the long-standing sentiments regarding the separate mouth policy. The overwhelming consensus was that, although sediments might constitute some sort of a problem, the significance of the uMfolozi as a source of fresh water and driver of mouth dynamics was an overriding factor.

In March 2011, a decision was taken by the management authorities to lower the level of the beach in those areas where dredge spoil had previously been deposited with the then purpose of maintaining the separation between the uMfolozi and the St Lucia Narrows. In November 2011, the bar closing off the uMfolozi was breached following the national DWS directive previously mentioned. This directive was subsequently found to have no legislative basis. The mouth of the uMfolozi then began its typical northward migration, but closed off in late June 2012, when it had reached a point approximately 200 m south from where it would have relinked with the Lake St Lucia Estuary.

The iSimangaliso Board had previously ratified a policy decision that natural mouth movement would not be obstructed, a decision in direct contradiction to the 50-year-old previous policy. A further decision was then taken to open a channel between the northern limit reached by the then closed uMfolozi and the Narrows in June 2012, without incorporating a marine link. This decision amounted to an emergency procedure, but was in keeping with the argument that this action restored a previously natural process and was in line with the general reversal of the historic separate mouth policy.

The now realised inevitability of a recurrence of the desiccation of the lake under any future drought situation, i.e. with no inputs from the uMfolozi River nor the four northern rivers (Figure 2), mandated both an extensive restoration programme and a reconsideration and potential revision of the previous policy, including further consideration of the emergency action taken in June 2012. This process had in fact been initiated in 2010, with financial assistance from the Global Environmental Facility (GEF), which provided a sum of US$9 million, approximately one third of which would be directed towards the estuarine restoration component.

In terms of the GEF conditions, a post was created by the Authority to oversee the development and implementation of the restoration programme and was filled in August 2010. By mid-2011, this programme had brought to the attention of the Authority the various pieces of independent scientific research showing that it was not the drought alone that had led to the catastrophic conditions in the lake, but that the loss of the uMfolozi River from the St Lucia Estuary was a major contributing factor (Lawrie and Stretch 2008; Cyrus et al. 2011; van Heerden 2011; Clark et al. 2014). Based on this research the Authority officially adopted the new Management Policy in 2012, which was ratified by their Management Board and the South African Department of Environmental Affairs, to abandon the artificial breaching regime and allow the uMfolozi River to follow its natural path back into the Lake St Lucia Estuary.

In September 2012, approximately 400 mm of rain in the catchment resulted in a natural estuary breach and the common inlet remained open until October 2014, when it closed and remained in this condition until the time of writing (September 2019). The link between the uMfolozi and the St Lucia Estuary was, however, retained and the significance of this input became overwhelmingly apparent, because it was able to restore water levels in the lake over the period March 2016 to July 2017, when there was little to no flow from the four northern tributary rivers (Figure 2). What was encouraging for future restoration outcomes was the reappearance in the estuary of both penaeid prawns and some estuarine-associated fish species, such as the spotted grunter, *Pomadasys commersonnii* (photographic email correspondence with Mr Glenn de Gasparay, a St Lucia angler, correspondence dated 14/12/2013).

Arising out of the work being undertaken with the GEF grant and with the input of many South African and international estuary scientists at dedicated St Lucia workshops was the realisation that more detailed studies were needed to assess the broader economic and social aspects of the restoration programme. The GEF project was therefore broadened in parallel with the emergency restoration actions taken in the mouth area, to include multidisciplinary studies aimed at finding a long-term solution to the problems that the St Lucia Estuary and village were experiencing. This investigation was contracted to a team of specialists with a range of expertise in hydrology, coastal engineering, estuarine ecology, sociology and economics to consider the various physical restoration options, as well as the economic and social implications of any interventions and to present their findings to the Authority (Clark et al. 2013).

In summary, the studies confirmed that water from the uMfolozi was critical for the estuary as a whole and that its connection to the St Lucia Estuary should be restored. The studies also confirmed that the uMfolozi River controlled the St Lucia Estuary mouth's natural cycle of opening and closing, and that the sediments it carried posed little threat to the physical functioning of the estuary (Basson et al. 2014). It also critically and significantly indicated that under the influence of the uMfolozi River, the St Lucia Estuary should be open more often than it is closed (Clark et al. 2014). The study supported and affirmed the rationale behind the 2012 emergency strategy to restore the natural course of the uMfolozi River. It further recommended the removal of the dredge spoil that had been placed in the uMfolozi's natural path, and that the diversion of the uMfolozi into the sea at Maphelane be stopped. It also recommended removing levees that had been placed across the path of the uMfolozi River on its floodplain and ultimately limiting fishing in parts of the lake so that populations could recover.

Funding for implementation of the above-recommended restoration actions, in particular the removal of the dredge spoil blockage from the path of the uMfolozi River towards the Lake St Lucia estuary was made available from iSimangaliso's own funds and the GEF project. The removal of the dredge spoil was initiated in late 2016 and by the end of the project in December 2017, approximately 1.4 million m^{-3} of sediment had been removed. Unfortunately funds were insufficient to complete this task and at the time of writing an additional 1.2 million m^{-3} still have to be removed.

Since the start of the implementation programme in 2016, a real-time physico-chemical monitoring system has been put in place to track both physical and chemical changes in the estuary that have arisen as a result of intervention in the mouth area. Data from this monitoring system showed that the influence of the return of the uMfolozi River to the Lake St Lucia Estuary has been marked, despite the rainfall regime remaining depressed with no significant flows entering the estuary from the northern catchments. Although variable and often low, the input from the uMfolozi River resulted in greater stability in water levels through mid-2017, 2018 and up to May 2019, in contrast with the early 2016 condition (Figure 4). The 2017 to 2019 coverage included the dry winter months when the lake components are prone to evaporation, and contrasts strongly with the previous 10 years, when these areas had been almost completely dry.

Between July 2017 and the time of writing, salinities in the Narrows remained below 4, except for a single peak of 5 in September 2017. Salinities in North Lake and False Bay dropped from 10 to <4 between mid-2017 and early 2018. No data are available for South Lake over this latter period, but by May 2018 salinities were <2 throughout South Lake, North Lake and False Bay and remained <6 into 2019, i.e. generally just within the salinity tolerance ranges of the historical St Lucia invertebrate and fish fauna. At the time of writing (September 2019) the uMfolozi River had not received enough rain within its catchment to result in significant flows that would begin to shape the lower estuary and breach the beach berm to create a marine linkage once again.

The tourism industry

Turpie et al. (2013) point to the changes in St Lucia Village tourism, a possibility anticipated by Mann et al. (2002). In the early 1990s the estuary was a prime angling destination and anglers made up c. 60% of visitors. The combination of the national ban on beach driving in 2001, interpreted incorrectly in some quarters as a local decree by the Authority, mouth closure and a decline in fish stocks, resulted in a decrease in fishing effort. This manifested in a decline in demand for accommodation and several establishments and self-catering resorts closed down. The situation also generated increased social pressure and demands from the fishing fraternity for a rescinding of the beach driving restrictions and a breaching of the mouth. Comments on social media and antipathy toward the Authority could only be described as vitriolic.

Paradoxically, the number of establishments in the study area doubled between 2000 and 2013 and the number of beds increased by 14%, all during a period when the lake components of the estuary were in their worst condition and the fish stocks essentially non-existent. Again following Turpie et al. (2013), in 2013 there were approximately 122

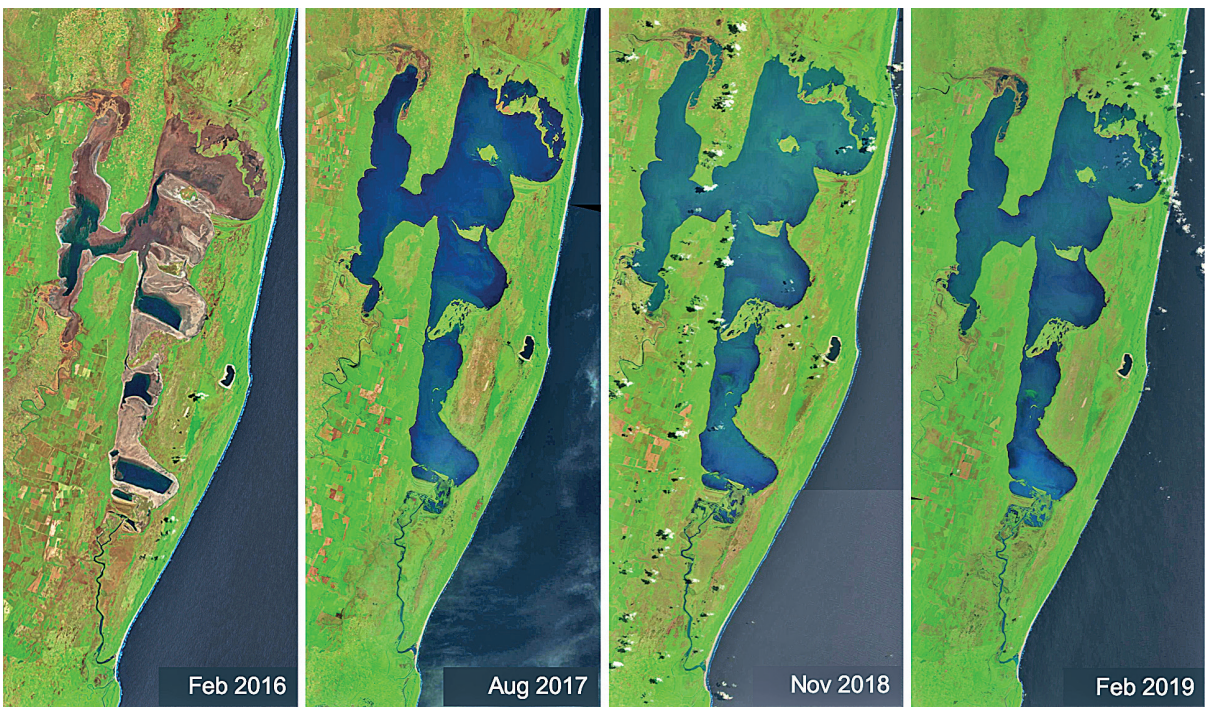

Figure 4: Satellite photographs of the Lake St Lucia Estuary under different water level conditions. Photographs taken in 2017, 2018 and 2019 show the stable water levels maintained by the uMfolozi River inputs, following the dry conditions of 2016

accommodation establishments and 6 660 beds in their study area, which incorporated the Eastern and Western Shores and St Lucia Village. The Authority granted concessions to 19 tourism activity businesses in the village, whereas at least 17 locally based businesses and several regional and national tour operators were bringing visitors to the IWHS. At the time of the survey it was estimated that there were c. 460 000 visitors annually, of whom 301 000 overnighted and 42% were foreign. Visitors were estimated to spend at least R46 million on an estimated 157 000 tours. The total annual expenditure was estimated to be R917 million, of which R570 million derived from international tourists. The bed night figures quoted by Mann et al. (2002) for 1991, could have been exceeded in 2013 in less than 10 days, whereas the amounts paid to private accommodation providers in 1991 would have been exceeded inside two months in 2013. Clearly from an economic point of view, the loss of the fishing attraction had not resulted in any long-term damage to the economy of the local area and the village.

Conclusions

The catastrophic and unprecedented environmental conditions that developed in the estuary after 2003 were most obviously demonstrated by the scale and diversity of the fish kills, as well as the zoobenthos exposed by the disappearing water. The knock on effect on stocks of estuarine-associated marine fish species and migratory invertebrates was less obvious and very much less known outside the research fraternity. What was obvious was the unanticipated long-term effect of the separate mouth policy, in combination with periods of below average rainfall, when flow in the more ephemeral northern rivers could not compensate for evaporation effects. There was a manifest need for a change in management policy towards a more holistic evidence-based approach, rather than the fisheries oriented values and perceptions that had characterised the previous 60 years.

At the same time there was the realisation that the scale of the area to be restored in relation to the restoration options and the resources available created a daunting situation. It was also apparent that many of the problems encountered in the estuary could, as often occurs in such cases, be attributed to human activities in the tributary river catchments where the Authority had very little or no jurisdiction and could only appeal to the relevant authorities to control activities, such as afforestation, water abstraction and contamination. Consequently the physical restoration activities were focused on the estuary mouth area where, because of the significance of the uMfolozi River as a driver of mouth dynamics and a source of freshwater, it was argued that best use could be made of the available finances. Unfortunately, as mentioned elsewhere, it was not financially possible or practical to reproduce a large open water St Lucia Bay type condition in its previous position between the uMfolozi River and St Lucia Estuary.

The obvious critical question arises here: is the restoration programme working? From a local economy point of view, the figures presented above indicate a remarkable expansion relative to the situation when St Lucia was basically a fishing resort economically subject to the vagaries of fish availability. Currently, the restoration programme has benefited the boat cruises in the Narrows by providing an adequate water level, although fine sediments do present a navigation problem in the lower reaches. These cruises provide a unique national opportunity to have close up views of hippopotamus and crocodile. Elephant and buffalo have been seen on cruises, as well as the occasional leopard. No other facility in the country provides such boat based opportunities.

From a system perspective, the St Lucia estuary has retained water for the past three years (as of December 2019). There has been expansion of the submerged aquatic plant *Stuckenia pectinata,* which had historically occurred in the system, and was to be expected to reappear based on the prevailing salinities. In this case recovery has followed total water loss, as opposed to the historical situation when the abundance of this species was related to the water column salinity. The question then arises whether the appearance of other submerged aquatic plants, particularly *Ruppia spiralis* and *Zostera capensis* based on seed bank survival, can be expected under suitable salinity conditions. Available unpublished information indicates a degree of recovery by the benthic macroinvertebrates of the lake compartments.

Repeated concerns have been expressed regarding the accumulation of uMfolozi derived fine sediments, which have significantly penetrated into the Narrows and, in combination with salinities bordering on fresh water, have allowed the proliferation of the reed *Phragmites australis* downstream of the R618 road bridge. Although the system has been closed since October 2014, there are no historical data to indicate just how long the mouth may remain closed and hence no basis for comparison with the current condition. The gap in the coastal dune cordon between Maphelane and St Lucia is however indicative of the geologically long-standing ability of the uMfolozi River to break through this barrier. It is significant that two modelling studies (Lawrie et al. 2011, Basson et al. 2014) do not express any concern regarding the potential for natural mouth breaching and consequent tidal conditions to remove the accumulated silt. It is also notable that recent studies (Fitchet 2018) suggest a greater future frequency and southward extension of tropical cyclones in the south-west Indian Ocean, which can be expected to contribute to breaching frequency.

Full estuarine function, i.e. where fish and invertebrate migration between the estuary and the marine environment is possible, has not yet been restored although it has to be recognised that mouth closure will still occur. The extent to which the programme will meet the above target remains moot. There is no national precedent for estuarine restoration on the present scale and no indication regarding the succession stages that might occur. Although estuary-associated fish species life cycles are well documented, little is known of the life-history strategies of most of the zoobenthos within this system. A hoped for outcome would be a greater knowledge of these processes such that the facilitation of these strategies can be better managed in the future.

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