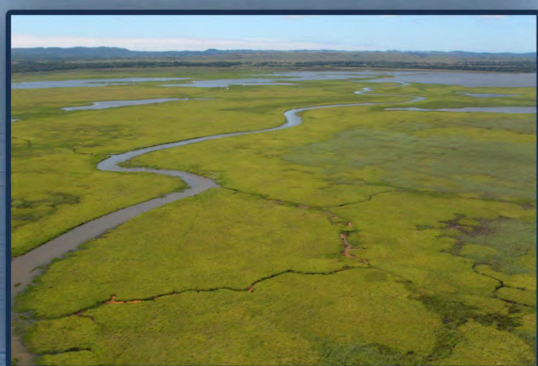
Proceedings of the St Lucia Natural Sciences Workshop:

Change, Connectivity and Conservation in a Major Wetland System

AK Whitfield (Editor)



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PROCEEDINGS OF THE ST LUCIA NATURAL SCIENCES WORKSHOP: CHANGE, CONNECTIVITY AND CONSERVATION IN A MAJOR WETLAND SYSTEM

AK Whitfield

(Editor)

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EXECUTIVE SUMMARY

This report is structured around the seven major themes identified and agreed upon at the St Lucia Natural Sciences Symposium held at St Lucia Village in May 2013. These themes, all of which fall under the umbrella title of “Change, Connectivity and Conservation in the St Lucia System”, include:

Theme 1: Catchment hydrology and hydrodynamic processes
Theme 2: Catchment and floodplain rehabilitation
Theme 3: Wetland dynamics and roles – local to landscape scale
Theme 4: Palaeoenvironments and geomorphological evolution
Theme 5: Biodiversity census and invasive species
Theme 6: Ecology of indicator species and red data taxa
Theme 7: Biotic responses to abiotic extremes

Although each theme can be regarded as a stand alone St Lucia natural science ‘proposal’, it is also true that a number of the themes have closely overlapping areas of research, e.g. Theme 3 has the potential to be integrated into a broader St Lucia research programme along with the themes on hydrology and hydrodynamics (Theme 1) and the ecology of indicator species (Theme 6).

In essence, a primary aim of the workshop was to place on record those areas of research that will require attention in the future. Although no assessment of this nature is ever completely comprehensive, this goal was largely achieved with the resources at our disposal. It is also important to note that at both individual/project and collective/ programme levels, the above themes have the overall approval of the delegates to the symposium. Authors of particular themes are now encouraged to develop their contributions in this report into formal funding applications, with the hope that in the not too distant future, all seven research themes will be successfully launched for the benefit of our knowledge of this World Heritage Site.

The way forward for research at St Lucia is well articulated by Dr Ricky Taylor in the final section of this report. Dr Taylor has spent his entire working career on the system and continues to be involved in its future, even though he has now formally retired from EKZN Wildlife. In his concluding comments he makes the important point that there is no easy recipe for promoting science at St Lucia – it is more about the creation of an environment that supports good science and the sharing of data and ideas by motivated researchers. He also appeals for a coming together of the natural and social sciences for the good of St Lucia and all the people who are dependent on, or enjoy, this important natural asset.

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INTRODUCTION

At the beginning of the 21st century Lake St Lucia entered the most critical part of its recent history when more than 90% of the total water area evaporated and the aquatic biota was pushed to extremes it had never before experienced. The primary reason for this situation can be traced back to the separation of the Mfolozi River from the St Lucia Estuary in the early 1950s. This original decision was taken mainly because of excessive silt loads entering the St Lucia system from the Mfolozi – a situation that arose directly from floodplain sugar cane cultivation and canalization of the river through the Mfolozi Swamps. As expected, the loss of St Lucia's major freshwater source resulted in major changes in the way that the system functioned and over the past six decades the lake pendulum has swung to ever increasing artificial extremes.

The latest drought crisis at St Lucia prompted a request by Ezemvelo KZN Wildlife to the Consortium of Estuarine Research & Management (CERM) to convene a workshop to investigate the availability of information from the estuarine portion of the lower Mfolozi and Msunduzi rivers, thus providing management with the sort of data and ideas that could assist with forward planning, and ultimately lead to the re-linkage of the Mfolozi and St Lucia systems. Sponsorship for the Mfolozi/Msunduzi Indaba was obtained from the Water Research Commission (WRC) and in May 2010 more than 20 scientists and conservationists gathered at St Lucia Town to present their research findings and debate future options. Soon after the indaba, work started on collating the presented information into a single report which was published by the WRC the following year (Bate et al. 2011). This report, which was structured around 14 major contributions from various disciplines, emphasized that Mfolozi connectivity is vital to the future of St Lucia. An important step was taken by the iSimangaliso Wetland Park Authority and Ezemvelo KZN Wildlife in July 2012 towards the full relinkage of the Mfolozi River to the St Lucia Estuary. Although the 'old' St Lucia Estuary berm has remained closed to the marine environment, there is now an indirect joint connection to the sea via a backchannel to the south of the previous St Lucia mouth. Given the excellent spring rains in October 2013, it is possible that a fully developed joint St Lucia/Mfolozi mouth will migrate northwards during the summer of 2013/14, and that the system can then undergo a rapid recovery in terms of functionality, diversity and productivity.

The relinkage of the Mfolozi/St Lucia systems gave rise to discussions amongst scientists in 2012 on the need to prioritize research and monitoring of the system during this important recovery phase. Once again, the WRC provided financial support so that both senior scientists and young postgraduate students working on the system could participate in planning for the road ahead. The St Lucia Natural Science Symposium was held on the 16th May 2013 at the same venue as the Mfolozi/Msunduzi Indaba and once again the discussions took place in a spirit of co-operation and understanding of the importance of the ideas that were being shared and developed. In essence, this meeting represented an opportunity for natural scientists to make their voices heard and to provide guidance on the type of research that they deemed important for the future ecological well-being of the system.

A total of 24 projects/programmes/thrusts were tabled at the symposium and, during the first session, these were discussed and developed with the assistance of the proposers and the other delegates. Subsequent sessions involved the linkage of these proposed projects into themes, with the main aim being to expand each theme under the guidance of a nominated senior scientist. Draft texts were then prepared for each theme after the symposium and these were submitted to the editor of the WRC report for further processing. There was also general consensus from the workshop that all the themes formed part of an overall research thrust entitled "Change, Connectivity and Conservation in the St Lucia Wetland System".

The conservation of Lake St Lucia and the protection of its World Heritage values is primarily the role of the iSimangaliso Wetland Park Authority. Together with Ezemvelo KZN Wildlife, this authority deals with improving the health and sustainability of the entire St Lucia system, thus providing optimal benefits for existing stakeholders and future generations.

iSimangaliso was awarded a GEF (Global Environmental Facility) Grant in 2009. One of the components of this project aims to implement restoration actions to improve the estuarine functioning of the Lake St Lucia System based on the "Analysis of Alternatives Study" currently underway and based upon best available knowledge. The study, which has a US$9 million grant through the World Bank, is entitled "Development, Empowerment and Conservation in the iSimangaliso Wetland Park and Surrounding Region Project". There are three main components to the project, namely:

- Biodiversity conservation, hydrology and ecosystem functioning of the iSimangaliso Wetland Park;
- Promoting conservation-compatible local economic and cultural development through the implementation of a rural enterprise development programme, a bursary and academic support programme for students studying tertiary qualifications in tourism and conservation fields, and capacity building for a co-management programme with land claimants; and
- Institutional capacity building for biodiversity conservation.

In terms of St Lucia estuarine functionality, this project has already initiated new research on mouth dynamics and the results will be immediately used in a management strategy for this system. A detailed report and recommendations arising from the GEF Project will be made available (following peer review and approval) in 2014.

The contents of this WRC report on the "St Lucia Natural Sciences Symposium: Planning for the Future" will complement the above GEF report in that the focus of the former is exclusively on the scientific gaps in our knowledge of the structure and functioning of the St Lucia system, whereas the latter incorporates a strong socio-economic component that is very necessary in order to serve existing and future human needs and interests in the area. This WRC report will therefore highlight the sort of natural scientific studies that need to be conducted on the system and will provide motivations as to why this research is necessary to support the implementation of wise ecological management decisions.

Reference

Bate, G.C., Whitfield, A.K. & Forbes, A.T. (eds) 2011. A review of studies on the Mfolozi Estuary and associated flood plain, with emphasis on information required by management for future reconnection of the river to the St Lucia system. WRC Report No. KV 255/10, 264 pp. + Appendix.

THEME 1: CATCHMENT HYDROLOGY AND HYDRODYNAMIC PROCESSES

Derek Stretch, Robynne Chrystal & Katrin Tirok

1.1 Rationale/Motivation

1.1.1 Catchment hydrology and the water balance of Lake St Lucia

The St Lucia estuarine-lake system is a large and shallow system fed by a number of freshwater sources, namely the Nyalazi, Mpate, Mzinene, Hluhluwe and Mkhuze rivers, as well as groundwater seepage from the eastern shores. The Mfolozi River can be a major contributor to the water balance during dry periods but was diverted from the system between 1952 and 2011. River inflows are important drivers of the mouth state functioning, the physico-chemical processes and hence the biological functioning. Episodic floods act to periodically reset the system by flushing out salt and accumulated sediments. They contribute an immense quantity of fresh water, most of which flows into the sea when the mouth opens. Changes in land-use patterns over the last century have led to degradation of the catchments surrounding St Lucia. There are perceptions that these have led to significant increases in sediment yields, particularly from the Mfolozi catchment. On-going degeneration of the Mkhuze catchment and the Mkhuze swamps is a potential threat to the St Lucia lake system and requires further investigation.

The first detailed analysis of the regional hydrology of the St Lucia and Mfolozi systems was carried out by Hutchison & Pitman (1973, 1977) and formed part of a larger study of the water and salt budget of Lake St Lucia. Several other unpublished hydrological studies were carried out since then but were generally limited in scope (e.g. Weston et al. 1995, Quibell, 1996; Van Niekerk, 2004). A recent review of the hydrology of the St Lucia/Mfolozi system is given by Stretch & Maro (2013). A new study of the catchment hydrology forms part of a new GEF funded project to guide the future management of the St Lucia system.

Like many rivers in South Africa, flow gauges are not available for all the rivers that feed St Lucia and, where they do exist, they are located some distance away and can have incomplete and/or inaccurate records. Hutchison & Pitman (1973) used a rainfall-runoff model (Pitman 1973) to simulate monthly inflows from the contributing catchments for the period 1918 until 1971. Hutchison & Midgely (1978) and Hutchison & Pitman (1977) used these data to construct a multi-cell model to simulate the water budget of St Lucia, where each cell has its own inputs and outputs and provision is made for the exchange of flows between these cells. Lawrie and Stretch (2011a, 2011b) used the same hydrological data but extended it from 1972 to 2010. The data were used as an input for a water and salt budget model that was used to simulate what if scenarios to investigate past anthropogenic impacts. Lawrie & Stretch (2011a) found that the Mfolozi not only had an important role as a source of freshwater to the system during below average rainfall conditions, but also played a key role in providing a more stable mouth state regime (see also Stretch et al. 2013, Chapter 7 for a detailed overview).

These past modelling efforts give insight into the long term hydrodynamic functioning of the system but are all based on a monthly time step and therefore do not resolve the detailed impacts of episodic events such as floods and/or mouth breaching. In addition, they are based on outdated bathymetry data and the impacts of abstractions, afforestation and (small) dams on freshwater inflows have not been accurately estimated since the hydrological study in the 1970s (Hutchison & Pitman 1977). Forty years later, these losses are likely to be different due to continued land use changes and development. Future changes in land use patterns and climate change are also expected to cause further alterations to the hydrology. Anthropogenic impacts are not only expected to alter flows, but also nutrient and sediment loadings. Further research and data are required to fully understand the changes that have occurred in the surrounding catchments and in turn the transport and fate of nutrient and sediment inputs to St Lucia, both of which could have significant impacts on the biological functioning of the system.

Recent work reported by Stretch & Maro (2013) has produced updated simulated hydrological data for the Mfolozi/St Lucia catchment system on a daily time step using the ACRU model (Schulze 1995). Their results suggest significant changes in both water and sediment yields due to land-use changes over the last century and further significant changes are anticipated for climate change scenarios (Mather et al. 2013).

Groundwater inputs to the lake are generally small compared to river inflows but can be important during dry periods as they are more persistent than surface flows (Hutchison 1976, Taylor 2006, Kelbe et al. 2013). Hutchison (1976) and Van Niekerk (2004) estimated that groundwater inputs make up 6-7% of the total water balance of Lake St Lucia. Groundwater seepage along the eastern shores of the lake provides microhabitats that create refuge areas for certain biota during dry/hypersaline conditions (Taylor et al. 2006, Kelbe et al. 2013). Despite its importance, managers often neglect groundwater inputs because they are difficult to quantify without comprehensive and costly monitoring (Kelbe et al. 2013).

1.1.2 Information required for water resources management of Lake St Lucia

Resource Directed Measures (RDM) are one of the four regulatory activities defined by the National Water Act of 1997 to optimally use water resources while sustaining aquatic ecosystems. The objective of the RDM is to ensure the protection of water resources (i.e. rivers, estuaries, wetlands and groundwater resources) by protecting ecosystem functioning and maintaining a desired state of health (DWAF 1999). An important component of this exercise is setting the Ecological Reserve, which is to determine the quantity and quality of water required to support ecosystem functioning. In order to determine the RDM (i.e. Reference Condition, Present Ecological State, Ecological Importance, Ecological Reserves Category and Ecological Specification) data and information need to be collected to characterise and understand the ecosystem functioning. St Lucia is one of the few South African estuaries with existing monitoring initiatives and it has been labelled as one of the best researched estuaries in South Africa; however there is insufficient data with which to perform a Comprehensive Reserve Determination. A Preliminary Determination of the Ecological Reserve was drafted for St Lucia on a Rapid Level (Van Niekerk 2004); however it was never officially approved for public dissemination. In order to complete a Comprehensive Reserve Determination for St Lucia, more extensive data sets are required and the collection of abiotic and biotic data should coincide in order to establish linkages between abiotic and biotic parameters.

1.1.3 Hydrodynamic processes and biophysical interactions

Lake St Lucia is a large, shallow lake and is therefore subject to wind driven flows and waves. Wind generated flows are important drivers of horizontal advection and mixing in the lake and facilitate the dispersion of micro-organisms in the system. Furthermore, pollutants and nutrients can be similarly dispersed. To understand species distribution and the potential for re-colonisation following extreme events as well as the potential threats from pollution and eutrophication for the entire system, it is important to understand the prevailing circulation patterns under different hydrological conditions.

A comprehensive understanding of the catchment hydrology and lake hydrodynamics is therefore necessary and should be linked to (a) water quality parameters (nutrients, TSS, other contaminants) and (b) impacts on the biological functioning of the system.

Apart from water circulation, wind generated waves drive resuspension of sediment, nutrients, and organic material into the water column. The dynamics of resuspension depend on the variable wind conditions as well as different water level conditions and are still not fully understood. For example the effects of benthic fluid mud on wind-wave generation and the feedback processes are not well understood. The dynamics of fine suspended sediment in the clay/silt particle size range can also depend on the flocculation process that is complex and poorly understood. For example turbulence in the water column can influence floc formation, as do suspended sediment concentrations and organic content. The re-suspension of fine sediments is strongly linked to the biological functioning of the lake system; it increases turbidity thus influencing primary production and feeding behaviours of higher trophic levels (e.g. zooplankton, fish) (Cloern 1987, Cyrus & Blaber 1988, Carrasco et al. 2007). Resuspension of nutrients and detritus/microalgae facilitates benthic-pelagic coupling (Corbett 2010).

Another important aspect of the functioning of the system concerns the inlet hydrodynamics and sediment transport processes. Studies of these processes are required in order to improve our understanding of the mouth opening and closure dynamics, e.g. how much flow is required to stabilize the St Lucia inlet? How much scouring of sediments takes place during episodic mouth breaching events that follow periods of mouth closure? The tidal exchange flows also play a key role in the connectivity to the ocean when the mouth is open and are therefore critical to the estuarine nursery function.

1.1.4 Relevance to the local marine environment

The outwelling of the St Lucia/Mfolozi system may also be regionally important in the coastal waters. Oliff (1973) and Porter (2009) measured low nutrient concentrations across the shelf at Richards Bay and inshore waters in the region south of St Lucia, respectively. Porter (2009), however, measured lower nutrient concentrations between St Lucia and Kosi Bay and suggested that the lack of river discharges and very narrow shelf were reasons for this (after Connell & Porter 2013). The export of nutrients and detritus from estuaries/mangroves is not fully understood but it has generally been considered to be important for offshore biological productivity (Lee 1995). The importance of the St Lucia/Mfolozi system as a source of nutrients and dissolved organics to the marine environment is unknown.

1.2 Aims/Objectives

Research within this theme aims to enhance knowledge on catchment hydrology and hydrodynamic processes, how these processes have changed over the last 3-5 decades, and how they are likely to change in the future due to land use and climate changes. This knowledge will contribute significantly to the overall understanding of the system and its biophysical interactions. It will aid management in making informed decisions.
Specific aims are:

a) Catchment hydrology
   - To investigate the long term temporal and spatial trends of freshwater inflows to Lake St Lucia and their effects on the water/salt balance of the system.
   - To identify the impacts of changing land use patterns and climate change on the catchment yields into the system.
   - To investigate details of the transport and fate of nutrients and sediments in the system.

b) Water circulation within the lake basin(s)
   - To understand the dynamics of wind driven water circulation and consequent sediment transport/resuspension and dispersion of planktonic biota.
   - Elucidate the residence times in different areas of the lake basins and their links to biological responses.

c) Water Reserve Determination
   - To collate and develop all the required data in order to undertake a Comprehensive Reserve Determination for the St Lucia system and to collect/estimate/simulate any missing data.

d) Eastern Shore connectivity
   - To analyse groundwater inputs and determine their role in terms of the water balance of the system.
   - To analyse the role of groundwater flows in ameliorating salinities particularly on the Eastern Shores and for the river-estuary interface.

e) Mouth dynamics
   - To understand the factors that control the opening and closing of the tidal inlet and the role of tidal exchange flows in the functioning of the system.
   - To understand the dynamics of breaching events and their role in the sediment budget of the system.

f) St Lucia outwelling hypothesis
   - To investigate the role of the St Lucia/Mfolozi estuary system(s) in the nearshore marine environment in terms of the export of biomass and nutrients.
   - To understand how the inlet configuration (e.g. links between the Mfolozi and St Lucia inlets) influences the outwelling process.

1.3 Methods/Approaches

In general the research methodology should include field work (and/or laboratory experiments) in combination with the development of mathematical/numerical models. Furthermore, since the physical processes addressed under this theme have important implications for the biological functioning of the lake, the approaches used should be linked to those used in other themes (e.g. Themes 2, 3 and 7). This would include issues such as the frequency and location of sampling or measurements, etc.

a) Hydrology
   - A modern, spatially distributed, process-based catchment model is required to simulate updated catchment responses (particularly water, sediments and nutrients) on daily or shorter time scales. The model should be calibrated and validated against field measurements of river flows and sediment/nutrient loads, and should be designed to assimilate new data as they become available. The model should be capable of incorporating land use changes and catchment developments.
   - A recommended strategy for catchment modelling is to use the newly developed PyTOPKAPI open source modelling system (Liu & Todini 2002, Pegram et al. 2006). PyTOPKAPI was developed and tested for South African conditions during two WRC funded projects. It is a gridded process-based hydrological model that is well suited to take advantage of remotely sensed data. The model topology is based around the SRTM DEM (Shuttle Radar Topography Mission Digital Elevation Model) and ingests spatial data of soil and terrain properties. The dynamic data forcing the model are remotely sensed rainfall (TRMM 3B42RT) as well as an estimate of actual evapotranspiration derived using a combination of remotely-sensed variables and the output of a numerical weather model. Information on the model can

be found at sahg.github.io/PyTOPKAPI and references cited there. Previous WRC projects concerning the application of the PyTOPKAPI modeling system (e.g. for flood now-casting) are K5/1429 and K5/1683. The PyTOPKAPI modelling system will need to be extended to include catchment sediment and nutrient yields since that capability is not currently included in the model.

- Water, salt, sediment and nutrient budgets for the system should be analysed using data from the updated hydrological model at appropriate spatial and temporal resolutions.

b) Water circulation

- Field measurements of currents, wind-waves, and water levels under different lake hydrodynamic conditions are needed. This can be achieved using boat mounted acoustic Doppler instrumentation, with wave measurements using pressure sensors. The methodology should allow for resolution on spatial and temporal scales that account for basin scale variations and diurnal cycles.
- Numerical models are expected to comprise 2D depth averaged models with the appropriate spatial and temporal scales (as above). Where practical, an open source modelling approach is preferred (such as the open source DELFT3D) and all modelling resources should be provided as a deliverable of the project with adequate user guides and documentation.
- The modelling approach should allow for full coupling of hydrodynamics (physics) with biological responses and biogeochemical processes.

c) Water Reserve Determination

- Collate available abiotic and biotic data from published and unpublished literature. This includes measured or simulated monthly inflow data for present and reference conditions over a 50 to 70 year period.
- Estimation of flood hydrographs for present and reference conditions for: 1:1, 1:2, 1:5 floods (influencing aspects such as flood plain inundation); 1:20, 1:50, 1:100, 1:200 year floods (influencing sediment dynamics).
- Collect and analyse a series (several years) of sediment grab samples for particle size distribution (PSD) and origin (using microscopic observations) along the length of the estuary (200 m to 2 km intervals) and after major floods.
- Survey cross section profiles (at about 500 to 1000 m intervals) taken every 3 years to quantify the sediment deposition rate in the estuary.
- Collect near-shore wave data records and associated turbidities.
- Collect and analyse measured river inflow data over a 5-15 year period from gauging stations.
- Collect and analyse water level recordings from several locations along the length of the Narrows over a spring/neap tidal cycle.
- Collect longitudinal salinity and temperature profiles (in situ) over a spring/neap tide during high and low tide at: (1) end of low flow season (i.e. period of maximum seawater intrusion), (2) peak of high flow season (i.e. period of maximum flushing by river water).
- Water quality measurements (i.e. system variables and nutrients) along the length of the Narrows (surface and bottom samples) on a spring and neap high tide at: (1) end of low flow season, (2) peak of high flow season.
- Measure organic content and toxic substances (e.g. trace metals and hydrocarbons) in sediments along the length of the Narrows and at various locations in the lake.
- Water quality measurements (e.g. system variables, nutrients and toxic substances) for the rivers entering the system.
- Water quality measurements (e.g. system variables, nutrients and toxic substances) for near-shore seawater.

d) Eastern Shore connectivity

- Groundwater seepage: quantify groundwater seepage that is going into the lake using *in situ* measurements from monitoring wells. Investigate groundwater flow convergence zones where groundwater seepage converges to form streams, e.g. Nkazana Stream. Suitable groundwater models (e.g. Været 2008, Været et al. 2009) for the Eastern Shores should be used to simulate long term inputs to the system from the surrounding catchments.
- Simulated groundwater seepage and flows should be integrated with hydrological and hydrodynamic models of Lake St Lucia to analyse the role of groundwater inflows in ameliorating high salinities, especially during dry periods.
- Link the importance of groundwater inputs to the functioning of the system, i.e. groundwater-dependant habitats, by linking with Themes 2, 3 and 7.

e) Mouth dynamics

- The development and application of numerical models for sediment transport and morphodynamics of the mouth region, supplemented by field observations to calibrate and validate these models.
- Hydraulic modelling with sediment transport, of mouth breaching events to understand and quantify the role of these events in the sediment budget.

f) St Lucia outwelling hypothesis

- A nutrient and biomass (carbon/detritus) budget for the system needs to be performed to quantify imports to and exports from the system.
- Quantify outflows through the mouth with respect to different mouth configurations and mouth states.

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THEME 2: CATCHMENT AND FLOODPLAIN REHABILITATION

Ricky Taylor

2.1 General Introduction

Many of St Lucia's hydrological problems originate in the catchments of the estuarine system, yet our knowledge of these catchment areas is limited. In addition, very little management is implemented to maintain the environmental quality within the catchments and we do not have adequate knowledge to underpin catchment management actions with sound scientific knowledge. Although scientific knowledge, skills, technology and capability are available in the country, there is limited access to this currently in the St Lucia catchments to guide actions which will reduce degradation or promote natural processes and the rehabilitation of parts that have been damaged.

Implementation of a scientific programme in the catchments aimed at benefitting the conservation of the St Lucia ecosystem cannot be done in isolation of the needs of all the land-uses and the people who live there. There is a need for an institutional structure to integrate the efforts of the government and provincial agencies, municipalities, NGOs, business and individuals who have an interest in the wellbeing and wise use of these catchment areas. And as part of this, there is a need for a cooperative scientific committee to focus on the catchment. This would be best set up under the aegis of the WMA (Water Management Agency) which is mandatory for each catchment under the National Water Act (Act 36 of 1998). Such a scientific committee would need a mandate to conduct basic and applied science, so that management decisions are underpinned by sound scientific knowledge. It needs to develop a framework for data and information sharing to enable a broad understanding of the problems and then a dissemination of information to stakeholders. It needs to attract technical expertise to do this task and to build partnerships to integrate skills and disciplines. Catchment science needs teams of scientists to integrate science to promote rational planning. It needs a full time facilitator, whose task is to develop a predictive capability to plan for prevention or mitigation of existing and future problems

The scale of knowledge requirements as well as the amount of work that is needed is overwhelming and it is unlikely that such a committee would be established for a long time. So, in the interim, it is recommended that three catchment research projects are initiated that would focus on where science could have the largest impact. These will provide insights and direction that can guide effective restoration and rehabilitation management actions that will ameliorate harmful conditions developing at St Lucia (Note: these initiatives are cross-cutting with Theme 1 of this report).

2.2 Research Initiative 1: Identification of salient features in the catchments

This research initiative is to identify salient features within the catchment; to identify sensitive and conservation-worthy sites and processes; and to identify those human activities in the catchment that cause inordinately high levels of damage, e.g. soil erosion. This knowledge will focus restoration and rehabilitation activities where they will be the most effective.

2.2.1 Rationale/Motivation

Although a comprehensive and holistic approach to catchment management should be taken, it is possible to rapidly take some initial steps for the rehabilitation and restoration of important portions of the catchment. To be most effective all management actions need to be well focused. This research initiative aims to identify the most important places and actions needed to improve the state of the catchment with minimal resources. The proposal is to apply a systematic conservation approach, for instance as described by Margules & Pressey (2000) and using programs such as MARXAN and CLUZ; and to use remote sensing tools (satellite imagery and remote monitoring equipment) to achieve this.

Similar methods can be used to identify the worst sites and land-uses that cause damage to water quality, reduce/alter flows and result in the greatest amount of sediment delivery to St Lucia. Thus the focus would be on specific sites, e.g. the identification of sources of mine dump seepage that enter the rivers as point-source pollution or where unsuitable agricultural land is being ploughed and resulting in extensive soil erosion. The recent desk-top exercise to evaluate the Present Ecological State (PES) and Ecological Importance-Sensitivity (EIS) of the rivers (DWA in progress) provides an initial assessment on this issue. It would also be necessary to identify the land-uses that have the greatest impact on the landscape – often in the form of dispersed pollution.

While doing the above, it would be useful to analyse catchment land use patterns and determine how we can be most effective in applying rehabilitation/restoration management. It should also be recognized that restoration of lost or damaged wetlands is very important to the future evolution of the lake ecosystem.

2.2.2 Aims/Objectives

a) To apply Systematic Conservation Planning tools and expert local knowledge to identify those salient features or processes that are critical for conservation (i.e. those that must be maintained or, if damaged, restored).
b) To identify those 'hot spots' where most damage is being caused, or which most need to be cared for.
c) To identify those land-uses that have the greatest impact upon the landscape.
d) To develop scientifically based management plans to focus and guide the implementation of management to restore these features.

2.2.3 Methods/Approaches

Systematic conservation planning

This initiative should be GIS-based and should document and describe:

- land uses and changes in land uses;
- natural vegetation and the state of the habitat (identify over-grazing, alien plant invasions, wooding up by indigenous trees, etc.);
- areas most prone to erosion (e.g. steep slopes, friable soils affected by over-use),
- water catchment areas (e.g. upper-catchment forests); and,
- areas most important if damaged, or most in need of repair if damaged.

There is a need to focus much more on processes than is currently being done, especially processes relating to water and sediments. Changes in land-use have already being mapped by EKZN Wildlife but, this is at a provincial scale and possibly needs to be done at a finer resolution. This mapping is also needed for the research initiative on pollution within this theme.

Rehabilitation and restoration

The systematic conservation planning will identify where to focus the limited resources that are available for catchment management. The management to be implemented to repair and conserve the area should be based on sound science and guidelines should be developed to direct these efforts. Institutional structures will need to be established to implement this work and this will need to be done with the cooperation of local communities.

This work will range from the repair of salient features (such as wetlands and upper-catchment forests) to the control of point-source pollution (such as mine-dump seepage, waste-water treatment plants, feed-lots, etc.) and the control of those land-uses causing unacceptably high impacts.

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2.3 Research Initiative 2: Maintenance of large-scale wetland processes on the Mfolozi Flats

2.3.1 Rationale/Motivation

The Mfolozi floodplain is inextricably linked to St Lucia; arguably having more connectivity and a greater influence on the well-being of St Lucia than any other part of the catchment. However, this floodplain is subjected to intensive sugar farming activities. The sugar farming community has the continuous fear of being ‘wiped-out’ by large floods and is affected by the impacts of back-flooding whenever the Mfolozi Mouth closes. From the conservation perspective there is an imperative to re-link the Mfolozi River to St Lucia. This comes at a time when there are ever-increasing demands on the Mfolozi for the supply of water and when there is increasing sedimentation, more pollutants and a greater need for flood control. In addition, aquatic and riparian alien invasive species are becoming a major problem in the area. Several of these issues are possibly being aggravated by global changes, such as a rising sea level and changes in rainfall and storm-event patterns.

It is recognised that in the Mfolozi floodplain the sugar industry is a legitimate land-user, which has been serving the country for over a century (Dobeyn 1987). As a cooperative, UCOSP manages the overall infrastructure relating to flood protection and drainage, as well as the road and rail network. It has a long history of undertaking drainage of the floodplain and breaching of the Mfolozi mouth to support the needs of the sugar industry.

This research initiative focuses on the need for conservation to work closely with the sugar industry, to develop a scientific programme that will support the sugar-farming industry on the Mfolozi Floodplain and at the same time minimise the impacts of these farming activities on the St Lucia ecosystem. It would aim to enhance the large-scale ecological processes and features of the floodplain that are of importance to the St Lucia system, but at the same time, all management recommendations would have to be economically rational for the farmers. It would, *inter alia*, focus on flood management and the general management of water and sediments in the wetland, as well as address the build-up of agri-chemicals on the natural water systems. In addition, it would consider the impacts that the conservation management activities would have on the sugar farming activities (such as the backing up of water during Mfolozi Mouth closure periods, which results in the flooding of the lower sugar lands). It would also consider the management of the farm drainage systems to enhance the wetland values of the floodplain for waterbirds and other conservation assets.

Some of the above issues are likely to be addressed by the iSimangaliso GEF project that is currently underway. This research initiative will provide additional dimensions to the above focus – especially relating to close collaborations with the sugar farming community and by taking a look at the large-scale processes that affect the floodplain as an integrated entity. This research initiative deliberately focuses on the sugar-farming community because of their key impact on the St Lucia system. There are other stakeholders affected, but these are not considered as the primary concern is to establish a research initiative that addresses the modifications of the floodplain by the sugar farming activities.

For a study to promote the co-existence of the sugar industry and the St Lucia conservation area, as a fully integrated system, the following questions need to be answered:

a) What are the large-scale processes that drive the floodplain and how have they been modified?
b) How can the sugar farming and associated activities be changed to reduce the negative impacts on the functioning of St Lucia and at the same time enhance the wetland values of the floodplain?
c) Likewise, how can the conservation management of St Lucia be changed to minimise the impacts of this on sugar farming activities?

The above initiative will enhance and care for the intrinsic wetland conservation values of the floodplain and is cross-cutting with Theme 3 of this report.

2.3.2 Aims/Objectives

- To identify large-scale floodplain processes that are of importance for the maintenance of the St Lucia estuarine ecosystem.
- To identify which of these processes have been altered (or could be in the future).
- To identify the risks that farming activities are exposed to (e.g. flooding) and the impacts of actions taken to manage the St Lucia ecosystem (e.g. back-flooding caused by mouth management activities).
- To gain an understanding of the sugar farming needs and identify new paradigms for farming activities. Similarly, gain an understanding of the conservation needs of the Mfolozi Floodplain and identify new paradigms for conservation activities.
- To develop, scientifically based, management plans to guide the implementation of management actions to restore these processes and at the same time improve current sugar farming practices to minimize environmental impacts.

2.3.3 Methods/Approaches

For this initiative to succeed it is necessary for the responsible conservation agencies (iSimangaliso Wetland Authority and EKZN Wildlife) to work closely with the sugar farmers (represented by UCOSP and the Sugar Association). At all stages it must be seen as a joint venture which will benefit both the conservation of St Lucia as well as the sugar industry. Work should be conducted at the full floodplain scale, not at the individual farm level. In addition, time scales should be large enough to include 1:100 year floods. The main processes to be considered are:

- Hydrology (base flows): What water is required for irrigation (where is this pumped from?) and how much runoff is there after irrigation (where is this discharged?).
- Management of farm irrigation drains and canals to maximise wetland function – especially for waterbirds, fish and crustaceans.
- Hydrology (floods): How are floods routed through the floodplain, what processes occur, and what sediment erosion, transport and deposition patterns are active?

- Alteration of river channels by both humans as well as the tendency for the river to periodically switch channels.
- Sediment dynamics: Quantify the rates of sediment slumping. What sediment processes are affected by the slumping of sediments in the floodplain and how do these affect the flood hydrology?
- Flood diversion structures and their effectiveness.
- Tidal flooding and drainage.
- Storage capacity of the area when there is back-flooding, and which areas are flooded.
- Water quality and sources of pollutants and contaminants.
- Habitat connectivity – including corridors and wetland matrices.
- Invasive species – both from the conservation perspective (alien species) and from the agricultural perspective (weeds).
- Global changes – including sea level rise, altered rainfall and an increase in extreme events (floods and droughts).

A first step would be to produce a status assessment of the present situation, identify the issues of conflict and to list emerging problems, especially those that are showing trends. To date much of the focus has been only on the lower part of the Mfolozi Floodplain (Bate et al. 2011, Van Loon et al. 2013)

What also needs to be recognised are the conservation assets of the floodplain and how these could be enhanced. These would include the prawns (penaeids and *Macrobrachium*) and fish nursery functions of the drainage canals; the waterfowl populations and how they utilise the drainage canals; the preservation of large fig trees; and the sediment-trapping capability of the floodplain during large floods.

There are a number of socio-political and socio-economic issues relating to various communities which need to be researched and understood. The communities include the formal sugar farming sector, the upstream and downstream neighbours, as well as those people living in the region. These are not considered in this section which deals only with the physical and biotic environments relating to the commercial sugar industry.

2.3.4 Research focus

The main focus is to be on the large-scale processes associated with the Mfolozi Floodplain.

- Modelling will be needed to simulate flood flows across the floodplain. These must also include sediment erosion, transport and deposition patterns during flood events.
- Of importance are the geomorphological dynamics – including those of sediment slumping as well as sediment deposition. The main focus must be on what happens during floods – including channel avulsions, channel switching and meandering.
- Studies into the formation and palaeo-environments of the floodplain will offer insights into the long-term processes that have happened since the last Glacial Maximum some 18000 years ago (cross-cutting with Theme 4 of this report).
- Of particular importance are the insights by Van Heerden (2011) into the floodplain processes. Some of his work does need to be supported by more detailed studies on sediment compaction and deposition rates.
- Sugar farm management activities need to be reviewed to consider items such as irrigation systems and the management of drainage canals – especially the management of water plants within these canals (there are opportunities for these to be enhanced as wetland habitats). Also of importance are the use of chemicals, the

impacts of these on the eutrophication and the contamination of water that could enter St Lucia.
- At present there have been several studies relating to the transfer of water from the lower Mfolozi Floodplain to St Lucia and how, if this is allowed to back-up, it then acts as a sediment trap (Kelbe & Taylor 2011, Van Loon et al. 2013).

2.3.5 Floodplain enhancement and opportunities

Consideration should be given to applying for the extension of the Ramsar status of St Lucia and the lower Mfolozi Floodplain site to include the full floodplain as well as inclusion of Lakes Teza, Mvuya and Futululu, and possibly also inclusion of the off-stream pans upstream of the N2 bridge. This research initiative should produce all the necessary information needed to identify and evaluate the situation and then, if appropriate, to draft the application document for a Ramsar listing (to be done through the DEA).

A single integrated management strategy needs to be devised. At present there are several different flood control structures, including the Riverview spillway, the raising and protection of berm walls containing the Mfolozi River, and the planting of trees to direct excess flood water along the Msunduzi pathway. But these measures do not consider their effects on the flood avulsions of the river into the Link Canal. Similarly the backing-up of water caused by Mfolozi Mouth closures is not part of the planning for coping with removal of water from the lower fields.

Activities that can enhance the conservation status of the floodplain include the maintenance of some areas of natural vegetation, especially riparian communities, and the better management of weed growth in drainage canals. Improved management could enhance the area for the protection of waterfowl, possibly by planting small areas to provide food, and to improve the management of swamps and water bodies. At all times management should be aimed at providing conditions that reduce disease (e.g. malaria and bilharzia), as well as being aware of the implications for the promoting of cane diseases and pests (e.g. *Eldana* moth).

All management proposals need to be underpinned by scientific findings and recommendations. For issues focusing on water and sediments, relevant and focused models should be developed that can be tested against recorded data. Lessons learnt from this work need to be applied to the other floodplain/swamp systems that enter St Lucia. Of special importance in this regard is the Mkhuze Swamp (Whitfield & Taylor 2009) and also the floodplains associated with the Mzinene, Hluhluwe and Nyalazi Rivers (see Theme 3 of this document).

2.3.6 References

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2.4 Research Initiative 3: Pollution studies

2.4.1 Rationale/Motivation

To date, St Lucia appears to have been relatively little affected by pollution and nutrient enrichment from the catchment or by those pathogens which are usually linked with eutrophication. This is a problem of the future as is evident from similar systems elsewhere in the world. The apparent low incidence of pollution may, however, be partly due to the absence of an adequate pollution monitoring programme. There are, however, early signs of eutrophication in the Mfolozi Floodplain, especially along the Msunduzi where there are micro-algal scum formations and extensive filamentous algal growth in the Mkhuze River, especially downstream of the N2 road (Taylor, personal observations).

2.4.2 Aims/Objectives

This proposal is for a ‘pollution audit’ to obtain an assessment of the pollutants and pollution status of the catchment area and of what may be entering St Lucia. It has the following objectives:

- To conduct an audit of land-uses in all the St Lucia catchments and of the chemicals used by each land use (this is to identify possible pollutants and their quantities).
- To assess trends and identify where interventions are required to prevent the adverse increase in pollution.
- To identify impacts of contaminants on the St Lucia system and develop a conceptual understanding of the implications of these pollution effects.
- To develop scientifically based guidelines for the management of pollution.
- To establish a monitoring and surveillance system to detect changes in pollutant levels and where they originate.

2.4.3 Methods/Approaches

Pollutant audit

Develop a high resolution land-use map for all the catchment areas in collaboration with EKZN Wildlife. For each land-use, identify what chemicals (fertilizers, pesticides, herbicides, plant hormones, etc.) are used and quantify their use. An initial report of this nature was conducted by McKay (1993) which could be expanded to address present and future pollution issues. It will also be necessary to produce a total audit of chemicals of concern and where they are being applied in the catchment. Similarly identify other sources of pollution (e.g. acid mine-dump drainage, industrial waste, sewerage, garbage dumps, cattle dips and other activities). The purpose is to obtain as complete a picture as possible of the chemicals of concern which are entering the catchment.

For each chemical, understand its chemistry and how it behaves in the catchment and in St Lucia, once it gets there. These may be fertilizer run-off that causes eutrophication and the resulting de-oxygenation, heavy metals that bio-accumulate or are bound in sediments, acid drainage that alters pH, etc. There is also concern about pathogens and toxins (such as from microcystis and botulism) and hormone-mimicking compounds.

Conceptual understanding

The conceptual understanding should be incorporated in a document or decision support model which includes:

- Inventory of pollutants in the catchment.
- In what quantities/concentrations?
- Where in the catchment?
- What reaches Lake St Lucia and in what concentrations?
- What are the impacts on the St Lucia system?
- What use patterns can be altered or what mitigatory measures can be applied?
- How to cope with accidental spills into catchment rivers (e.g. from road and rail transport) and will such spills reach the St Lucia system?
- Who all is affected by pollutants and what agencies are involved?
- What legislation covers pollution?
- Management guidelines.
- Monitoring needed.
- Who has the responsibility for management and monitoring implementation? (e.g. DWA).
- Coordination and collaborations.

This pollution research initiative ties in with the monitoring programme recently initiated in St Lucia by the Estuaries Section of DWA which has a mandate under the National Water Act to monitor the state of estuaries in South Africa.

2.4.4 References

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THEME 3: WETLAND DYNAMICS AND ROLES – LOCAL TO LANDSCAPE SCALE

Jane Turpie & Ricky Taylor

Note: This research theme can stand alone but also has the potential to be integrated into a broader St Lucia research programme along with the themes of hydrology and hydrodynamics and the ecology of indicator species. Elements of this research can also be linked with catchment studies.

3.1 Rationale/Motivation

Wetlands tend to be a particular focus for conservation because of their high levels of biodiversity and productivity, coupled with their vulnerability to a variety of human activities that impact on them, either directly (e.g. through habitat transformation and overexploitation) or indirectly (e.g. through the alteration of surface and groundwater flows)(Cowan 1995). The St Lucia system is within a designated Ramsar Wetland which focuses specifically on its international and national values as a wetland. As such, South Africa has the obligation to care for all the wetlands within this designated site. The iSimangaliso protected area is designated a 'Wetland Park' but much of the historic research has been directed at the lake and estuary, with little emphasis being placed on freshwater wetland areas within the park.

3.1.1 The wetlands and their functioning

The St Lucia estuarine system is a highly dynamic saline wetland system that responds to a combination of surface water, groundwater and seawater inputs. These result in dynamic variation in habitats at local scale and ecosystem scales, and interplay with the dynamics of wetland habitats at a regional scale. This connectivity, in turn, affects the biota of the system and their local and regional populations and conservation status. However, as a result of half a century of human interventions following the separation of the Mfolozi system from St Lucia in 1952, the natural ecosystem dynamics of the St Lucia Estuary when connected to the Mfolozi River are not very well understood. Most research has been carried out since this artificial separation of the two systems – making it difficult to understand its natural integrated functioning (Bate et al. 2011).

Surrounding the St Lucia estuarine system are numerous freshwater wetlands of various types. These wetlands have variable levels of connectivity with the estuary over space and time. The connectivity of these fringing wetland systems with the St Lucia estuarine system means that it is important to manage the system as a whole. There are three main types – river floodplains, groundwater-dependent wetlands and ephemeral rainwater-fed pans. Depending on their hydrology, their settings in the landscape and the patterns of sediment accumulation, they exhibit a variety of different wetland forms, each having different assemblages of plant and animal species.

These freshwater wetland systems cover an extensive area and are likely to play an important role in influencing the physical dynamics and biota of the St Lucia system through processes such as trapping of sediments and nutrients, evapotranspiration and flood attenuation, as well as through the production of autochthonous carbon (Ellery et al. 2013). Yet relatively little is known about their functioning, ecological importance and current state of health (Anon 1975, Alexander 1976, Ellery et al. 2013).

Of these wetlands, the most important for the St Lucia estuarine system are the **river-dependent floodplains and swamps**. These are sediment-filled extensions of the ancestral Lake St Lucia, and are now important as flood-buffers, sediment traps and their intrinsic biodiversity. Associated with them are lateral blocked-valley pans (such as Teza, Futululu, Mavuya, Muzi and Nsumu). A few studies have described the biota of the Mfolozi floodplain wetlands (e.g. Pike 1979, Howard-Williams 1980, Roberts & Pike 1984) and the Mkhuze Swamps (Blaber 1981, Taylor 1982, Skelton et al. 1989). Humphries (2006, 2008) studied the sedimentation and chemical processes on the lower Mkuze floodplain. McGill (1982) looked at the effects of abstractions from the Mkuze River on salinity in Lake St Lucia. Garden (2008) and Cyrus et al. (2010) have studied the functioning and ecological role of the Mfolozi floodplain, but only during a period of its isolation from St Lucia.

Studies of the coastal floodplains are needed. These should include more work on their formation, sediment patterns, hydrological drivers, hydrological variability, and geomorphological processes. These studies should consider the dynamics under normal conditions and also during floods. We also need to know more about the rivers that snake through these swamps, how flood waters burst their banks to inundate backwaters, cut off valleys form lateral pans, the patterns of river meandering and the changing of river courses, the formation of oxbow features, the wetting and drying related to flooding and storage of water, the plant responses and how all these processes have been altered by human endeavours. Studies of the other floodplain wetland systems that are linked to the St Lucia estuarine system should include the Mkhuze Swamps, and the Mzinene, Hluhluwe and Nyalazi floodplains.

Also important are the **groundwater-dependent wetlands**; especially those of the Eastern Shores (including coastal lakes such as Lake Bhangazi-South and swamps such as the Mfabeni Mire) which are important for certain species during drought periods. In addition, there are large areas on the Eastern Shores where groundwater seeps out of sand aquifers at the edge of the lake, creating low salinity environments which allow the development of freshwater wetland habitats in areas that are surrounded by saline habitats (Adams et al. 2013). These groundwater-fed wetlands appear to play a critical role as a refuge for plant and animal species during extended droughts (Taylor et al. 2006, Vrdoljak & Hart 2007).

The groundwater feeds specific types of wetlands that rely on the consistent supply of fresh water. The constant seepage of water along slopes feeds wetlands where *Sphagnum* moss thrives and the wetlands are also rich in insectivorous plants. Where pans are associated with these seeps they form the stable environment in which rare species of fish may occur – such as *Redigobius dewaalii* and *Hypseleotris dayi*. Recently the former has been discovered by Vrdoljak & Hart (2007) for the first time in the St Lucia area, and the latter found for the first time since the late 1940s. Stability of water flows is also required for the formation of peat. There are a number of such deposits in the region, the largest of which is Mfabeni on the Eastern Shores which has trapped pollen to give an archive of environmental conditions dating back more than 40 000 years (Finch & Hill 2008).

There has been monitoring of groundwater levels in the central Eastern Shores since the early 1970s. However, monitoring is poor in other areas adjacent to St Lucia (Kelbe et al. 2013) and our understanding of the groundwater dynamics upon which these wetlands depend is still relatively poor. Nevertheless, this knowledge is improving, with recent studies by Taylor et al. (2006), Vaeret et al. (2009) and Grundling et al. (2010) covering mainly an extended below average rainfall period. Considerably more work is required to cover a wet cycle, especially now that the forestry plantations on the Eastern Shores have been removed.

More disconnected from the lake are the **ephemeral rainwater-fed pans** of False Bay Park and the Mkhuze Game Reserve. They are endorheic and rely on periodic rainfall to gain water which accumulates in temporary pans. When there is an extended dry period, these pans dry up completely.

3.1.2 The St Lucia wetlands complex in a landscape context

At a regional scale, the St Lucia estuarine system is part of a mosaic of wetlands which are used by birds which select the food sources that are available in different places during the different phases of a wet-dry cycle. At the international level, St Lucia is an important link along the chain of wetlands used by migrating water birds. Also at the international level, it has conservation value as a relatively secure place where hippos and crocodiles are protected. So, not only do we need to consider the wetlands as support systems for the wellbeing of the St Lucia estuarine system, but also as conservation assets in their own right and as wetlands linked into much larger wetland networks.

While we have much to learn about the habitat dynamics of the St Lucia Estuary as a whole, even less is known about the role of St Lucia as one of many wetland systems in the Maputaland coastal plain of northern KwaZulu-Natal and southern Mozambique, several of which are important from a conservation perspective (Begg 1986, McCarthy & Hancox 2000). St Lucia Estuary supports large populations of many waterbird species, making it one of South Africa's most important estuaries from a waterbird conservation perspective (Garland 1944, Berruti 1980a,b, Underhill & Cooper 1984, Ryan et al. 1986, Williams & Randall 1995, Turpie 1995, Turpie et al. 2013). Furthermore, the iSimangaliso Wetland Park itself includes many wetlands which have both RAMSAR and IBA (Important Bird Area; BirdLife South Africa) status. Examples of IBAs include the Kosi system, Lake Sibaya, St Lucia system and Nsumo Pan (Mkhuze Game Reserve). IBA sites are designated in order to conserve bird species which are globally threatened, range restricted, or occur in specific vegetation types, amongst other criteria. The importance of these individual sites has been widely acknowledged; however the dynamics and connectedness of wetlands in the surrounding areas has not been well studied. Currently there is a study on the ducks of this wetland mosaic – being conducted by Dominic Henry of the University of Cape Town.

Waterbirds are highly mobile organisms which often use complexes of wetlands to meet the various resource requirements of their life cycle or move to different wetlands when conditions become suitable. One of the most serious threats to waterbirds is a bottleneck in resource availability, which increasingly occurs as a result of human impacts, particularly the reduction in environmental flows (Kingsford et al. 2010). While some information is available on long distance movements (e.g. Whitfield & Blaber 1979, Taylor 1980), the interdependence between the St Lucia system and other wetlands in the region is not well understood, nor is the degree to which the different types of wetlands in this landscape mosaic provide critical habitat under certain climatic conditions. There is thus a need for landscape-level wetland studies which also investigate movements of individuals among multiple sites. An important consideration is that these sites may fall outside traditionally protected areas (e.g. the Phongolo River floodplain).

Ecological studies need to take place at much larger spatial and temporal scales if the conservation strategies that they inform are to be effective. For example, St Lucia may play a crucial role in the life histories of certain species when resources in the region are scarce, and similarly other wetlands may be vital to the maintenance of St Lucia's biodiversity. There is a clear need for research to be conducted over large areas and with multiple species, i.e. a movement away from projects that are typically focused on a few small areas and over short time periods.

Waterbirds are dependent on the characteristics of wetlands within the landscape (not so much what lies between these wetlands), and the way that they move between wetlands depends on aspects of their life history and behaviour. Waterbirds may use multiple wetlands within and among various phases of the annual cycle, but may also exhibit pronounced aggregation in restricted areas during some stages of their life cycle, making them vulnerable to habitat degradation (Haig et al. 1998). Research directed at describing and understanding waterbird movements will be important for understanding wetland connectivity and designing conservation strategies.

In spite of the fact that most of the freshwater wetlands fall within a protected area, many of these, especially in the swamp forests and on the floodplains, are under increasing threat from small-scale farming activities, grazing, fishing and natural resource harvesting activities, and in parts they have been altered by drainage and canalisation.

In summary, wetlands in this important wetland park are not as well understood as the lake itself. Their dynamics, biodiversity and their connectivities within a larger wetland system and their importance to the well-being of the St Lucia estuarine system need a research focus to provide the information-base to underpin management.

3.2 Aims/Objectives

To better understand the dynamics of the St Lucia wetland system at a local to regional scale, by building an improved knowledge base of the dynamics and role of the freshwater wetlands and the role of the whole system in a dynamic landscape context.

Specific objectives:

1) To develop an **inventory and classification** of the wetlands of the areas peripheral to Lake St Lucia. As part of this task, it is necessary to understand the hydrology of each wetland, its setting in the landscape, and to describe the species of plants and animals as well as the communities that occur in the individual wetlands.
2) To understand the **hydrological and hydrodynamic functioning** of the freshwater wetlands associated with the rivers flowing into the St Lucia lakes. The focus should particularly be on those wetlands with the highest degree of connectivity to the St Lucia estuarine system, e.g. the Mkhuze and Mfolozi Swamps.
3) To understand the **importance of the groundwater systems** that influence the St Lucia system. This should include groundwater impacts on the water levels, salinity and vegetation in different parts of the system, and the system as a whole. An important feature is the dependency of the lake-fringe vegetation on groundwater.
4) To understand the **role of these wetlands** in the physical dynamics of the lake system, e.g. through sediment trapping and evapotranspiration.
5) To understand the role that these wetlands play as **refuge areas for biodiversity** in the St Lucia system (especially during hypersaline periods in the lake) and what is their contribution to habitat and species diversity.
6) To understand the **regional importance of the St Lucia system**. This would include the dynamics of the St Lucia system in relation to that of wetlands in the region, to ascertain whether (or under what conditions) it can provide critical habitat for regional biodiversity; and the degree to which the system forms part of a network of habitats used by birds in the region.

3.3 Methods/Approaches

3.3.1 An inventory and description of the wetlands

This is to achieve objective (1) above and would build on the work done by Goge (2003). The work needs a systematic approach and should include all the wetlands of the area. It should document the types of wetlands, their geomorphic situation, their hydrology drivers, their evolution and trajectories of future change, the biotic expressions as a result of their physical dynamics, and their conservation values. Once classified, the wetlands need to be mapped. For each wetland the main physical characteristics should be described and an inventory conducted of its biota. Threats need to be identified and sensitivities to disturbance highlighted – and if necessary, management requirements articulated. Although there is an importance of the connectivity of these wetlands to the St Lucia system, they also have immense conservation value in their own right.

Wetlands have already been spatially delineated and classified at a national-scale by SANBI (2010), which means there is a coarse-resolution map of all wetlands within the study area. This will be useful in defining the boundaries of the study area and a set of representative wetlands to monitor in detail. Nevertheless, most of these wetlands have not been mapped in terms of habitat or vegetation types within them, and these characteristics will need to be described for the selected wetlands, based on remote imagery. Wetland water level changes should be monitored using water level recorders, in conjunction with the analysis of imagery.

3.3.2 Functioning and role of freshwater wetlands around the St Lucia system

This is to achieve objectives (2) to (5) which all deal with aspects of wetland processes and connectivity within St Lucia and its adjacent areas.

River-dependent wetlands

Some basic work has been done (Garden 2008, Van Heerden 2011, Ellery et al. 2003, Ellery et al. 2013.) which needs to be built upon. Analysis of cores to provide sediment types, deposition rates and insights into palaeo-environments and processes is a field which would, by understanding the past, give insights into current dynamics and likely trajectories of change.

To understand current pressures research should focus on historical and present-day land-use patterns and the prediction of future trends. This will give an understanding of the impacts of human-caused transformations and how to manage and reduce these impacts.

Groundwater-dependent wetlands

In the sand-aquifers of the Maputaland Coastal Plain, many of the wetlands depend on groundwater. This was recognised in the early 1970s when a network of shallow boreholes was installed on the Eastern Shores. These have been monitored since then – and provide valuable long-term monitoring of the responses of the groundwater table to changes in rainfall and land cover. Recently this monitoring network has been enhanced by SAEON who have installed loggers in some of the boreholes to provide better insights of how the system responds to rainfall events (Kelbe et al. 2013). Another recent initiative is that of the Mgobezeleni Catchment Study near Sodwana, where DWA have established a number of deep boreholes and shallow ones are also being installed. One purpose of these initiatives is to develop a high-resolution hydrological model for the region.

The modelling and long-term monitoring provide opportunities for researchers to develop projects that make use of these to support their own studies that may require detailed hydrological information. These include studies on geology, water chemistry, palaeo-environments, solute transport, responses of plants to hydrological regimes, soil and peat formation, and issues relating to changes in land-use and settlement patterns.

One subject that is very important is to describe the vegetation successions that occur during a decadal wet-dry cycle. This should be initiated by the setting up of fixed vegetation monitoring transects at sites that are affected by water level fluctuations.

Some of the groundwater-fed wetlands contain deep peat deposits – the deepest being the 10 m peat in the Mfabeni Mire. The peat deposits contain pollen which can be analysed with dated layers of peat to provide insights into past environments (Finch & Hill 2010). There is still scope for more work using this natural archive of past environments and climates.

A particular problem relating to the peat soils is that of gardening in them, e.g. on the Mfolozi floodplain. This requires that the natural vegetation is cleared and that the peat is drained. This damages the peat and is unsustainable. A research focus on this issue may be able to assist with better management of this valuable resource.

Ephemeral rainfall-dependent wetlands

Generally, as they tend to be endorheic, these wetlands do not have much connectivity to other wetlands and to St Lucia. However they are important components of the biotic diversity of the park as they support rare species – especially of frogs and crustaceans and a fish that can survive short-term desiccation. The species in these wetlands are adapted to the very special conditions that occur in these habitats. These wetlands also tend to be highly variable – drying out in dry periods and filling in response to rainfall events.

Role of freshwater wetlands in the physical habitat dynamics of St Lucia

The ongoing iSimangaliso study being funded by the GEF has produced a DEM of the entire area up to the 5 m contour, based on LiDAR and bathymetry surveys. This will enable high-resolution hydrological studies to be undertaken and linked to patterns of biotic distribution. This DEM does not cover the bulk of the Mkhuze swamps as aerial LIDAR information is not useable from certain areas of the swamp and land-based surveys are virtually impossible.

The iSimangaliso study will also generate information on the extent to which the freshwater wetlands surrounding St Lucia may experience back-flooding from the estuary; based on the extent to which this could penetrate beyond the 5 m contour line. However, it will not describe the full extent of any such back-flooding, and may not necessarily shed light on the extent to which these wetlands depend on such back-flooding, as historical data are not available to compare the extents of flooding with the extents of the wetlands over time. Thus this study will undertake monitoring and modelling of the hydrodynamics of the wetlands to determine factors influencing the extent of wetland habitats.

Another focus needs to be on sediment accumulations in all the wetlands. Humphries (2006, 2008) has studied the dynamics of precipitates in the Mkhuze Swamps. Van Heerden (2011) has initial estimates of sediment depths in the Mfolozi Swamps, and how these are slumping and becoming more compact over time. The accumulation of sediments in Lake Teza (Scott & Steenkamp 1996, Neumann et al. 2010) and in the St Lucia mouth (Wright 2010) have been studied, and the results used to indicate rates of sedimentation and also to provide an estimate of palaeo-environments. These data are useful in understanding sediment formation of the area and the processes giving rise to such formations.

A sedimentation study should investigate the extent to which the floodplain wetlands influence the sediment dynamics of St Lucia Estuary, firstly by estimating the extent to which sediments are removed from water flowing into the estuary, and then by incorporating this into models of water quality and sediment dynamics within the estuary. The impact of canalisation of floodplains and swamps will also be investigated. The study will require monitoring of sediment transport into the wetland systems and modelling of the extent of sediment trapping based on the detailed hydrodynamic models described above.

3.3.3 The connectivity of wetlands

A study to achieve objective (6) is needed which assesses the regional connectivity of wetlands, and also includes parts of objectives (5) and (2) which deal with the more local connectivity. This is particularly important for the use of the region by birds, but also includes, inter alia, the connectivity for fish, frogs, insects and plants. Connectivity may also mean the inflow of river-borne pollutants (such as seepage from mine dumps, DDT, fertilizers and other agricultural chemicals) and the associated eutrophication and other ecosystem responses. Also of concern is the connectivity relating to the spread of diseases (such as botulism, avian flu and bilharzia), as well as alien invasive species (such as the plant *Hydrilla* and the snail *Tarebia*).

Future bird studies will build on the work currently being done by Dominic Henry who is conducting a regional study on the ducks of the Maputaland coastal plain. It will investigate landscape-level dynamics both from a structural perspective (i.e. the pattern of resources in the landscape) and from a landscape connectivity perspective (i.e. the functional relationship among those resources or habitat patches due to their spatial distribution and the movement of organisms in response to landscape structure; Taylor et al. 1993, With et al. 1997).

There are many kinds of bird movements, such as forays to find breeding sites, movements between breeding and feeding areas, and movements to moulting areas. One of the most common ways of studying these movements is by marking, followed by monitoring to record sightings of marked birds. However, the chance that a research team will encounter marked individuals diminishes rapidly with distance, and mark-recapture methods require a greater than 50% probability of recapture to generate meaningful results (Haig et al. 1998). If this is not feasible, then regular counts of all the wetlands in the study area can also provide useful data for the analysis of wetland use, and where large areas are involved, this can be done by aerial surveys (e.g. Guadagnin et al. 2005, Guadagnin & Maltchik 2007). Radio or satellite telemetry is a powerful tool for studying movements but is limited by cost and the size and longevity of batteries, and so usually involves a relatively small sample size (Samuel & Fuller 1996, Roshier et al. 2008). One can also use population-specific molecular markers, but this requires capturing birds at all the sites under study. Thus it is usual to use a combination of these methods.

Movement studies need to be scaled temporally and spatially to match the attributes of the species being studied. It is thus advisable to restrict the study to a subset of species encompassing a range of life-history patterns, and a similarly selected variety of wetland sites. It may also be useful to complement the findings with the use of landscape-level population dynamic modelling in order to investigate factors affecting persistence of species in the region (Haig et al. 1998). It is therefore proposed that the study involves (a) monitoring of environmental conditions, including rainfall and wetland hydrological and vegetation characteristics, (b) regular monitoring of waterbird numbers, (c) satellite telemetry and (d) population modelling.

Regular counts should be made by aerial census of a representative set of wetlands and be undertaken every one to two months for a period of two years. Given that the St Lucia Estuary is already counted by air, this would amount to an extension of the existing counting method. Because of the limitations of counting from the air, the study will need to focus on larger species, and not on waders, passerines or species that tend to occur under cover of vegetation. Analysis of these data, extended into modelling studies for selected species, should provide insights into which wetland complexes are important to specific assemblages of waterbirds. Ground and/or boat based counts on other wetland bird species could be used to complement the information obtained from the aerial counts.

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THEME 4: PALAEOENVIRONMENTS AND GEOMORPHOLOGICAL EVOLUTION

Greg Botha, Marc Humphries, Andrew Green & Jemma Finch

4.1 Rationale/Motivation

The development of the St Lucia wetland system is closely connected to the geological and geomorphological processes that influenced the Maputaland coastal plain during the Quaternary Period (the last 2.6 million years). The evolution of the wetlands is inextricably linked to the glacio-eustatic cycles that resulted in climatic changes associated with dramatic fluctuations in sea-level. Understanding the changing geomorphic process balances between opposing fluvial and marine influences on the lacustrine basin is key to the management of the system in response to present anthropogenic and environmental stressors and the impact of global change.

Anthropogenic stressors brought about by increased population density and agricultural development over the past few centuries have triggered changes in the vegetation cover, degradation of catchment soil landforms, altered runoff response and increasing fluvial sediment load (Stretch & Maro 2013). Canalisation of the lower river channels, dredging of the narrow marine interface and catchment discharge variability due to global climate change will compound the insidious rise of sea-level and climate change influences, summarised recently by Mather et al. (2013). Co-ordinated multidisciplinary scientific research is necessary to address knowledge gaps and to predict how future changes could impact the ecosystem, possibly challenging the resilience of this environment and its biota to short-term changes.

Most South African coastal lake systems evolved from fluvial networks during the Last Glacial Maximum (LGM ~18,000 BP) that were slowly drowned by the rising sea levels of the Holocene (Wright et al. 2000, Cooper et al. 2012). These coastal lakes thus comprise a type of incised valley system reflecting a sea-level cycle of fall and subsequent rise (e.g. Zaitlin et al. 1994, Cooper et al. 2012). The infilling of these incised valleys by sediment represents a change from early, high-energy fluvial deposition to more tranquil deposition as these systems evolved from transitional marine incursion to lagoonal and lacustrine conditions associated with the rising sea-level of a marine transgression followed by the withdrawal of the sea during the regression (Wright et al. 2000). Lake St Lucia is no exception; the lake bed is underlain by a complex network of buried river channels (Van Heerden 1987, Green 2009) which reflect almost continual deposition since the start of the Holocene period. The positioning of these channels, spatial distribution of the infilling sediment packages and the architecture of these deposits provide insight into the complex relationships between sea-level variation, sediment supply and the sedimentological/geomorphological response of the lake system to these primary forcing agents (e.g. Green et al. 2013).

Multidisciplinary scientific studies conducted in the region have interpreted the Quaternary sedimentary record to expose the influence of marine transgressions and regressions on the extent and depth of the lake system and surrounding dune landscape (Orme 1973, Wright et al. 2000, Green & Uken 2005, Botha & Porat 2007, Porat & Botha 2008). The St Lucia lake basin ecosystem has alternated between that of a marine embayment and shallow continental shelf environment for short intervals between longer periods when the littoral environment became sub-aerially exposed as a shallow valley incised by river channels during sea-level lowstands (Botha et al. 2013). The lake shoreline has constricted since the sea-level highstand of the early Holocene Epoch, reaching the present extent with restricted marine influence during the past ~1000 years (Botha et al. 2004). The system evolved during a period when the influence of the earliest pastoralists and agricultural practices had already been established but it is the direct impact of ever increasing catchment modification during the Anthropocene that has mobilised scientists to improve their understanding of the direct impacts on the estuarine environment and semi-restricted lacustrine basin.

4.1.1 Lake sedimentological studies

The comprehensive, multidisciplinary assessment of the status of Lake St Lucia and its catchments by the "Commission of Enquiry" (Kriel 1965, Kriel et al. 1966) included an assessment of the unconsolidated sediment infill using steel probing rods along transects to record the thickness of mud. Penetration of 15 m was achieved, defining steep sided, infilled depressions below the lake bed. Using an average sediment load of 0.5% of runoff derived from the catchments, the rate of sediment accumulation within the lake was deduced. Radiocarbon dating of sediments from depths of up to 9 m yielded age estimates in the 1,820 to 3,960 years BP range, from which the oldest sediment infill was extrapolated to have accumulated since ~ 4,900 years BP (Kriel et al. 1966).

These findings suggest that current sediment accumulation rates are about three times the average rate of the past (Kriel et al. 1966). This does not take into account the changing climate of the mid to late Holocene, nor the effect of a possibly higher lake level and current circulation within the deeper lake channels.

The drilling of seven boreholes which were sunk to bedrock in False Bay, Hell's Gate, the northeastern shallows and Catalina Bay was reported by Vogel & Van Urk (1975) who measured isotopic ratios and derived radiocarbon dates from organic matter and shells in the sediments at various depths. Foraminiferal evidence derived from analysis of seven cores (Phleger 1976) showed that intermittent marine incursions were common during the Holocene sedimentation history of the lake. Cholnoky (1965) studied the diatom flora down to 20 m from a borehole at Hell's Gate and regarded the sediment as being chiefly of marine origin. A sedimentological analysis by Van Heerden (1975) of a core from southern False Bay near the confluence of the Hluhluwe River provided a detailed analysis of the 12.2 m of lake sediment overlying bedrock. Granulometric and statistical analysis provided the basis for interpretation of the accumulation of basal lagoonal mud and overlying sandy tidal channel deposits being replaced by deposition of flocculated clays from suspension in a water body with reduced tidal influence dominating the upper 5 m of the profile.

Fortuin (1992) reported on a bathymetric and sediment sampling survey of the lake along 32 east-west oriented traverse lines sited about 1 km apart. The 400 sediment samples were sieved and the silt/clay fractions analysed using a Sedigraph. Monitoring of sediment accretion on the lake bed was initiated by the Department of Water Affairs (1978, 1984, 1985) and hydrographic surveys along traverses across the lake to determine the lake water capacity. A bathymetric and seismic survey of the lake conducted by the CSIR during 1985 produced a bathymetric map (Sydow & Van Heerden 1987a) and represented the lake palaeosurface during the LGM sea-level lowstand (Sydow & Van Heerden 1987b).

Using bathymetry and sampling along traverses across the estuary, Wright (1995) studied the sediment dynamics of the St Lucia and Mfolozi estuary mouths during 1988/1989, following the 1984 and 1987 flood events. This sedimentological study showed how shoaling of marine sediment in the estuary mouth had continued despite dredging and deepening.

4.1.2 Mfolozi and Mkhuze River floodplain sedimentological studies

Lake St Lucia is constantly changing in response to fluctuating discharge and sediment introduced by the five fluvial systems that feed into the lake. The Mfolozi and Mkhuze rivers are the largest of these and thus constitute the primary fluvial inputs to the lake in terms of water flow and fine sediment transport. Tidal influx of marine sediment is restricted to the estuary below Honeymoon Bend. While sediment input to Lake St Lucia from the river catchments is often viewed as a threat to the system, the freshwater that these rivers supply is vital for the long-term conservation of the lake. From a wetland management perspective it is therefore necessary to incorporate knowledge regarding these catchment systems into the overall understanding of the processes operating at Lake St Lucia. The dynamic system is at a point in its geological evolution when lake processes are sensitive to changes in runoff, sediment supply, and nutrient input. In particular, the effects of upstream human-induced modifications, such as land use change, water diversions, and canalisation on the functioning and evolution of Lake St Lucia need to be recognised.

The Mfolozi and Mkhuze floodplain systems occupy incised valleys that formed during the LGM when sea level was ~120 m below that of today (Ramsay 1995). Subsequent sea level rise flooded these valleys and formed basins that were once part of an ancestral Lake St Lucia (Orme 1973). These basins have gradually been filled by sediments brought down by the Mkhuze River in the north and the Mfolozi River in the south. While the larger Mfolozi River has largely filled its valley, infilling of Lake St Lucia at its northern margin by the smaller and more variable Mkuze River is still in a premature stage. The Mkhuze delta is currently expanding into the Mbazwana swamp and northern section of Lake St Lucia. McCarthy & Hancox (2000) estimated that the delta had advanced about 25 km during the past 6500 years, an average of 3 m yr^{-1}.

Knowledge regarding the hydrology and sediment dynamics of the fluvial systems that enter Lake St Lucia is rather limited. The Mfolozi and Mkhuze rivers are both highly variable in nature, typically characterised by low flow, but also prone to large episodic flood events (Grenfell & Ellery 2009). Although infrequent and of short duration, these floods carry much of the annual river flow and it is during these periods that most geomorphologic changes occur (Grenfell et al. 2009). The floodplains are vital sinks for clastic sediments and provide considerable benefits to Lake St Lucia with respect to water quality. Input of sediment onto the floodplain typically occurs only during flood events when rivers overtop their levees and sedimentary fill is dominated by clastic sediments, composed largely of silt and fine sand (Grenfell et al. 2009, Humphries et al. 2010a). Using ^{127}Cs and ^{210}Pb techniques, Humphries et al. (2010b) calculated average sedimentation rates on the Mkhuze floodplain of 0.25 to 0.50 cm yr^{-1} for the last 100 years. In addition to the role the floodplains play in retaining particulate material, the Mkhuze floodplain is also recognised as an important site for chemical sedimentation, trapping and immobilising solutes within the sediments (Humphries et al. 2010a, Humphries et al. 2011).

Aggradation along the Mkhuze and Mfolozi river channels has resulted in the formation of numerous blocked tributary valley lakes, such as Teza and Futululu on the Mfolozi floodplain, and Muzi and Yengweni on the Mkhuze floodplain. The sedimentary infill of Lake Teza and Lake Futululu has been described by Scott & Steenkamp (1996) and Grenfell et al. (2010), respectively, while Neumann et al. (2010) examined a palynological record from Lake Teza and interpreted changes in Holocene vegetation. Scott & Steenkamp (1996) noted dramatic increases in sediment deposition rates over recent decades in the record they examined. Similar trends have recently been found within lake deposits on the Mkhuze floodplain (Humphries et al. in prep.) and indicate significant impacts associated with human activity in the two largest catchments supplying water and sediment to Lake St Lucia. These observations are supported by the modelling results of Maro (2012) and Stretch & Maro (2013) which show marked increases in catchment sediment yields as a result of land use change.

4.1.3 Palaeoenvironmental studies

Long-term records of environmental and climatic change are required to provide benchmark understanding of natural variability over ecologically meaningful timescales (Willis & Birks 2006, Brewer et al. 2012). Growing emphasis on long-term environmental monitoring has provided motivation for palaeoenvironmental research initiatives, which can provide a unique perspective on change through time. The recent climatic warming trend has strengthened the call for such studies, as regional climate models require palaeoenvironmental datasets for validation through data-model comparisons. Continuous lake sequences and deep sedimentary deposits are rare in southern Africa, resulting in a spatially and temporally discontinuous representation of palaeoenvironmental history across the subregion, based largely on small wetlands with limited catchment size (Scott 2000, Chase & Meadows 2007, Nash & Meadows 2012, Stager et al. 2013). Several key investigations from South Africa have been undertaken, derived from a range of natural archives, viz. speleothems (Lee-Thorp et al. 2001, Holmgren et al. 2003), hyrax middens (Chase et al. 2010, 2011), peatlands (Grundling et al. 1998, 2000, Finch & Hill 2008) and coastal lake systems (Neumann et al. 2008, 2010, Stager et al. 2013). However, available records are often coarsely dated and/or inadequately-resolved (Stager et al. 2013), limiting the reliability of long-term data concerning climate change and environmental response.

Current understanding of late Quaternary palaeoenvironments in the greater St Lucia region has been derived from a series of coastal lakes and interdune wetland peat deposits associated with the Maputaland Coastal Plain (e.g. Scott & Steenkamp 1996, Neumann et al. 2008, 2010, Stager et al. 2013, Grundling et al. 1998, 2000, Mazus 1996, 1997, 2000, Finch & Hill 2008, Turner & Plater 2004, Scott et al. 1992, Oschadleus et al. 1996). Lake Teza (Neumann et al. 2010) and Lake Sibaya (Neumann et al. 2008, Stager et al. 2013) and have yielded high resolution pollen records for the Holocene, and late Holocene, respectively. The majority of peatland sediments in the area are of Holocene age (Grundling et al. 2000), with the exception of the c. 45,000-yr old Mfabeni Peatland on the eastern shores of Lake St Lucia (Finch & Hill 2008).

These records provide a coarse understanding of long-term climatic variability and short-term anthropogenic impacts on the landscape for the greater St Lucia area. However, additional data are required to improve temporal resolution and account for spatial variability and site-specific ecosystem-response. High-resolution palaeoenvironmental reconstructions, particularly for the Holocene period, should be undertaken for all sedimentary archives in the greater St Lucia area to provide a more detailed understanding of past climatic and environmental change in the lake and surrounds. These data can provide unique insight into natural variability within the broader lake system and link into climate change modelling at the regional scale.

The sedimentological and palaeoenvironmental studies proposed will build on the foundation of multidisciplinary research reviewed above, justifying a stand-alone research theme. This research will derive critical data from “Theme 1: Catchment Hydrology and Hydrodynamic Processes”, which will address catchment discharge and sediment yield aspects.

4.2 Aims/Objectives

A focus area during the “Commission of Enquiry” (Kriel et al. 1966) into St Lucia was the rate of sediment accumulation and calculations of the effect of increased sediment yield from the catchments on the lake’s ecosystem and potential impacts on the sustainability of the lake ecosystems. A similar range of concerns were expressed by the participants at the 1992 workshop organized by the St Lucia Scientific Advisory Council (SCADCO). Group discussions highlighted the lack of evidence of significant sediment deposition in the lake and the role of the Mfolozi/Mkhuze swamps as sediment sinks. The meeting concluded that long-term sediment accumulation and redistribution monitoring in the lake and continuous monitoring of salt and sediment loads at hydrological gauging stations on the rivers discharging into the system was necessary. Evaluation of the sediment trapping efficiency of the Mkhuze swamp was identified as a priority. It is clear that many of the same issues raised by the Kriel et al. (1966) and 1992 assessments remain unanswered or the accuracy of critical data is of low precision. Connectivity of the Mfolozi and Mkhuze floodplains is of critical importance to the future of Lake St Lucia. Knowledge of the processes taking place on these floodplains is thus crucial in understanding the role of anthropogenic impacts on the future development of Lake St Lucia. Future work on the Mkhuze and Mfolozi systems should thus be aimed at addressing such issues.

Future multidisciplinary earth science contributions towards the proposed research programme addressing the broad St Lucia wetland system must be based on the understanding of high resolution sedimentary records that permit adequate chronological contextualisation of the geomorphological processes and environmental changes which are reflected by the response of different ecosystem components.

4.2.1 Proposed thematic research objectives

The contribution of geomorphological and palaeoenvironmental change research to the understanding of the St Lucia wetland system over time and the significance of forcing factors in the future, must address the following components:

a) Catchment influences including vegetation cover and landuse change, runoff variability, sediment yield from different parts of the catchment and fluvial sediment loads under the normal range of seasonal flows and extreme flood conditions. This aspect will be the focus of a specialised modelling investigations of Quaternary and Quinary catchments under “Theme 1: Catchment Hydrology and Hydrodynamic Processes”, which should expand the modelling undertaken by Stretch & Maro (2013) on the Mfolozi catchment. However, detailed mapping of erosion features and susceptible sediments within these areas or assessment of records of palaeo- and historical erosion falls within the ambit of Theme 4, the geomorphological and palaeoenvironmental studies group.

   Catchment studies should also focus on the identification of extreme events that cause severe ecological changes which could be recorded within the sedimentary records of floodplain pans or protected parts of the main lake basins.

   Intensification of small-scale commercial agriculture and an increase in the number of people living in the catchment area of the lake have raised concerns regarding the deterioration in water quality entering Lake St Lucia. Historically, little regular water quality monitoring has taken place and knowledge regarding nutrient fluxes and accumulation trends thus represents a critical element of broad based studies into long-term changes in the system.

b) Lacustrine systems including the semi-restricted estuarine lake, tributary rivers close to the confluence with the lake shore, floodplains and isolated pans in the surrounding dune landscapes are suitable sites where multiproxy evidence can be collected to undertake palaeoenvironmental reconstruction as a basis for inferring long-term environmental change. Identification of the critical forcing factors can inform management recommendations. Coring using specialised vibra-coring apparatus should, where possible, be preceded by seismic profiling in order to identify deep channel fills.

c) The estuarine and littoral marine environment including longshore and beach sediment processes and sedimentation associated with mangrove systems at the freshwater interface are a critical aspect.

d) Although unlikely to influence the system in the near future, the relationship between the rivers feeding the lacustrine environment and the continental shelf in the geological past, represent a dynamic that is represented in the lake bed sedimentary record and must be clearly understood. Seismic profiling of buried channels beneath the lake bed and in the shallow continental shelf zone could identify zones of fresh groundwater discharge beneath the coastal barrier dunes.

4.3 Methods/Approaches

4.3.1. Sediment sources, sedimentation rates and geomorphological evolution

Mapping of buried channels and interpretation of lake sedimentary records

Early attempts to determine the thickness of lake sediments above bedrock using geophysical techniques include the electrical resistivity sounding traverses conducted by the CSIR (Van Zyl 1971) and subsequent seismic profiling by Sydow & Van Heerden (1987b) revealed buried channels more than 35 m deep (Van Heerden 1987). A series of deep penetration, low resolution seismic profiles were produced along the Eastern Shoreline by Soekor in the 1970s as part of a regional oil exploration programme.

Incised valleys and their fills are best examined by means of very-high to ultra-high resolution seismic profiling techniques (e.g. Nordfjord et al. 2006). Seismic profiling reveals subtle variations in the acoustic properties of the sediment beneath the lake floor and allows for the extrapolation of discrete depositional environments and key unconformity surfaces based on acoustic intensity and the geometry of seismic reflectors (Vail 1987). By providing a dense grid of seismic reflection profiles, channel surfaces and their key infilling packages can be identified and their spatial distributions mapped throughout the lake system. Similar studies have been conducted on the Lake Sibaya (Miller 2001) and Kosi Bay (Wright 2002, Cooper et al. 2012) systems to great effect. However, the degree of resolution of the seismic tools used in these studies can be greatly improved upon by use of modern CHIRP seismic sub-bottom profilers that can image subtle contrasts in sediment density at the centimetre scale. This tool can thus delineate extremely fine details within typically condensed sedimentary records of lacustrine systems (e.g. Colman et al., 2002; Colman et al., 2013). As this tool operates at both low-end and high-end frequencies, a complete high resolution image of the channel base and its fill can be obtained. The ultra-high resolution CHIRP seismic data would be collected from the main lake basins and comprise a grid of coast parallel and coast perpendicular sections spaced 500 m apart, the density of which is sufficient to image the underlying 18 000 BP incised valley and fill.

Though some delineation of the various depositional environments can be made from the seismic profiles, this is a remote sensing tool that must be supplemented by groundtruthing in the form of coring. By accurately delineating targets of interest via remote sensing, the coring programme can then focus specifically on areas of interest. These include deposits that may not be intersected by random core siting. Coring would involve a barge mounted vibrocorer capable of retrieving up to ten metres of continuous sedimentary material. Due to the length of cores it is unlikely that any given core can penetrate through the entire Holocene sedimentary sequence. In this case it is imperative that detailed seismic mapping proceeds first so that a mosaic of targeted cores can reflect the entire record of infill for the lake system.

The key coring targets comprise early fluvial deposits, palaeo-beaches and drowned barriers, lagoonal sediments and early lacustrine deposits. This succession provides a near continuous record of the Holocene evolution of Lake St Lucia, in particular its transition from a river system to a segmented coastal water body. The targeting of these deposits will be based on their depth and accessibility to the coring platform and again will be focussed throughout the main lake basins. Once cores have been taken, these are then reconciled with each seismic unit and dated according to their key sedimentary units and surfaces. By further extrapolation based on the seismic coverage, the entire lake system's temporal and spatial geomorphic and sedimentological evolution can be examined and related to forcing agents such as sea-level, climate and sediment supply.

Catchment sediment yields and lake bed accretion are strongly influenced by large episodic flood events and it is necessary to understand these events from a long-term geological perspective. Extreme events such as Cyclone Domoina also result in rapid and severe ecological change. Cores are needed to unravel past sedimentary processes and detect important historical events. The frequency and influence of such events is important to understand, as such impacts are likely to increase in severity in response to anthropogenic pressures and climate change. Wetland and floodplain lake deposits offer potentially useful palaeo-archives from which long-term environmental changes can be interpreted.

Further applications of the geophysical data set include the imaging of faults (e.g. Colman et al. 2002, Doughty et al. 2013) and the underlying acoustic basement geology. The role of neo-tectonism and antecedent geology on lake evolution may thus also be examined, especially considering many international models of lake infilling consider these as dominant evolutionary controls (e.g. Dingler et al. 2009, Doughty et al. 2013).

Characterisation of fluvial sediments and sedimentation rates

The St Lucia system has been subjected to extreme ocean wave action and tidal surge, as well as high intensity river flood events and increasing anthropogenic impacts, over the past few centuries. The most sustained threat results largely from upstream modifications and land use change that have occurred in the Mkhuze and Mfolozi River catchments. Although the accumulation of fluvial sediment within the lake has remained a recurrent management issue, there are few accurate records against which future trends in accumulation can be assessed. Sedimentary records from wetlands and floodplain lakes can serve as a basis for interpreting the impacts associated with catchment change and the Mkhuze and Mfolozi systems are host to several deposits that offer potential. Recent sedimentation rates and changes associated with anthropogenic activities in the catchment can be accurately reconstructed through the detailed analysis of well-preserved sediment records extracted from the lake bed or wetlands using vibra-coring apparatus.

Verification of the long-term average lake sedimentation rate calculations that have been presented in published literature requires a structured approach to sampling the lake bed in order to derive accurate figures and include:

- Accurate measurement of suspended and bed load sediment in the major tributaries at the entrance point to the lake across seasonal discharge variations in order to derive peak and average sediment loads.
- Assessment of lake margin erosion on the sandy Eastern Shores to derive local sediment contributions.
- Coring of the lake bed in each of the major compartments on a grid pattern with numerous radiocarbon dates to establish uniform sediment accretion patterns that can be used to derive long-term average sediment accretion rates. Seismic profiling is necessary in order to correlate the sedimentary successions within buried channel

with the thinner deposits on the ancient floodplain margins where sediment accumulation rates were probably significantly slower.

- Delineation and characterisation of flood event deposits and bracketing within the sedimentary successions to reduce the influence of extreme sediment deposition events from normal deposition.
- Measurement of sediment compaction rates and derivation of meaningful bulk density data.
- Measurement of suspended sediment loads in flood waters leaving the system via the estuary. This is necessary in the mass balance equation to calculate the relative volumes of fluvial sediment input and sediment eroded or entrained in waters leaving the lake.

Water quality and nutrient flux

A lack of essential long-term monitoring data for the river catchments makes it necessary to rely on palaeolimnological methods to detect potential changes in trophic state and provide baseline data to support future monitoring efforts. Sediment records can be used to reveal information about catchment run-off and changes in nutrient availability over time. Attention should be given particularly to the nutrients which influence lake productivity, such as organic matter, nitrogen, and phosphorus.

4.3.2 Palaeoenvironmental change analysis

Proxy analysis serves as a remote sensing tool, providing snapshots of environmental conditions at particular points in time. When analysed along a continuous sedimentary record extracted from a lake or peat deposit, these tools can provide high resolution records of change through time. Accelerator Mass Spectrometry (AMS) radiocarbon dating can be used, in concert with complementary Optically Stimulated Luminescence (OSL) or radioisotope dating techniques, to provide tight chronological control for such records.

There are a growing range of proxies available for palaeoenvironmental reconstruction which include, *inter alia*, microorganisms, palaeobotanical evidence and geochemical signatures.

a) Fossil pollen analysis, or palynology, is one of the most widely applied techniques for detecting past environmental change (Edwards 1983). Pollen grains are extremely resistant to decay and morphologically diverse, thereby lending themselves to detailed analysis. These microbotanical indicators can be applied to create reconstructions of past vegetation communities surrounding a sedimentary deposit. Depending on the size and characteristics of the deposit, the fossil pollen assemblage may be more representative of the local or regional vegetation cover. This technique can be combined with quantification and size-classing of microfossil charcoal, to provide an indicator of past fire regimes (Whitlock & Larsen, 2001).

   The most complete records are typically from enclosed or semi-restricted interdune wetland basins. The detailed studies conducted on cores from Mfabeni wetland (Grundling et al. 2000, Finch and Hill 2008) provide palaeoenvironmental information for a groundwater fed wetland that discharges into the main lake. Other studies have analysed core from Lake Teza in the Mfolozi catchment (Scott & Steenkamp 1996, Neumann et al. 2010), Lake Sibaya (Neumann et al. 2008) and Mdlanzi swamp near the Mkhuze swamps (Turner & Plater 2004) have provided evidence of the anthropogenic impacts on the lakes. The rapidly increasing rates of sediment accumulation in these lacustrine settings highlight the impact of human settlements, agriculture, forestry and road construction. However, the proxy indicators from these settings reflect environmental change on the major rivers or parallel, largely disconnected wetland components of the system.

The Meme wetland on the northern lake margin and Selley's lakes are isolated from the main lake basin by raised beach ridges. The wetland was an integral part of the main northern lake system during the early to mid-Holocene marine transgression and was closed off from the main lake during the late Holocene marine regression. Coring and analysis of sediment from this wetland will provide the best opportunity to identify the environmental conditions that existed while the northern lake basin had a direct marine link, possibly located in the area near Leven Point. The sedimentary succession should also reflect the changing salinity and sedimentation conditions as the marine link was sealed by accretion of the high coastal barrier dunes in the late Holocene (Porat & Botha 2008).

Wetland and floodplain lake deposits offer potentially useful palaeo-archives from which long-term environmental changes can be interpreted. The lower floodplain reaches of the Hluhluwe, Mzinene, Mkhuze and Nyalazi Rivers should be investigated to identify possible wetland sites where short-term records can be derived covering a period over the past several hundred years. Borehole cores from the lake bed have yielded evidence of the reduction of marine influence and increased fluvial sediment accumulation in the lake over the past several thousand years (Van Heerden 1975). Proxy indicators from sediment in protected freshwater wetland environments are more likely to preserve indicators of catastrophic flood events that must be factored into the assessment of sediment accretion rates.

b) Microfossils, such as diatoms and foraminifera are sensitive to environmental parameters and are useful proxy indicators for changes in pH, nutrients and salinity. Microfossil analysis that have contributed towards the present understanding of the changing lake environment include that by Cholnoky (1965) who studied the diatom flora of St Lucia from 12 boreholes down to 10.5 m and regarded sediments in lagoon as chiefly of marine origin. Stabell et al. (2004) described the diatom flora from a shallow core near Brodie's Crossing. There is some concern regarding the preservation of diatoms at depth in the lake bed sediments.

c) Analysis of carbon and nitrogen isotopes within sediment can provide insight as to the relative contributions of C_3 and C_4 plants within a system, in addition to the proportion of aquatic and terrestrial plants contributing to sediments (Meyers & Teranes 2001, Mackie et al. 2005). Combined, these techniques can be used to provide a holistic picture of environmental change through time, based upon independent lines of multi-proxy evidence (Lotter 2005).

The contribution of earth science research towards the long-term evaluation, monitoring and management of the St Lucia wetland system poses challenges from the perspective of geological and geomorphological paradigms. The Hutton/Lyell doctrine of "Uniformitarianism", being "The Present is the key to the Past" where slow incremental changes are recorded by geological records, cannot be applied uncritically to the St Lucia wetland 'sink' or the river catchment 'source' areas. From a wetland ecosystem perspective, the gradual geomorphological processes of marine transgression and regression and sediment aggradation within the lacustrine environment, place stresses on all associated biota that lead to changes, evidence of which can be preserved in lake bed strata. The most significant short-term impacts on the system imposed by floods, droughts and anthropogenic intrusions, all represent potentially far-reaching impacts that would be reflected as material evidence in the geological record of the "Catastrophism" doctrine espoused by

Cuvier. The increased rates of geomorphological process change and addition or removal of sediment from different parts of the wetland system that are achieved over short timescales, represent significant changes in the process balance that also stimulate short-term responses by biota. A holistic view of the ecosystems from the cyclical, long-term geomorphological perspective is necessary in order to contextualise seemingly catastrophic short-term impacts. Critical events in the history of the system must be identified in order to define the period that will determine the baseline environment which management policies strive to conserve in the St Lucia wetland system.

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THEME 5: BIODIVERSITY CENSUS AND INVASIVE SPECIES

Renzo Perissinotto & Nelson Miranda

5.1 Rationale/Motivation

Species are the building-blocks of any ecosystem, yet in the St Lucia case there are many misidentifications and few voucher specimens being deposited in museums or other recognised and adequately curated collections. A few detailed taxonomic studies of selected invertebrate groups have already been undertaken by the UKZN research team, starting from 2010**.** These have consistently revealed the occurrence of species that were either previously confused with others or completely unknown to science. The first alert to this happened when large numbers of an unsegmented worm-like organism appeared in macrofaunal collections undertaken at Catalina Bay and Charter's Creek during the period 2005-2009. Upon submitting photographs of the organism to local macrofaunal experts, most returns identified it as a "sipunculid" or "priapulid" worm.

A need to resolve the above controversy led to the submission of fixed specimens to a meiofaunal worm specialist overseas, Prof. Antonio Todaro at the University of Modena & Reggio Emilia in Italy. High resolution dissections in Todaro's lab proved unequivocally that the organism was not a worm but a true anemone, exhibiting several tentacles with numerous batteries of nematocysts. Specimens that had been fixed in formalin solution after collection had withdrawn their tentacles below the crown, making the anterior portion of the organism look like the introvert or proboscis of sipunculid and priapulid worms. Specimens were eventually sent for identification to the world specialist on the group, Prof. Marymegan Daly at the Biodiversity Museum of the Ohio State University. Here it turned out that the species belonged to the genus *Edwardsia,* but was unknown to science and had several features unique within the genus. It was thus described as *E. isimangaliso,* with the provision that it be regarded as a microendemic to Lake St Lucia until it is found at other localities (Daly et al. 2012).

At approximately the same time, an investigation into the dynamics and biodiversity characterising the northern part of Lake St Lucia during the most intense hypersaline phase revealed the occurrence of several taxa that had not been reported previously from the system. These included the bloom-forming cyanobacterium *Cyanothece* sp., the flatworm *Macrostomum* sp., the ciliate *Fabrea* cf. *salina* and an unknown species of harpacticoid copepod in the genus *Nitocra* (Carrasco & Perissinotto 2012). Of these, only *Nitocra taylori* has been adequately described to date (Gómez et al. 2012), while the others are still in the process of investigation/preparation under the guidance of world specialists such as David Muir (New York, USA), Tom Artois (Diepenbeek, Belgium) and Wolfgang Petz (Neufahrn, Austria), respectively. It has also been communicated that the previously recorded copepod species *Apocyclops* cf. *dengizicus* most likely also represent a new species that will eventually require description (Frank Fiers; Brussels, Belgium).

In the wake of these discoveries, it was realised that there was a strong likelihood that other taxa that were reported in past surveys may have been mistakenly identified. It also became evident that updated taxonomic studies of invertebrates and protists, including modern molecular techniques, had not been undertaken in the system. Therefore, in 2011 the first comprehensive census of the bivalve molluscs of the St Lucia estuarine system was initiated. This resulted in two species that were previously lumped with other close relatives being recognised as new to science (Nel et al. 2012), i.e. *Tellinides kilburni* and *Siliqua herberti* (Huber et al. in press). This was followed in 2012 by similar censuses of the gastropod molluscs and the true crabs, with findings revealing once again the occurrence of a snail species previously included in the Assimineidae and confused with *Assiminea* *bifasciata/ovata/capensis* (Day et al. 1954, Pillay & Perissinotto 2008, MacKay et al. 2010). A combination of molecular and morphological data has now shown that the species, tentatively identified as *Coriandra durbanensis* (Raw et al. 2013), is not a true assimineid and thus not nearly related to *Assiminea* (Van Rooyen et al. in prep.). The brachyuran census also revealed the occurrence of a freshwater crab of the genus *Potamonautes* in the streams and rivers entering False Bay, which appears to differ significantly from *P. sidneyi* to possibly warrant description as separate species (Peer et al. in press). A comparative molecular analysis is currently being undertaken to resolve this issue.

It is evident, therefore, that similar censuses are required for all other groups of invertebrates and protists, as identifications have so far relied entirely on outdated taxonomic literature and limited local expertise. To compound this, entire invertebrate phyla have been completely ignored in all investigations conducted so far in St Lucia. This is the case for most minor phyla that generally contribute substantially to the diversity and biomass of meiofauna. The first survey of the Gastrotricha was conducted in 2010 and immediately revealed the existence near the St Lucia mouth of a species previously unknown to science, *Halichaetonotus sanctaeluciae*, and another four that could not be assigned conclusively to known species, thus requiring further investigation and possible description as new species (Todaro et al. 2011). A second new species, *Kijanebalola devestiva*, was recently described, following a more comprehensive survey undertaken by Prof Todaro in February 2013 (Todaro et al. 2013) and according to the same specialist at least another 10 species are new to science, with three of them currently in description (Todaro pers. comm.).

Phyla such as Kinorhyncha, Sipuncula and Echiura are known to occur within the St Lucia system (MacKay et al. 2010; Bownes & Perissinotto 2012; Biseswar pers. comm.), but their identity to species or even genus level still remains virtually unknown. The situation is even worse when bacteria, archaea and viruses are considered. Marine sediment-dwelling bacteria are reportedly the most abundant life-form on the planet in terms of biomass, while viruses are the most numerically abundant organisms in the ocean (Nee 2004). Yet in the St Lucia system, no investigations on these organisms have been undertaken to date, with the exception of a small, selected group of cyanobacteria that were recently identified under bloom-forming conditions (Muir & Perissinotto 2011; Perissinotto et al. 2013a).

Prominent invasive species have unfortunately arrived at St Lucia during the last few decades. Among these are the gastropod mollusc, *Tarebia granifera*, which originates from south-east Asia, was probably introduced to South Africa via the aquarium trade in the early 1990s. Studies undertaken in St Lucia have shown that, although generally regarded as a freshwater dweller, *T. granifera* can tolerate high salinity levels for prolonged periods (Miranda et al. 2010). It was recorded in Catalina Bay and adjacent seepage points for the first time in 2005 (Pillay & Perissinotto 2008) and has subsequently spread through most of South Lake and the Narrows, particularly since 2011 in response to the large freshwater inflow experienced during the recent ongoing wet phase (Raw et al. 2013). *Tarebia granifera* has been shown to be an extremely successful invasive species, mainly through its parthenogenetic and ovoviviparous traits, but also though the use of chemical signals used to displace indigenous species (Miranda et al. 2011, Raw et al. 2013). Should the current freshwater dominated phase persist in St Lucia for several more years, this snail will most likely become one of the most serious threats to ecosystem integrity. Thus, further investigations on its biology, ecology and control mechanisms need to be undertaken as a matter of urgency.

Aside from *T. granifera*, at least another four alien macroinvertebrate species have been recorded so far in the lake system or in the immediate vicinity. These are the hydrozoan *Moerisia maeotica,* the heteropteran insect *Trichcorixa verticalis* and the gastropod molluscs *Pseudosuccinea (Lymnaea) columella and Aplexa marmorata* (Miranda & Adams 2013). The most recent confirmed record of an alien invasive species within the St Lucia Estuary is the Australian reef-building polychaete worm *Ficopomatus enigmaticus*. This fouling species can now be found growing on boats and jetties in the Dredge Harbour. Specimens from St Lucia were conclusively identified by Dr Harry ten Hove of the Zoological Museum, University of Amsterdam. *Ficopomatus enigmaticus* was probably introduced to St Lucia on floating debris that entered the mouth from the ocean. This serpulid worm has invaded several estuaries and coastal systems around the world (Bazterrica et al. 2013), e.g. USA, Italy, England, New Zealand, Argentina and Uruguay, and was recorded in South Africa prior to the 1950s (Day 1951). It has the potential to form extensive reefs that can affect the hydrodynamics and ecology of invaded ecosystems, as seen in Mar Chiquita Lagoon in Argentina (Schwindt et al. 2004) and the Coorong in Australia (Dittmann et al. 2009). Its invasion of St Lucia can therefore have very serious implications for the future ecology of this system.

Among the plants, prominent invasive species recorded in the St Lucia area are the tamarisk, *Tamarix ramosissima*, the Brazilian pepper, *Schinus terebinthifolius*, and the triffid weed, *Chromolaena odorata* (Miranda & Adams 2013). Both tamarisk and Brazilian pepper trees are extremely tolerant of high salinity and can form impenetrable thickets to the detriment of other plants, while *C. odorata* is exceptionally prolific and suppresses the growth of indigenous species (Leslie & Spotila 2001). The latter has also been shown to interfere with the microclimate of crocodile nesting sites, eventually causing a change in sex ratio in this animal (Combrink et al. 2013). Another species with potential to invade the estuarine habitat of St Lucia is the coastal beefwood or horsetail tree, *Casuarina equisetifolia*, which was deliberately introduced to the area several decades ago and is now regarded as an emerging weed (Miranda & Adams 2013). At least another 10 alien plant species have recently been recorded in and around St Lucia, but their potential to become invasive in the region remains unknown (Miranda & Adams 2013).

In recent decades there has been an exponential increase in marine invasive species recorded along the South African coastline. Potentially new invasive species are therefore expected to enter the system once the St Lucia Estuary mouth is re-opened and these should be identified and investigated as soon as possible. The zooplankton and benthos are likely to recruit the largest number of alien species once communication with the open ocean is fully re-established.

5.2 Aims/Objectives

The taxonomic revisions using global expertise that started in 2010 need to continue with full review of each taxonomic group, in order to provide a modern and updated identification list of the species occurring in the St Lucia estuarine system. Realistically, this can probably be achieved within a reasonable time-scale for the larger invertebrate groups, while it may take much longer to achieve significant taxonomic progress with the minor invertebrate phyla and the protists. With bacteria, archaea and viruses, on the other hand, estimates of their total abundance and biomass, and first-order identification into broad taxonomic grouping, will already represent a quantum leap forward. The main aims and objectives of this theme can therefore be summarised as follows:

a) To complete the identification to species level of all higher invertebrate groups, from the segmented worms all the way up to the chordates. This should include the life history and biology/ecology of at least the dominant and keystone species. While the molluscs have been dealt with adequately during recent work, outstanding groups include virtually all the crustaceans, with the exception of the brachyurans, copepods and mysids for which the ongoing census is already at an advanced stage. Priority orders here are the amphipods, isopods, cumaceans, tanaids, caridean shrimps, cladocerans and ostracods. It will also be necessary to investigate whether and to what extent the endemic Maputaland fairy shrimp, *Streptocephalus dendrophorus* (Order Anostraca) occurs in and around St Lucia, as this is an endangered species that has virtually disappeared from its known habitat in north-eastern KwaZulu-Natal (Hamer & Lovell 2004).

Virtually nothing is also known of the aquatic insects that use Lake St Lucia and its fringing freshwater bodies as a habitat, particularly during wet phases. With the exception of the early reports of Day et al. (1954) and Millard & Broekhuysen (1970) and the more recent, albeit superficial, investigation by Vrdoljak (2004), insects have been neglected in all the major studies undertaken on the system. The mites have received some attention in the recent work of Bownes & Perissinotto (2012), but this is far from the comprehensive census needed for this important group, which is particularly abundant and diverse in mangrove ecosystems (Procheş & Marshall 2002). To our knowledge, no study has been carried out on the apparently remarkable diversity of water-associated spiders living on the fringes of the estuarine lake (Combrink & Kyle 2006).

Polychaete annelids are among the most abundant invertebrates regularly recorded within the benthos (Millard & Broekhuysen 1970, Owen & Forbes 1997, Pillay & Perissinotto 2008, Mackay et al. 2010, Pillay et al. 2013), but their identification has so far relied entirely on the old taxonomic keys of Day (1967) which have not been revised in recent times. Thus, it is necessary at this stage to update the taxonomy of this key class in collaboration with current international experts. The other annelid classes, viz. the hirudineans and oligochaetes, although not represented by a large diversity within the St Lucia system, have been recorded regularly but only identified to broad class/order level (Day et al. 1950; MacKay et al. 2010). With the exception of the bryozoans, reported as Polyzoa in Day et al. (1954) and Millard & Broekhuysen (1970), none of the other phyla of lophophorates have ever been mentioned from St Lucia, but it is possible that some may enter the system during open mouth conditions. The same may be the case with the echinoderms, chaetognaths, hemichordates and invertebrate chordates. Indeed, Day et al. (1954), Millard & Broekhuysen (1970) and Grindley (1982) mentioned the occurrence of the chaetognath *Sagitta* sp. in South Lake, and Carrasco et al. (2010) reported bloom concentrations of the appendicularian *Oikopleura dioica* at the mouth of the estuary when the system was fully connected to the ocean. Thus, adequate identification of marine intruders from these phyla will need to be undertaken once the mouth is open.

b) To escalate the census of lower invertebrates and protists on the basis of preliminary efforts made during the recent dedicated surveys of gastrotrichs (Todaro et al. 2011, 2013), rotifers and kinorhynchs (Bownes & Perissinotto 2012), and cnidarians (Neethling et al. 2011, Perissinotto et al. 2013b). Recent results obtained through intensive collaboration with international group experts shows that there are many new species to be described from the area. Other phyla, such as sipunculids, priapulids, echiurids, nemerteans, nematodes, ctenophores and platyhelminthes have been recorded occasionally within the system, but have consistently been identified only to a very coarse level (Millard & Broekhuysen 1970, Grindley 1982, Pillay & Perissinotto 2009, MacKay et al. 2010; Carrasco & Perissinotto 2012, Bownes & Perissinotto 2012).

Among the protists, only the diatoms have received sufficient attention and a species catalogue/checklist has been compiled for these microalgae from the St Lucia system (Cholnoky 1965, Bate & Smailes 2008, Gordon et al. 2008). All the other algal classes, including the green, brown and red macroalgae, remain poorly known. Of those generally referred to as protozoans, only the foraminiferans and the ciliates have recently received some attention, with several species now identified to genus or species level (Carrasco & Perissinotto 2012, Bownes & Perissinotto 2012).

c) To undertake an initial investigation on the abundance, biomass and production of the microorganisms comprising the bacteria, archaea and viruses. This will provide an estimate of the role that the microbial loop plays in the estuarine lake ecosystem. Preliminary identifications, at least to broad taxonomic level (e.g. Phylum, Division or Class), should also be targeted, as currently virtually nothing is known about the diversity of these organisms. It is only for a few cyanobacteria that identification to genus level has been successfully achieved in recent studies using advanced DNA bar-coding techniques (Muir & Perissinotto 2012). This, however, has been limited to "red water" species that have formed dense blooms under extreme conditions. Because of their importance, the ultrastructure and ecophysiology of these species needs to be investigated in great detail. There are probably a great number of other microbial species in St Lucia that have not been identified and this shortcoming needs to be rectified with a full inventory of the major taxa being undertaken as soon as possible. In addition, the relationships between microbial organisms, physico-chemical parameters, water level and the origin of "new" water (marine, riverine and freshwater seepage) require investigation if the full scale of ecological functioning of the system is to be adequately understood.

d) To undertake surveys on an on-going basis to monitor the status of currently known invasions by alien organisms and to detect new invasions as early as possible. This will allow opportunities for gathering information which will be useful in risk assessments of ecological impact, as well as feedback and recommendations for management activities. These surveys can be combined with biodiversity census data and surveys towards the revision of taxonomic groups as outlined above. Additionally, a holistic audit to determine the status of alien fringing vegetation as well as aquatic species, such as the red water fern *Azolla filiculoides*, needs to be conducted. International expertise and comprehensive studies of ecological and evolutionary history are required to differentiate between newly recorded native species and alien species that had been recently introduced. Some species, such as the clam *Meretrix morphina* (previously erroneously reported as *M. meretrix*) may be considered cryptogenic, since historically they have a wide distribution range but they are also suspected to have been introduced to St Lucia Estuary by people. There is also a need for empirical approaches, addressing the extent and specific mechanisms around the ecological impact of alien invasive organisms such as *T. granifera*. The current lack of knowledge about alien invasive species and their ecological impact on Lake St Lucia must be urgently addressed in a manner that allows for quick formulation of knowledge and feedback to management. When new alien invasive species are detected, such as the reef-building tubeworm *F. enigmaticus*, studies on their environmental tolerance, population viability and potential ecological impacts must be conducted as soon as possible.

5.3 Methods/Approaches

Collecting methods are numerous and variable, depending on the taxon and the habitat to be sampled. Plankton nets (WP-2 UNESCO, 100-200 µm), either free or attached to a hyperbenthic sled, can be used to collect most classes of crustaceans, adult insects, mollusc and polychaete larvae, chaetognaths and medusoid cnidarians. Benthic grabs (Zabalocki-type Ekman) and corers (Perspex/PVC, 20-100 mm diameter) are normally employed in the collection of infaunal polychaetes, small molluscs and crustaceans, insect larvae and virtually the entire meiofaunal assemblage. Quadrats and transects, as well as aerial surveys, are typically conducted to quantify vegetation population structure. Targeted, dedicated searches will be required for large and/or fast moving species that are either not sufficiently abundant to be collected with the above gear, or are able to avoid it. These include most brachyuran species, bivalves, prawns and adult insects. Special hand-held D-nets, shovels, baited traps and light traps will be used in these cases. While specimens can be processed for morphological taxonomy in any reasonably supplied laboratory, where both dissecting and compound microscopes with image analyser capabilities are available, molecular DNA analysis will require access to a specialised laboratory (e.g. SAIAB, UKZN/NMMU Genetics).

Estimating the impact of alien organisms is a difficult task that is confounded by the presence of, and interactions with, other anthropogenic stressors. The best approach involves the use of multiple, and sometimes novel, techniques. Experimental manipulations and feeding studies at small scales, together with field surveys over a variety of scales, are needed. The techniques outlined by Miranda et al. (2010, 2011, 2012) and Raw et al. (2013) address the ecophysiology, potential impacts and ecological interactions of a single target alien invasive organism, *T. granifera*. These involve both *in situ* as well as laboratory experiments that can be applied to adequately study other target alien species. Lethal and sub-lethal environmental tolerance can be studied by isolating and monitoring target organisms in controlled enclosures. Grazing impact can be measured using gut fluorescence techniques and with the aid of fluorometers and probes, e.g. the Turner 10-AU fluorometer and the bbe Moldaenke bentho-fluoroprobe. Interspecific behavioural interactions can be quantified with the aid of video and image analyses. Stable isotope assessments, together with gut content analyses and mass balance techniques, can be employed to investigate diets and address trophic interactions. Different techniques will have to be used for new alien species, e.g. settlement arrays composed of tiles where organisms can settle and grow, should be deployed in different areas to monitor recruitment and growth of the alien tubeworm *F. enigmaticus* in St Lucia.

A special effort will be required to establish the necessary international network of expertise for the biodiversity census to be successful. The approach used during the past few years has focused around providing high resolution photos to experts via e-mail attachments. This helps with first-order identification and generally the expert is able to decide on this basis whether further photographic details or the actual specimens are required for identification to species level. In the latter case, a selection of specimens preserved both in formalin (5-10%) and ethanol (75-99%) solutions are sent using courier services for both morphological taxonomy and molecular DNA studies.

Group experts already involved in the census, or identified as potential collaborators are as follows (taxon of expertise in brackets): Andrew Gooday, Southampton National Oceanographic Center, UK (Foraminifera); Wolfgang Petz, Consulting Office for Ecology and Evironmental Protection, Austria (Ciliophora); Marimegan Daly, Ohio State University, USA (Anthozoa, Actiniaria); Mark Gibbons, University of the Western Cape, South Africa (Scyphozoa); Hendrik Segers, Royal Belgian Institute of Natural Sciences, Belgium (Rotifera); Antonio Todaro, University of Modena & Reggio Emilia, Italy (Gastrotricha); Birger Neuhaus (Kinorhyncha); Ramlall Biseswar, University of KwaZulu-Natal, South Africa (Echiura); Martin Hendricks, University of the Western Cape, South Africa (Nemata); Tom Artois, Hasselt University, Belgium (Platyhelminthes, Turbellaria); Lukas Schärer, University of Basel, Switzerland (Platyhelminthes, Turbellaria); Markus Huber, University of Zurich, Switzerland (Mollusca, Bivalvia); Winston Ponder, Australian Museum, Australia (Mollusca, Assimineidae); Samuel Gómez, Mazatlan Academic Unit, Mexico (Copepoda, Harpacticoida); Frank Ferrari, National Museum of Natural History, USA (Copepoda & Cladocera); Şerban Procheş, University of KwaZulu-Natal, South Africa (Chelicerata, Acari); Alfred Newton, Field Museum of Natural History, USA (Coleoptera, Staphylinidae).

This theme would be better linked to a cluster of research programmes due to its high degree of relevance to a number of the other themes. Specifically, Theme 3 (Freshwater Wetland Dynamics) is of relevance since many freshwater species enter the lake system during periods of high freshwater inflow and runoff. The current situation is an example of this, as during the past two years lake levels have risen to the pre-drought state as a result of the heavy rains and floods that have occurred in the area. Freshwater bodies near the estuarine lake also act as a reservoir for several alien species that have invaded the system in recent times (Miranda & Adams 2013). A typical example of this is provided by the expansion that the gastropod *Tarebia granifera* has undergone recently in South Lake and the Narrows, mainly in response to the freshwater dominance of these areas (Raw et al. 2013). Prior to the heavy rains of 2011-2013, the species had withdrawn to a small area associated with a seepage point in Catalina Bay and the Nkazana Stream (Miranda 2012).

Theme 6 (Ecology of Indicator Species) is also very relevant, as all indicator species need to be identified with the greatest accuracy, especially because of their important status. Also, as mentioned above, it would be necessary within the biodiversity census to investigate the life cycle, habitat and other fundamental ecological aspects of at least all the dominant and keystone species. Some of these may turn out to be good indicator species too, as will most probably some of the alien invasives. Similarly, Theme 7 (Biotic Responses to Abiotic Extremes) will have, by necessity, core components of species identification and tolerance ecophysiology, as was clearly shown during the 2002-2011 investigation of the system's hypersaline phase (Nel et al. 2011, Carrasco & Perissinotto 2011, Carrasco & Perissinotto 2012, Muir & Perissinotto 2012, Nel et al. 2012, Carrasco et al. 2013).

5.4 References

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THEME 6: ECOLOGY OF INDICATOR SPECIES AND RED DATA TAXA

Xander Combrink & Alan Whitfield

6.1 Indicator species: Mangroves and selected invertebrates

Janine Adams

6.1.1 Rationale/Motivation

The overall health and survival of the mangrove habitat is important as this makes an important contribution to current biodiversity in the St Lucia Estuary. There is a need to investigate the effects of environmental extremes on the functional integrity of this ecosystem, especially in the context of a more naturally functioning estuarine mouth. During the 2013 brachyuran census, it was found that all the *Uca* species (fiddler crabs) have virtually disappeared from the St Lucia mangroves, possibly due to prolonged mouth closure and lack of tidal action. The consequences of this for the health and survival of the mangroves trees and associated biota needs to be understood.

Mangroves survive best in intertidal saline habitats. A recent study by Hoppe-Speer et al. 2013 at St Lucia showed that the drought and closed mouth conditions resulted in dry conditions which influenced mangrove recruitment and growth. Since the drought has broken and the water level has risen, conditions have now changed but new pressures are apparent, e.g. high silt inputs from the Mfolozi River into the lower St Lucia Estuary. This is likely to have an impact on the mangroves as silt can coat the air roots (pneumatophores) and lead to die-back due to decreased gaseous exchange. Research is needed to understand the response of the mangrove ecosystem to these changes.

6.1.2 Aims/Objectives

To understand the health and functional integrity of the mangrove ecosystem by measuring growth, phenology and population structure of the mangrove trees and the abundance of indicator biota such as the mangrove snail and crabs.

6.1.3 Methods/Approaches

The growth, phenology and population structure of the mangrove trees should be measured in quadrats at sites along the length of the Narrows. Similar sites as those used by Hoppe-Speer et al. (2013) would allow for an assessment of changes over time. The abundance of indicator biota such as the mangrove snail and crabs should be quantified in the same quadrats. Abiotic factors such as water depth, sediment salinity, water content, particle size composition, depth to the water table and water table salinity should also be measured. A study on biotic interactions such as the role of the crabs in aerating the sediment and stimulating mangrove growth would also be important. The impact of the predicted increase in suspended sediment from the Mfolozi River also needs to be investigated by measuring the growth and survival of pneumatophores and propagules at selected sites.

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6.2 Indicator species: Brachyuran crabs

Nasreen Peer

6.2.1 Rationale/Motivation

A change in diversity of brachyurans within the St Lucia estuarine system has been recorded between 1948 and 2012, with the loss of approximately 15 species from the lake and surrounds (Day et al. 1954, Millard & Broekhuysen 1970). Although the system has undergone major abiotic changes, it is still unclear which of these changes has the most effect on diversity. The diversity of brachyurans could be a good indicator of ecosystem health as brachyurans are mobile and thus quick to respond to changes within the environment by moving to more favourable habitats (Bowen & Depledge 2006).

In particular, the mangrove-dwelling fiddler crabs belonging to the genus *Uca* require a connection to the sea for larval development (Crane 1975, Papadopoulos et al. 2002). This is most likely why they were absent from the St Lucia system during the period of prolonged mouth closure, from 2002 to 2011 (Cyrus et al. 2011). Fiddler crabs are, therefore, indicators of the degree of communication between the estuary and the open ocean. However, the effects they have on their habitat, especially microphytobenthic communities, are not completely understood and should be investigated to determine the role they play within the system.

Other important crabs found alongside *Uca* in the mangroves, where they play a more prominent role as 'bio-engineers' (Lee 1998, Hoppe-Speer et al. 2010), are the sesarmids, which breed in the system regardless of the mouth state. Knowledge of the factors influencing their breeding and survival (e.g. flooding, salinity, dissolved oxygen and high sediment loads) is required, for the effective use of these crabs as indicators.

Also important to the benthos of St Lucia is the crab *Paratylodiplax blephariskios*, an endemic species that was once widespread throughout the Narrows (Millard & Broekhuysen 1970) and has now retreated from the St Lucia lakes, largely because of the wide salinity fluctuations within that part of the system (Owen & Forbes 2002).

Varuna litterata is found at St Lucia in both brackish and freshwater areas but has an early marine larval phase, followed by megalopa larvae swimming up estuaries and into freshwater areas. During a freshwater phase it is expected that the species would expand its distribution in and around the lake, while the onset of a drought phase would create hypersaline conditions in the main basin, thus confining *V. litterata* to the Narrows and freshwater areas adjacent to the system.

The freshwater genus *Potamonautes* is found in fringing wetlands around the lake and enters the system under low salinity conditions. In particular, several populations have been discovered recently in the False Bay area. It is uncertain whether or not the St Lucia populations all belong to one highly variable species or represent multiple taxa. This genus is important, particularly if the system shifts towards predominantly freshwater conditions during the next higher rainfall cycle.

6.2.2 Aims/Objectives

- To investigate the impact of *Uca* spp. on the microphytobenthic community of the St Lucia mangrove system.
- To examine the effects of abiotic conditions on breeding and survival of sesarmids.

- To determine the life cycle of *Paratylodiplax blephariskios.*
- To examine the pseudo-cryptic nature of *Potamonautes* cf. *sidneyi* and highlight aspects of its ecology, more specifically feeding.
- To examine the distribution of *Varuna litterata* during various salinity regimes and determine the factors that affect the survival of this species at St Lucia.
- To determine the factors influencing the diversity of brachyurans within the St Lucia estuarine system.

6.2.3 Methods/Approaches

- By monitoring changes in microphytobenthic (MPB) communities it would be possible to determine whether or not *Uca* spp. feed selectively on specific algal groups, as well as estimating the effects of population density on these communities. Any impact on MPB communities will be relayed through the entire food web.
- Monitoring the distribution of *Varuna litterata* and examining population dynamics of the species around the lake.
- Investigating the effects of flooding, salinity, dissolved oxygen and sediment loading on the spawning of adult sesarmids, the number of eggs per female and survival rate of larvae would provide insight into the main factors affecting their populations within the system
- Rearing individuals *in situ* and sampling populations routinely within the estuary, mouth and swash zone will allow for an accurate description of this endemic species' life cycle, including the determination of spawning grounds and the length of the development period.
- Genetic and morphological analyses will be employed to determine if different populations represent cryptic or separate species. Stable isotope and gut content analysis will be used to determine the diet of these populations at key locations within the iSimangaliso Wetland Park. Any seasonal or geographic variations will be identified.
- MAXENT models (Phillips et al. 2006) could be used to examine any correlation between diversity and changes in abiotic conditions using past and present data.

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6.3 Indicator species: *Macrobrachium* prawns

Iain Bickerton

6.3.1 Rationale/Motivation

Macrobrachium species are good indicators of connectivity between the Mfolozi/Msunduzi floodplain and St Lucia by virtue of their lifestyles and ecological requirements which are dependent on both riverine and estuarine habitats. The motivation supporting this assumption is as follows:

- The genus *Macrobrachium* comprises a group of river or freshwater prawns, represented in southern Africa by about seven species (Kensley 1981). All species of the genus *Macrobrachium* in southern Africa exhibit catadromous lifestyles where adults migrate downstream to breed, with juveniles returning upstream to grow to maturity (Bickerton 1989, 2011, Hart et al. 2001). Notably *Macrobrachium* species require access to brackish water, usually associated with an estuary, for larval development in order to complete their life cycles (Bickerton 1989, 2011, Hart et al. 2001). To enable this cycle, breeding adults either migrate or are washed downstream during floods and breed in the lower reaches of rivers where there is some estuarine or even marine influence.
- Adult river prawns mostly live in fresh or brackish water. During breeding periods the downstream movement by adults, whether caused by floods or swimming, enhances the possibility of larvae hatching in brackish or salt water. This is a requirement for successful larval development in all south-east African species (Cort & Schoonbee 1993). Females carry the eggs on the pleopods, larvae hatch and are released mostly in the brackish water of estuaries and lagoons. There are up to 13 stages in larval development (Williamson 1972), after which juvenile or post-larval stages migrate upstream where they grow to maturity in rivers, streams and swamplands.
- The common use of lagoons, estuaries and deltas by both penaeid prawns and *Macrobrachium* species has been described by several authors (Gamba 1982, Frusher 1983, Gamba & Rodriguez 1987, Robertson & Duke 1987). In all cases these ecosystems serve as nursery areas for penaeids and as both spawning and nursery habitats for *Macrobrachium* species.

- The Mfolozi River would have had a common mouth with St Lucia Estuary before 1952 and *Macrobrachium* spp. influxes into St Lucia during low-salinity phases would have been facilitated by these open channel connections across the floodplain.
- Of vital importance in the life-cycle of south-east African *Macrobrachium* species is that the movement of adults and juveniles between freshwater lakes, rivers and swamps and estuarine and deltaic brackish water habitats, be unhindered (even the most freshwater-orientated *M. lepidactylus* requires brackish water for larval development – Cort & Schoonbee 1993). The maintenance of populations of these prawns depends on recruitment of juveniles from saline breeding and nursery areas. Permanent exclusion of the critical stages of the reproductive cycle from such areas by natural or man-made obstructions will result in localized extinction of the *Macrobrachium* species population concerned.
- Annual flooding of the Mfolozi/Msunduzi usually occurs during summer (December to February) or early autumn (March/April). Breeding adult *Macrobrachium spp.* are washed downstream into the floodplain during such events. In this way floods provide the vehicle for transport to the habitat suitable for breeding and larval development. With the subsidence of floodwaters, adult river prawns in the lower Mfolozi/Msunduzi floodplain and St Lucia tend to be most abundant in salinities that represent the larval rather than adult requirements (Bickerton 1989, 2011).
- The low rainfall (and consequent reduced run-off) winter period (June to August) following the usual autumn breeding peak, allows retention of larval stages and juveniles in the quiet tidal backwaters of channels and canals in the lower Mfolozi/Msunduzi floodplain and the southern parts of St Lucia. If the early larval stages are associated with salt front regions (as demonstrated for *M. petersii* by Read 1985) such conditions could be found in the channels and drainage canals of the floodplain. Salt fronts could also prevail in the Narrows, particularly after floods when a high lake level causes low-salinity water to drain towards the sea.
- At the end of the autumn breeding period, adult *Macrobrachium* spp. in the Mfolozi/Msunduzi floodplain move into the deeper river courses and probably migrate upstream with the juveniles, either following at the end of winter, or remaining in the vegetation-lined backwaters of the floodplain until they have attained adult size. If the latter occurs, then the first upriver migration of this age group would be at the end of the following year's autumn breeding period (Bickerton 1989, 2011).
- The essence of *Macrobrachium* spp. life cycles is that the Mfolozi/Msunduzi floodplain and lower reaches of the St Lucia system have in the past served as breeding and nursery habitats when environmental conditions such as occur during wet phases have favoured these river prawns.
- The artificial removal of the Mfolozi/Msunduzi system from the St Lucia Estuary and the creation of a separate mouth opening directly into the sea have resulted in those river prawns that have been retained within the main river courses during flood flows potentially being flushed out of the system and deposited directly into the sea. The return of these river prawns back into the estuary when the floodwaters subside is unknown. When the Mfolozi had a common mouth with St Lucia, *Macrobrachium* prawns washed downstream during floods would have been initially deposited in the lower St Lucia Estuary, from where they could have dispersed into the Narrows and South Lake (Bickerton 1989, 2011).
- Because of their ecological requirements *Macrobrachium* spp. can be used as an indicator of the health of connectivity between the Mfolozi/Msunduzi floodplain and St Lucia. Furthermore, the key to the conservation of *Macrobrachium* spp. in the Mfolozi/Msunduzi and St Lucia wetlands is sound management of the Mfolozi/Msunduzi floodplain (Bickerton 1989, 2011).

6.3.2 Aims/Objectives

To monitor distribution and abundance of *Macrobrachium* spp. in the Mfolozi/Msunduzi floodplain and the lower reaches of St Lucia Estuary. Such a monitoring programme will provide data to assess the success of connectivity, not only for *Macrobrachium* spp. but also other invertebrates and fishes that require the physical link between the two systems and the sea in order to successfully complete their life cycles.

6.3.3 Methods/Approaches

- Hyperbenthic surveys by means of seasonal (spring, summer, autumn, winter) beam trawls at fixed sampling stations.
- Records of *Macrobrachium* spp. larval stages within zooplankton samples. Although identification of larvae and juveniles to species level is problematic, records for the genus would be adequate for the purposes of assessing the health of connectivity between the Mfolozi/Msunduzi floodplain and St Lucia.

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6.4 Indicator species: Amphibians

Adrian Armstrong & Jeanne Tarrant

6.4.1 Rationale/Motivation

Amphibians are currently the most threatened group of vertebrates on Earth, with one third of species listed as threatened by the IUCN Red List (IUCN 2012). This situation is reflected in South Africa, with 29% of our species listed as threatened (Measey 2011). The iSimangaliso Wetland Park contains at least 49 species of amphibians, equal to 42% of the total South African amphibian species richness (118 species). The Park is situated in northeastern KwaZulu-Natal, which is regarded as the most species rich area for amphibians in South Africa (Measey 2011).

Despite the high species richness, only two species in the Park are currently listed as Threatened (Measey 2011). The Pickersgill's reed frog *Hyperolius pickersgilli* was assessed in 2010 as Critically Endangered due to its limited and severely fragmented distribution and continuing decline in the quality of its habitat (IUCN 2012). It is the Provinces' only frog species with this status in KwaZulu-Natal. The spotted shovel-nosed frog *Hemisus guttatus* was re-assessed as Vulnerable due to its severely fragmented distribution and continuing decline in the extent and quality of its habitat (IUCN 2012).

Hyperolius pickersgilli (Raw 1982) is endemic to KwaZulu-Natal, being known from only a few isolated wetlands within a narrow strip of the KwaZulu-Natal coastline between Sezela in the south and St Lucia in the north (Tarrant & Armstrong 2013). Only two of 18 known subpopulations occur in Protected Areas; at iSimangaliso and in the Umlalazi Nature Reserve (Bishop 2004). Most of the remaining populations occur in habitats that are degraded or threatened by urban and industrial expansion, agricultural activities especially for sugarcane, invasive alien species, mining, or other factors, and local extinction is a possibility.

A key conservation intervention is the management of sites with extant populations (Tarrant 2012). Conservation management interventions are not only required at the breeding wetlands but probably also in adjacent habitats through which the species disperses between wetlands, or in which the frogs forage or overwinter. However, the latter habitat requirements are virtually unknown (Measey 2011). Barriers to dispersal may cause inbreeding in remnant populations and potential extinction through the results of genetic drift and loss of heterozygosity.

Hemisus guttatus spends much of its time underground and therefore is a cryptic species (Alexander 2004). It is near-endemic to KwaZulu-Natal. Although fairly widespread in iSimangaliso, not much is known of its overall distribution there, nor its abundance at any site, and its habitat has not been adequately described.

6.4.2 Aims/Objectives

Hyperolius pickersgilli

- Survey for the species and habitat availability, guided by the predicted distribution map (Tarrant & Armstrong 2013).
- Set up a long-term monitoring programme for one population and for estimating population size trends within iSimangaliso.
- Determine or estimate the limits of dispersal of the species and its ability to use altered habitats for movement between breeding sites (MSc project, building on the results of the first objective).

- Implement appropriate management procedures at sites with extant populations, including invasive alien plant eradication, correct fire regime management, and control of reed harvesting where relevant.

Hemisus guttatus
- Survey for the species and habitat availability, guided by a predicted distribution map that is refined after understanding the habitat requirements of the species in iSimangaliso.
- Estimation of abundance at one site that could be used for long-term monitoring of numbers of the species.

6.4.3 Methods/Approaches

- Identification of existing populations within iSimangalisovia ground-truthing of predicted distribution maps via active acoustic surveys during the breeding season.
- Implementation of standardised call monitoring protocol to estimate population trends.
- Habitat description using standard techniques.
- Possible MSc project on the limits of dispersal of *H. pickersgilli* and the ability of the species to use altered habitat for dispersal.

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6.5 Indicator Species: Flathead mullet

Alan Whitfield

6.5.1 Rationale/Motivation

The flathead mullet *Mugil cephalus* is a dominant marine fish species in the St Lucia system, initially spending approximately 3 years in the lakes whilst growing from newly recruited marine juveniles to mature adults (Wallace 1975a). *Mugil cephalus* is not only representative of the migratory life cycles undertaken by a wide variety of other mullet species that inhabit the lake, it also reflects the life histories of species from many other marine fish families that utilize the St Lucia system as a primary nursery area (Wallace & Van der Elst 1975). In addition, if the system is open to the sea, a proportion of the flathead mullet population return to the lake system following spawning (Wallace 1975b). This behaviour reinforces the importance of the marine/estuarine linkage that characterizes this and other fish species, and highlights the value of the flathead mullet as an indicator species (Whitfield et al. 2012).

Mugil cephalus can also be regarded as a keystone species in a naturally functioning Lake St Lucia food web. This is because of its numerical abundance and biomass dominance in the trophic functioning of both the lake and estuary under open mouth conditions (Whitfield & Blaber 1978a). As a detritivore and primary consumer of benthic microalgae (Blaber 1976), the flathead mullet occupies the broad base of the trophic pyramid and there is very strong evidence to suggest that this species is also an important prey item for a wide variety of apex predators, including crocodiles, fish eagles, pelicans, sharks and people (Whitfield 1980). Therefore loss of the flathead mullet from the ecosystem, for whatever reason, would be expected to have a material impact on the ecology of these top predators, thus reinforcing its importance as an indicator species for St Lucia.

A popular article in the SA Angler entitled “When the pelicans come to St Lucia” by Tooth (1946) reinforces the view that *M. cephalus* is a key species in the St Lucia system: “By some instinct all their own, the pelican knows when the mullet are to arrive, and a few days before this thousands of pelicans are to be seen waiting at the mouth of the estuary. And so from now, the pelicans will be followed by anglers in their hundreds who know that this is the time of the year to get the best results. It is usually about the beginning to the middle of May that the mullet arrive, thousands and thousands of them in great shoals milling and jumping out of the water, being chivvied and harried by large salmon and blackfin sharks. The mullet, in their efforts to escape, make for shallow water where the pelicans await them. Indeed, many a boat from which anglers have been fishing has been known to be swamped by hundreds of these mullet leaping out of the water (Tooth 1946).”

The above description captures the atmosphere of the natural annual spawning migration of *M. cephalus* from North Lake and False Bay, through South Lake, down the Narrows and then into the Estuary before finally entering the coastal waters where spawning occurs. What the article does not cover are the scores of Nile crocodiles that gather along the length of the Narrows each year to prey on the migrating mullet (Whitfield & Blaber 1979a). Fortunately we have scientific data to verify the important trophic role that *M. cephalus* plays in the functioning of St Lucia (Whitfield & Blaber 1978b, 1978c), including the spawning migration down the system in April/May each year and the associated predation on these shoals by both crocodiles and white pelicans (Whitfield & Blaber 1979a, 1979b). These data, plus new monitoring studies of *M. cephalus* distribution, abundance and cohort strength, could provide the basis for a very effective indicator of the overall health of the ecosystem.

During the recent drought decade (2001-2010), when the connectivity between Lake St Lucia and the sea was severely restricted or lost altogether, the system entered an evaporative phase and the annual flathead mullet spawning migration then ceased to occur (Cyrus and Vivier 2006). This fact alone is enough to suggest that *M. cephalus* is an ideal indicator of ecosystem health since it corroborates scientific evidence collected from other estuary-associated marine fish species which were also negatively impacted by the loss in estuarine connectivity (Cyrus et al. 2010).

6.5.2 Aims/Objectives

To monitor the presence/absence and magnitude of the annual *M. cephalus* spawning migration down the St Lucia system.

6.5.3 Methods/Approaches

During April and May each year the progression of the spawning shoals of *M. cephalus* can be followed down the system from North Lake and False Bay to the St Lucia Estuary due to the frequent jumping activity by this species. Notes and counts of the major predatory species associated with the migrating shoals (e.g. white pelicans and Nile crocodiles in the Narrows) should also be undertaken as this will validate the trophic importance of the flathead mullet to these top predators and give an indication of the general health of the ecosystem.

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6.6. Long-term monitoring of waterbirds

Aldo Berruti, Colleen Downs, Ricky Taylor, Meyrick Bowker & Caroline Fox

6.6.1 Rationale/Motivation

Lake St Lucia is nationally and regionally important as a conservation area for waterbirds (Turpie et al. 2013). It is the most important estuary in South Africa for waterbirds with the status of an Important Bird Area and the waterbirds are a significant reason for its proclamation as a Ramsar site (Turpie et al. 2013). The long-term survival of regional populations of several threatened waterbird species, notably Pink-backed *Pelecanus rufescens* and Great White Pelicans *P. onocrotalus* (iconic tourist attractions), is largely dependent on the long-term viability of Lake St Lucia as a functional ecosystem.

The waterbirds of Lake St Lucia are comparatively well-known, are a highly visible component of the biota of Lake St Lucia but vary greatly in numbers both temporally and spatially in response to hydrological conditions (Turpie et al. 2013). The numbers of larger waterbirds have been monitored since 1976, with breeding records pre-dating this (Turpie et al. 2013, Bowker & Downs 2012). However, the numbers of small waders have not been quantified because of logistical difficulties. Yet Lake St Lucia may harbour very significant populations of small Charadriiform waders at lower water levels (particularly Palaearctic waders in summer) and their numbers need to be quantified for improved ecological and conservation insights. This work could significantly increase the recognised conservation importance of Lake St Lucia to waterbirds.

Modelling studies of the biota of Lake St Lucia in relation to hydrology should include waterbirds because they are trophically significant and well-documented. Furthermore, the great variation in numbers and breeding of most waterbird species at Lake St Lucia reflect both the mobility of waterbirds and the variability in hydrology and resultant ecological conditions, leading to the concept of waterbirds as indicators of specific ecological states. Thus the ecological conditions for the occurrence and breeding of Pink-backed and Great White Pelicans at Lake St Lucia are well known (Bowker & Downs 2008a, 2008b, 2008c, Bowker et al. 2010). Using expert knowledge and literature, correlations between waterbird numbers and breeding in relation to the hydrology of Lake St Lucia can be evaluated in terms of their predictive value as indicators at varying trophic levels. Such an approach should identify which waterbird species, or groups of species, are best monitored and researched to better understand the functioning of Lake St Lucia as an ecosystem, particularly in modelling studies which seek to understand the biotic outcome of hydrological variability.

Research on Pink-backed and Great White Pelicans has shown how the populations centred on Lake St Lucia also make significant use of the uMkhuze and Phongolo wetland systems (Bowker & Downs 2008 a, 2008b, 2008c, Bowker et al. 2010) whilst the duck populations in this area are being researched by Dominic Henry of the University of Cape Town. Such work is critical for understanding the life strategies of threatened species and how regional hydrological conditions may affect numbers and breeding of waterbirds within Lake St Lucia, independent of hydrological conditions at Lake St Lucia. In summary, the importance of Lake St Lucia for sub-regional populations of selected waterbird species or groups of species under varying sub-regional hydrological conditions requires investigation. Such information will facilitate an improved understanding of waterbird ecology in the St Lucia system which could be used in studies focused on conservation, ecosystem function, ecosystem modelling and the selection of indicator species.

6.6.2 Aims/Objectives

- Maintain the long-term time-series of data on total numbers and breeding of larger waterbirds.
- Census of Charadriiform wader numbers under different ecological conditions.
- Develop an understanding of the importance of waterbirds within the ecosystem and the predictive use of waterbirds as indicators of ecosystem function
- To better understand the role of Lake St Lucia for larger waterbirds on a sub-regional scale, focusing on how waterbirds use Lake St Lucia and wetlands within a 150 km radius under varying sub-regional hydrological conditions.

6.6.3 Methods/Approaches

- Build on and improve the biannual CWAC counts.
- Annual or more frequent aerial and boat counts, maintaining constant search effort or document changes in search effort and techniques. Targeted (including annual survey of known colonies of larger waterbirds) and opportunistic records of breeding by conservation and research staff during surveys.
- Targeted surveys (at least four) of small waders in summer and winter at high and low water levels and medium to low salinities (a summer count under lower water levels with low to moderate salinities is most important). Count techniques should rely on a small core of experienced observers and ground counts using boats for access.
- A multi-disciplinary workshop or desk-top study pooling expert knowledge to understand the strength of correlation between the numbers (including absence) and breeding of particular species of waterbirds and hence predictive value for specific ecological conditions. Such a study should suggest ideal species or groups for further ecological investigation at Lake St Lucia (and possibly surrounding wetlands).
- Integrated ecological and population studies on selected species or groups in relation to hydrological conditions over a sub-regional scale. Techniques used will depend on the species to be studied.

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6.7 Indicator species: Zambezi shark

Meaghen McCord

6.7.1 Rationale/Motivation

Zambezi (bull) sharks *Carcharhinus leucas* are a large euryhaline species dependent on estuarine and freshwater ecosystems for the provision of critical habitats. In South Africa *C. leucas* has been documented in 21 river/estuarine systems along the KwaZulu-Natal coast (Olbers 2012), several estuaries on the Transkei coast (Whitfield 1997, KZN Sharks Board unpublished data) and the Breede Estuary on the southwestern Cape coast (McCord & Lamberth 2009). These systems are generally poorly understood despite being heavily utilised and impacted by human activities (Driver et al. 2012).

The St Lucia Estuary – the only formally documented nursery area for the species – has been heavily impacted by anthropogenic activities and remained closed to the sea for almost 10 years (Cyrus et al. 2011). The impact of this recent closure on the regional population of *C. leucas* remains unknown. The conversion and degradation of natural habitats resulting in high nutrient loading, excessive sedimentation, harmful algal blooms, and more frequent hypoxic conditions, are possibly the greatest threats to this species due to impacts on physiological, biological and population functioning. Additionally, as 3^{rd} or 4^{th} order consumers, *C. leucas* are likely to exert significant control over estuarine structure and functioning through consumption and movement ecology (Creel & Christianson 2008). The disappearance of *C. leucas* from estuaries, rivers and coastal ecosystems due to habitat degradation may lead to significant ecosystem change or even dysfunction. Due to its importance in the life history of *C. leucas* in South Africa, the St Lucia Estuary is a habitat of priority concern. It is therefore essential that a broader understanding of habitat dependency, connectivity, movement ecology, bioaccumulation of pollutants, and basic biology of the species, particularly within St Lucia, is achieved.

6.7.2 Aims/Objectives

- Improve understanding of ontogenetic habitat dependency of *C. leucas* in St Lucia through non-destructive population sampling and telemetry.
- Quantify relationships between ontogeny, spatio-temporal movement behaviour and environment to ascertain degree of developmental dependency on abiotic factors.
- Examine the nature and degree of habitat connectivity in St Lucia, the lake system and surrounding estuaries using telemetry.
- Examine genetic structure of *C. leucas* in St Lucia to describe site fidelity and philopatry.
- Quantify ontogenetic changes in trophic positioning to determine the ecological role of *C. leucas* in St Lucia.
- Quantify and describe pollutant loading in *C. leucas* in St Lucia.
- Use these data to assess the risk of critical habitat degradation to *C. leucas* in southern Africa.

6.7.3 Methods/Approaches

For Aims/Objectives 1-3 (above) a combination of passive and manual acoustic telemetry would provide insight into the general movement ecology, habitat dependency and habitat connectivity. To supplement existing satellite telemetry data from the Breede Estuary – that indicates transboundary seasonal movements northeast into the Indian Ocean – additional pop-up archival tags (PATs) would be beneficial for ocean basin connectivity analyses.

For Aims/Objectives 4-6 a combination of stable isotope, genetic (parental and sibling) and muscle tissue sampling will provide detailed insight into the ecological role, genetic structure and bioaccumulation of pollutants (ecotoxicology).

Data from Aims/Objectives 1-6 will be collated and used to inform a risk assessment that predicts how *C. leucas* would respond to various conservation and management scenarios in heavily impacted critical habitats.

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6.8 Indicator species: Nile crocodile

Xander Combrink, Ricky Taylor & Colleen Downs

6.8.1 Rationale/Motivation

Perhaps owing to its fierce reputation as the top aquatic predator, no other single organism symbolises the St Lucia estuarine system as does the Nile crocodile (*Crocodylus niloticus*). This is a charismatic and iconic keystone species associated with the lake, wetlands, streams and rivers of the St Lucia system and apart from playing a significant ecological role (Pooley 1982a, 1982b), its function as an import tourist attraction is increasingly recognised.

Lake St Lucia contains the largest crocodile population in a single waterbody in South Africa, hosts one of only a few remaining viable breeding populations in the country and might be regarded as the largest estuarine population within its range (Combrink et al. 2013). As a result of declining populations and escalating threats to the species, the conservation status of *C. niloticus* is listed as Vulnerable in South Africa (McLachlan 1978, Jacobsen 1988, Branch and Bates 2013).

As a top predator at Lake St Lucia, *C. niloticus* influence lower trophic levels and responds to spatial-temporal changes in hydrology, especially freshwater input influenced by prolonged low rainfall periods and estuary mouth management. The availability of freshwater has always been regarded as a key component to the health of the crocodile population. Four decades ago Pooley (1973) stated "The future status of crocodiles in the lake system depends mainly on solving the engineering and hydrological problems, i.e. the provision of an adequate water supply, and at the same time allowing for a free exchange of saline and fresh water and adequate organisms between the sea and the lake". Lake St Lucia is currently recovering from a decade of severe freshwater restrictions, due to reduced rainfall and a policy decision since 1952 to keep the Mfolozi River and St Lucia Estuary mouths separated (Taylor 2011). It seems likely that hydrological conditions such as the lake's connectivity with the ocean and availability and distribution of freshwater had a significant effect on body condition and reproductive output of *C. niloticus*, possibly through food webs and habitat conditions.

Fulton's condition factor, used in a number of crocodilian studies to evaluate body condition (Zweig 2003, Rice 2004, Fujisaki et al. 2009, Mazzotti et al. 2009, Mazzotti et al. 2012), indicated that crocodiles caught from 1994 to 1995 in Lake St Lucia (Leslie 1996) were in a significantly better condition compared to crocodiles captured between 2009 and 2011. The mean nest count prior to estuary closure (1982-2001) in 2002 was 103.07 ± 7.7 S.E. nests, while during the period when the estuary was closed (2003 to 2012) it decreased to 53.56 ± 5.92 S.E. nests. Growth, reproduction, and survival of crocodilians are invariably linked to food availability which is dependent on hydrological conditions (Mazzotti et al. 2009) This recognises the value of using crocodile body condition and reproductive output as an indicator of crocodile population health and together with a suite of other indicators is likely to provide evidence of the state of components of the St Lucia system.

Lake St Lucia hosts the most southerly viable Nile crocodile breeding population on the continent (Leslie & Spotila 2001), but its geographical positioning results in a relative longer and cooler dry season compared to more northern populations. Hutton (1987a) found that *C. niloticus* growth was slow at a high altitude lake in Zimbabwe, with females taking approximately 30 years to reach sexual maturity. The relatively long cool dry season at St Lucia might have a similar impact on crocodile metabolism and therefore the size, growth and age at sexual maturity of these individuals, thus influencing population dynamics.

Lake St Lucia is a popular fishing destination and routine post mortems have revealed lead sinkers (gastroliths) as part of nonprey items in the majority of crocodile's stomachs examined (Warner et al. in prep.). Crocodiles are lithophagic and naturally utilise gastroliths (Huchzermeyer 2003). Elevated lead levels were obtained from a number of crocodiles as part of a current ecotoxicology study (J. Warner unpublished data), and a blood sample from one specific animal had an extremely high lead blood level, i.e. 960 ug/DL; over ten times the lethal dose for birds and mammals (Warner et al. in prep.). It is evident that crocodiles with elevated lead levels are ingesting lead fishing sinkers in the lake where the lake floor and surrounds are entirely sand. High lead levels in yolk have been suggested to be the probable cause for early embryonic death in the American alligator (*Alligator mississippiensis*) eggs (Beeram et al. 2012).

Crocodile burrows and burrowing behaviour have been recorded at five localities at Lake St Lucia (Pooley 1982a, Combrink et al. in prep.). All localities along the eastern shoreline are known *C. niloticus* nesting areas and we have observed nesting females using burrows when disturbed, as well as non-reproductive males and females during the non-nesting season. Burrows are always associated with freshwater streams or seepage areas and in some areas the selection of nesting sites might be dependent on the presence of burrows for shelter, as adjacent freshwater sources are too shallow. Burrows are likely to provide microhabitats of stable temperatures and might be important for the nesting female's thermoregulation, including use during winter.

Dispersal dynamics and mortality of hatchlings may be an important demographic process (Hutton 1989) and parameter of a population model for *C. niloticus* at Lake St Lucia (see long term monitoring of crocodiles sub-theme). We observed dispersal patterns from the natal areas were mostly influenced by stream-flow conditions at the nursery area (Combrink et al. 2013) and assume this dynamic could influence the extent of intraspecific predation by 2-3 year old crocodiles still remaining in the vicinity of the natal grounds. Hatchling mortality levels at Lake St Lucia during the first year are unknown but is presumed to be relative high and influenced by habitat conditions, lake water levels and intraspecific predation.

A current research study by the University of KwaZulu-Natal is providing valuable information on a number of ecological aspects, especially spatial ecology. There is, however, a need to better understand the population condition and dynamics, prevalence of lead ingestion, food preferences, use and importance of burrows, and dispersal dynamics of hatchlings at Lake St Lucia.

6.8.2 Aims/Objectives

- Identify drivers, apart from food availability, that might be responsible for loss in crocodile body condition during periods of estuary mouth closure.
- Determine the rate of body condition loss as well as recovery for juvenile, sub-adult and adult crocodiles.
- Determine the age-size structure of the sub-adult and adult population.
- Investigate the extent of fishing sinker ingestion and Pb levels in the blood.
- Investigate patterns of prey availability and foraging habits through stomach content analysis.
- Examine the spatial and temporal use and importance of crocodile burrows, as well as spatial properties and temporal thermal ranges of burrows.
- Determine dispersal dynamics and hatchling mortality at a selected number of natal areas.

6.8.3 Methods/Approaches

- Feeding experiments at the St Lucia Crocodile Centre to determine rate of body condition loss and recovery for juvenile, sub-adult and adult crocodiles.
- Morphometric data such a snout-vent length, head length, tail girth and mass of juvenile, sub-adult and adult crocodiles will be collected and Fulton's K condition factor compared with data from a recent study during (2009-2012) during estuary mouth closure and restricted freshwater conditions.
- Determine the age-size structure through standard skeletochronology methodologies (Hutton 1986, Hutton 1987b, Tucker 1997).
- Investigate the number and size of fishing sinkers ingested by *C. niloticus* using the stomach flushing method of Taylor et al. (1978). Stomach flushing is a safe, effective technique to recover prey and non-food items from crocodilian stomachs. Investigate Pb levels in blood through standard laboratory analysis (Warner et al. in prep.).
- Prey item from stomach samples will be digitally photographed, identified and wet mass recorded (Wallace & Leslie 2008).
- Crocodile burrowing behaviour will be investigated by recording temperature ranges inside the terminal burrow cavity, quantify the spatial dimensions using LADAR technology and determine use through controlled infrared videography.
- Dispersal dynamics and mortality will be determined using acoustic (ultrasonic) telemetry (Franklin et al. 2009). The use of small transmitters (active > 5 years) combined with one or two listening receivers per selected nesting area and a detection range of 400-600 m are ideal for this study.

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6.9 Long-term monitoring of crocodiles

Xander Combrink, Colleen Downs & Ricky Taylor

6.9.1 Rationale/Motivation

The Nile crocodile is a threatened species in South Africa, assessed as Vulnerable in 1978, 1988 and 2013 (McLachlan 1978, Jacobsen 1988, Branch and Bates 2013). It is a species of high conservation value that requires national protection (Van Schalkwyk 2007). The conservation philosophy of the iSimangaliso Wetland Park is to maintain healthy and viable ecosystems. However, it is recognised that within this context, a specific management strategy is required for *C. niloticus*. This plan takes in consideration the special requirements of this important species, as well as dealing with potential public safety concerns (Taylor et al. 2007). It also highlights monitoring as a necessary and important tool to detect a decline in the population or nest effort early enough, so that management action can be instituted to conserve the population (Taylor et al. 2007). Currently the five main monitoring components are population counts and distribution, nest counts and distribution and age structure (Taylor et al. 2007). The first population survey was conducted in 1972 and first nest count in 1982 (Combrink et al. 2013), monitoring the age structure has not been implemented and will be subsequently discussed.

The greater Lake St Lucia system is extensive, the lake is ~35 000 ha with a shoreline of ~400 km (Taylor *et al.* 2006) plus numerous wetlands and pans in remote areas. Due to its size and shallowness (average depth < 1 m) the only practical technique for long term monitoring of the crocodile population is aerial surveys, during June or July, when water temperatures are at a minimum and most crocodiles are basking (Pooley 1982b, Leslie 1997) from about 10h00 (Downs et al. 2008). However, Hutton (1992) cautioned that aerial surveys are subjected to large biases, such as observer competency, density of vegetation and water visibility. The three most prominent reasons why crocodiles present at Lake St Lucia are not seen during aerial surveys are linked to being submerged in the lake's murky waters, concealed by vegetation and the speed of the aircraft. Crocodile nests are counted in January, which represents the middle of the nesting season (Pooley 1982a), minimising the risk of conducting the count before all females have laid their eggs. Despite a two week survey, some nests are invariably missed, especially nests situated in open areas surrounded by close canopy swamp forest. Such nests can only be located from an aerial platform (Combrink & Robertson 2012).

Despite the benefit of a long-term monitoring programme of aerial counts in winter and nest surveys in summer, the trend at best represents an index of relative abundance, as opposed to an absolute count. In order to obtain useful estimates of population parameters, we require a counting procedure to estimate the sampling fraction (Williams et al. 2002) or bias, i.e. the present, but unseen crocodiles and nests during a survey. This will improve the accuracy of the count. An index of abundance informs management if the population is stable, declining or on the increase, and if surveys have high levels of precision (random variation among counts), it increases the confidence in the count result. The coefficient of variation (CV) is the standard error as a percentage of the estimate (Graham 1987) and is used to measure precision. The only way to measure precision during a "total count" is by employing the double-count technique (Magnusson et al. 1978) using a second airplane (Combrink et al. 2011). In June 2013 we determined the precision of the Lake St Lucia crocodile aerial survey using this method and found a CV = 1.58 %, which is regard as very low, i.e. indicating a high level of precision.

Despite the challenge of wind, especially during the nesting season in summer, use of a double motorised paraglider could provide data required to estimate the sampling fraction. This survey craft has the ability to operate at speeds as low as 5 km^{-1} at whatever height required, providing a stable aerial platform for counting, recording positional data, still photography or video. Although ideal, the paraglider would not be required every year as part of the long term monitoring programme, but it would be valuable to use it every 3-5 years. GPS-GSM transmitters have allowed us to calculate the proportion of crocodiles submerged throughout the year (Combrink et al. in prep.). The only variable that remains unquantified is the number of crocodiles that are concealed by vegetation, which during winter should be minimal for a large heliothermic reptile such as *C. niloticus*.

The fifth component of the monitoring programme, i.e. monitoring the age structure, has not yet been implemented. Age structure data for the entire Lake St Lucia population is lacking and would be important to quantify for population dynamics. Due to the time and effort involved, this aspect has been identified as a specific short-term research intervention and would probably not form part of a long term monitoring programme at St Lucia. However, age structure data for the juvenile component (< 1.5 m) are regarded as very important because they represent recruitment and the future population. Monitoring juvenile recruitment might be the most sensitive method to detect population changes (Taylor et al. 2007), which has particular relevance in the light of an average decrease of 49% in nest effort during 2002 to 2012, due to the prolonged period of low rainfall and closed estuary mouth. Crocodiles < 1.5 m are generally not visible during aerial surveys (Parker & Watson 1970, Pooley 1982b, Bayliss et al. 1986, Botha 2005) due to their size, but also because they are absent from winter basking congregations as a result of ecological separation from larger crocodiles (Hutton 1989) due to intraspecific predation (Pooley 1982a, Hutton 1989, Rootes and Chabreck 1993). Hutton (1989) found a dispersal phase for *C. niloticus* from the river into the main Lake Ngezi at around a length of 1.2 m.

6.9.2 Aims/Objectives

- Develop a population model to simulate population dynamics. This could build on a crocodile count simulation model, developed for Lake St Lucia (Taylor 2003).
- Improve the accuracy of population and nest counts by developing a sampling procedure to estimate the sampling fraction for crocodiles and crocodile nests at Lake St Lucia.

- Determine nesting success, a key parameter for the population model, for a subset of nesting sites.
- Determine hatchling movements, dispersal dynamics, age structure, recruitment and role of intraspecific predation at natal areas.
- Continue with the annual Ezemvelo KZN Wildlife aerial and nests surveys to record relative abundance and distribution.
- Continue with ongoing efforts to quantify nest site fidelity and a visual database of nesting females
- Estimate the sub-adults proportion during aerial surveys.
- Survey effort. It is impossible to interpret survey data if survey effort remains unquantified.
- Monitor bush encroachment at nesting sites (Leslie & Spotila 2001).

6.9.3 Methods/Approaches

- Crocodile nest counts using double motorised paraglider from 13-18 January 2014 and a re-survey from 7-11 April 2014 to record the proportion of naturally liberated and predated nests, as well as those missed during the initial paraglider survey, and to check on unopened but recorded nests during the first survey.
- Crocodile population count using double motorised paraglider 16-21 June 2014.
- Ezemvelo crocodile nest foot survey in January and aerial survey in June.
- Nesting success, dispersal dynamics, recruitment, growth rates, age structure and role of intraspecific predation at natal areas will be determined by uniquely marking individual hatchlings through standard scute removal procedure (Combrink *et al.* 2012).
- Continue with the development of a spatially explicit distribution map of nesting *C. niloticus.*
- Continue with the marking of *C. niloticus* nests and the identification of nesting females through photography of caudal dermal pattern.
- Basking congregations will be photographed during aerial surveys to estimate the proportion of sub-adult and adult crocodiles.
- Integrate the use of a Cybertracker during nest surveys. This will increase the efficiency of capturing survey effort, which is a key aspect of any crocodile nest survey.
- Photograph each nest site in order to monitor bush encroachment at nesting sites.

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6.10 Indicator species: Hippopotamuses

Ricky Taylor

6.10.1 Rationale/Motivation

Hippos are an iconic species within St Lucia. More than any other species they contribute to the ‘brand’ recognition of the St Lucia estuarine system and have a large tourism value (Taylor 2013). They are also important as ‘bio-engineers’ that shape the environment they live in – by creating feeding lawns, paths, and channels in swampland. With their amphibious lifestyle they feed on land and deposit dung and urine in the water where they spend their days. A project is currently underway to test the significance of this, led by Jessica Dawson of the University of Cape Town.

Within an African context, the St Lucia population is one of few that are secure. Throughout the continent their numbers are declining rapidly as they are hunted and as wetland habitats are drained. Recent population estimates suggest that their numbers in Africa have declined by more than 20% over the past 10 years (Lewison & Olivier 2006). It is for this reason that they were placed on the CITES list as a Schedule II species and now have a Red Data classification of Vulnerable (VU A4cd) (Lewison & Olivier 2006).

From a management perspective, hippos do have the capacity to damage their environment if they exceed the carrying capacity of the area. They can also cause significant problems to neighbours by leaving a protected area and raiding crops. The factors limiting hippo numbers in aquatic environments are largely unknown, but it is likely that this is related to the social dynamics of the species (Klingel 1991). Thus, the removal of individuals from the population (through culling or capture) could destabilise the social structure and promote increased rates of breeding (Taylor 2009). A project studying the social aspects of hippo is currently underway by Alexa Prinsloo of the University of Cape Town.

In St Lucia, the hippo population is increasing at between 2% and 3% per annum. Small-scale removals of hippo have been taking place for the past several years – partly to slow the rate of increase and partly to gain expertise in the capture and handling of hippos. The hippos that are caught are sold to game farms and other conservation areas.

This section considers the research and monitoring required to underpin sound conservation of this species in and around the St Lucia estuarine system. However this should be seen in the larger context of the conservation of hippos in Africa. It is a large and important species in much of the continent but relatively little detail is known about its biology and ecology

(Eltringham 1999). Hence research conducted at St Lucia will contribute to the body of knowledge that increases the overall understanding of this species.

6.10.2 Aims/Objectives

- To gain an understanding of the hippo population dynamics and to develop a population dynamics model.
- To understand the social structure and interactions between hippos.
- To describe the impacts of hippos on the environment in their role as 'bio-engineers'.
- To determine the carrying capacity for the population – and what the consequences will be if this is exceeded.
- Understanding hippo-human interactions – both from the aspect of crop-damage and for tourism.

6.10.3 Methods/Approaches

What is required are some very careful and in-depth long-term studies of the hippos, especially where individual hippos are recognised. Most of the studies to date have been short-term, designed to meet the academic requirements of a higher degree. Although they do produce useful results, theses have serious shortcomings in that they are unable to provide the data and information that can only be obtained by more in-depth and long-term research.

Population dynamics

The annual aerial counts should continue. In addition detailed land or water-based counts of each group and age and sex classification are required. This intensive observation programme is required to provide the detailed parameters needed for population modelling, which include, inter alia:

- Lifespan
- Mortality of different age classes
- Age at first breeding
- Inter-calving intervals
- Social ecology and dynamics

It will be important to have recognisable hippos to be able to understand social hierarchies – both in the water during the day and while grazing at night. Some of the main questions to be addressed include:

- How are their social structures disrupted by management (e.g. capture or culling)?
- How would this affect group stability and hence alter birth and death rates?
- How does social behaviour (territoriality) affect the use of the environment and resources by the hippo – and hence controls their spatial distribution within the park?

Hippos as 'bioengineers'

This aspect ties in with carrying capacity. How do hippos modify their environment – and how does this affect the physical characteristics of the environment? (e.g. lawn formation and altered hydrology). How do the activities of hippos affect other species? (e.g. paths through emergent vegetation fringing the lake are possibly important in providing access for fish and aquatic invertebrates to adjacent wetlands). This work would require the skills of biologists and geomorphologists.

Carrying capacity (and trends in vegetation changes such as woody plant increase)

The carrying capacity of St Lucia for hippos is likely to be naturally controlled by one or more of several different components:

- Hippos consume mainly terrestrial grasses and therefore grasslands are their most important habitat. The capacity of many grasslands to support large herbivores around St Lucia is being reduced by woody plant increase (expansion of forest margins and also the formation of thickets). This is a problem that is not specific to hippos and needs to be addressed at the park management level. In addition, the configuration of the park boundaries and the fence affects use patterns by excluding hippos from certain areas. This needs to be considered when dealing with hippo-human interactions (see also hippos as damage causing animals).

- The availability of food, the distribution of food resources and current use patterns. This would require detailed quantitative grassland studies. If the food supply is exceeded, this would be manifested by reduced grazing and habitat deterioration during a grazing bottleneck (likely to be during a late winter period at a time when all the pans are full of water). There has been some relevant research in this regard (Conlong 1986, Dalton 2003, Dalton 2007, Payne 2004, Scotcher 1974, Taylor 1980) but it is woefully inadequate given that hippos form about half of the grazer biomass on the Eastern Shores (Taylor unpublished data).

- Availability of water. This changes from a wet to dry period – and affects the areas used by hippos. It is important to take this into account should any artificial water supplies be considered.

The carrying capacity study should determine the levels of impacts of hippo on the environment and express these as ‘Limits of Acceptable Change’ (LAC). A Population-Habitat Viability Analysis (PHVA) would integrate the results of much of the above research

Hippos as ‘damage-causing’ animals

The value of hippos (as tourism features) should be balanced against the costs incurred by crop damage and the relatively large number of humans in Africa who are killed or injured by this species each year. This is a focus that may provide useful management advice and policy recommendations.

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THEME 7: BIOTIC RESPONSES TO ABIOTIC EXTREMES

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7.1 Rationale/Motivation

The St Lucia estuarine lake system experiences dramatic changes in its physico-chemical conditions, which can vary both in time and space. Temporal changes may take place over long time periods, such as the cyclical wet and dry phases (up to 10 years) that the region characteristically experiences, or on shorter timescales as a result of seasonal influences (Perissinotto et al. 2013). While periods of drought are not uncommon to St Lucia, the most recent below average rainfall period (2002-2009) was prolonged and compounded by the management decision to allow the mouth of the St Lucia Estuary to close, while artificially maintaining its separation from the Mfolozi River (Lawrie & Stretch 2011a, 2011b), St Lucia's historic main freshwater supply during drought periods. The environmental extremes experienced within the system during the most recent drought are, therefore, artificial to a large degree (Stretch & Maro 2013).

Freshwater inflow is known to play a significant role in determining the state and functioning of St Lucia and the physico-chemical conditions prevailing in the system. During periods of high freshwater inflow (wet phase), the system tends to form one homogenous entity with similar environmental parameters across the lake, but during periods of low freshwater input there is a marked spatial variability, with parameters such as water depth and salinity in particular sculpting the distribution of different habitats within the system. While the lower reaches of the estuarine lake are relatively protected from the drought due to freshwater input from the Mpate River and groundwater flows from the eastern shores (Whitfield & Taylor 2009), hypersalinity and low water levels become increasingly more severe towards the north during drought conditions. This reversed salinity gradient and depth profile has the ability to fractionate the system into a variety of different habitats in relatively close range to one another, with each major portion assuming a unique biological community (Pillay & Perissinotto 2009, Perissinotto et al. 2013).

Biotic responses to the last hypersaline phase were investigated in some detail and included, in particular, the development of a halotolerant community in the northern part of the system (Carrasco & Perissinotto 2012), as well as tolerance limits of individual species to salinity increases (Nel et al. 2011, Carrasco & Perissinotto 2011a, Muir & Perissinotto 2012). On the other hand, flood events in the past have resulted in freshwater dominance, with limnetic conditions prevailing for long periods throughout the system. The exceptional case of cyclones Domoina and Imboa, that impacted the system in 1984 and resulted in a dramatic shift in both benthic and pelagic community structures (Cyrus 1988, Forbes & Cyrus 1992, Owen & Forbes 1997, Pillay et al. 2013).

Recently, the excavation of a beach spillway between the mouths of the Mfolozi River and St Lucia Estuary was completed on 6 July 2012. To date, it has been successful in serving as a channel for freshwater passage between the mouths of the Mfolozi River and St Lucia Estuary (Whitfield et al. 2013). Salinity levels throughout the lake have decreased substantially and water depths have increased dramatically over the entire system. This, however, is mainly due to rainfall in the St Lucia region having increased significantly since the beginning of 2012, with above average precipitation causing extensive river flooding during the 2012/2013 summer period. Increased freshwater input may also lead to the eventual re-establishment of the large joint St Lucia-Mfolozi mouth with the Indian Ocean. Not only is the increased freshwater supply expected to introduce a number of freshwater taxa into the system, but the connection with the ocean will also allow marine recruits to once again enter the St Lucia Estuary, increasing the overall biodiversity of the system. The changes in the biota will thus need to be monitored, both in terms of magnitude and time scales, as the system undergoes the transition from the hypersaline period that has prevailed for the past 10 years to the new wet cycle.

However, although the recent increased freshwater input into the system is largely positive and a major step towards the ecological recovery of the system as a whole, the main threat which was once responsible for the separation of the two systems, namely heavy siltation and sediment loading from the Mfolozi, still remains a possibility. Elevated turbidity and siltation levels can have a variety of adverse and beneficial consequences for aquatic ecosystems. For estuarine fauna, turbidity effects can influence feeding ability as well as alter predation risk. Fine inorganic sediments directly affect suspension-feeding animals by clogging feeding structures, interfering with particle selection, and requiring additional energy to remove unwanted particles (Hart 1986, Carrasco et al. 2007). On the other hand, decreased water clarity may offer a form of protection from visual predators. For algal assemblages, restricted light transmission may hinder productivity and have compounding effects on higher trophic levels (Hart 1987). Submerged macrophytes typically require more sunlight for photosynthesis than phytoplankton; this, combined with the constraint of being attached to the seabed, makes them especially susceptible to elevated suspended sediment concentrations (Duarte 1991; Markager and Sand-Jensen 1992).

In the St Lucia estuarine system, turbidity experiments have been undertaken on three key zooplankton taxa, the mysid *Mesopodopsis africana* and the copepods *Acartiella natalensis* and *Pseudodiaptomus stuhlmanni*, with each species showing specific and variable responses to increasing turbidity levels (Carrasco et al. 2007; Carrasco et al. 2013; Jones et al. in prep). On the whole though, the physiological response of these species to increased silt loading has been largely negative. This negative effect may also be transferred up the food web, as higher trophic levels may also be affected, if not directly by the high sediment load, then by food shortages caused by the decreased abundance of zooplankton (Carrasco et al. 2013). Tolerance experiments along the lines of those carried out for meso-zooplankton should be expanded to include other dominant and/or key species that occur permanently or most of the time within the system (e.g. *Gilchristella aestuaria, Brachidontes virgiliae, Solen cylindraceus, Crambionella stuhlmanni*). This will be useful towards establishing benchmarks of tolerance, but also potential ability by organisms to contribute to the removal of particles from the water-column (e.g. via pseudofaeces).

Although the last decade has been perceived as an adverse period for St Lucia, with harsh and variable conditions prevailing for the duration of the drought, increased research intensity during this phase has also allowed for the better understanding of how the system functions under artificially elevated hypersaline conditions. The extreme salinity levels (>100) that prevailed in False Bay during 2009 led to the development of an unique and possibly micro-endemic zooplankton community specialised to thrive under these conditions. These extremophiles were involved in a very simple food web (Carrasco & Perissinotto 2012). However, once salinity levels exceeded 130, virtually no zooplankton was recorded in the region, with only the cyanobacterium *Cyanothece* sp. persisting at the bloom stage (Muir & Perissinotto 2012). It was hypothesized though, that most species produce spores or resting cysts, capable of surviving unfavourable conditions for long periods of time. Elsewhere, it has been shown that during hypersaline conditions, sediments may harbour a potentially rich biodiversity in the form of dormant species, which is not immediately apparent when sampling the water-column alone (Moscatello & Belmonte 2009).

Resting stages have been associated with short-term as well as with long-term survival strategies (Uye 1985, Marcus 1996). The term ‘resting eggs’ covers three different forms of dormancy: quiescent subitaneous, diapause and delayed hatching eggs (Chen and Marcus 1997). Subitaneous eggs can become quiescent in response to adverse environmental conditions, but are capable of hatching as soon as conditions improve. Diapause eggs, on the other hand, only hatch after the completion of a compulsory refractory phase, even if conditions are beneficial (Grice & Marcus 1981) and delayed hatching eggs may remain viable in the sediment for months or even years, hatching gradually over an extended period of time (Chen & Marcus 1997, Katajisto 1996, Engle & Hirsh 2004). In the plankton, resting eggs are often regarded as a means of securing a population survival during unfavourable environmental conditions, but they are also recognised as possible mechanisms of temporal environmental partitioning, prevention of overcrowding, and even of slowdown in the rate of evolutionary change (Engle & Hirche 2004 and references therein).

All estuarine ecosystems are influenced by physical forcing but in St Lucia the artificial separation of the Mfolozi River from the once combined system has magnified the extent of these abiotic drivers. The reconnection of the Mfolozi River with the St Lucia Estuary, in conjunction with the above average rainfall the system has recently been receiving, has signalled the beginning of a new wet cycle with lowered salinities. It now remains to be seen how this resilient system responds as it undergoes this transition towards a new wet state.

7.2 Aims/Objectives

The overarching aim of this theme is, therefore, to identify and investigate the dynamics of response of organisms to environmental extremes, as the system changes from one state to the next. In particular, it is important to look at the key features of ecosystem change within the St Lucia estuarine lake, as it shifts from a dry to a wet state and to investigate the biotic responses to the salinity reversal currently in progress. The objectives can be subdivided into the following specifics:

a) To capture the critical events that are unfolding during the transition from dry to wet conditions, including all aspects of ecosystem dynamics as this shifts into a different state. Aspects requiring investigation are how the biota responds to changing physico-chemical conditions and how the dynamics of recolonisation and dispersal after the end of the adverse period that has prevailed for the past 10 years can be adequately monitored, both in terms of magnitude and time scales. This can be enhanced by having a conceptual/modelling basis to guide the monitoring. Quarterly monitoring surveys of the major physical and biological components of the benthic and pelagic environments were initiated by the University of KwaZulu-Natal in August 2004. These will need to continue, as the system moves towards a wet state. These data will not only add to the long term data set already existing, but will also make it possible to investigate the abiotic drivers under different system states and in different regions of the lake. While as many as 14-21 stations were sampled in the initial phase of the monitoring programme, from 2006 onwards only five representative stations have been regularly sampled. These were selected on the basis of a similarity analysis and include the Estuary Mouth, Esengeni, Charter's Creek, Lister's Point and Catalina Bay (Perissinotto et al. 2010, 2013). Additional stations were sampled during approximately the same period of time by the University of Zululand, but only at annual or six monthly intervals (MacKay et al. 2010, Jerling et al. 2010, Vivier et al. 2010). In addition to this, ad hoc sampling should also be undertaken in order to take advantage of opportunistic events (e.g. small floods in the Mfolozi, open mouth conditions, etc.), thus providing insight into the biological responses to both small- and large-scale events.

b) To investigate the various forms that different species adopt to survive in the estuarine portions of the lake, particularly in those areas prone to hypersaline conditions. Resting eggs will need to be extracted from sediment collected from the lake basins of St Lucia. These eggs will then need to be incubated in order to assess the biodiversity potential hidden within the sediment, as well as investigate the environmental cues that trigger their formation and hatching.

c) To determine the turbidity tolerance limits of key estuarine taxa in order to determine the effect of varying turbidity levels on the physiological functioning of key estuarine taxa such as *Gilchristella aestuaria, Brachidontes virgiliae* and *Solen cylindraceus.* Three different kinds of experiments can be employed, with indicators such as feeding, respiration and mortality rates used to assess the physiological response of these taxa as well as determine tolerance thresholds.

d) To investigate and elucidate details of the salinity budget for the system. The mechanisms and time scales for the redistribution of salt loading between the basins of the system, particularly between the northern and southern sections that are separated by the Fanies Island constriction. These exchanges, facilitated by wind-driven flows, depend on water levels and are important for understanding the dynamics of horizontal salinity gradients within the system. Under extreme hypersaline conditions, it is anticipated that there can be significant precipitation of salt, a mechanism that is still poorly understood and quantified. In cases where there is desiccation of large parts of the lake bottom, exposed salt precipitates may be lost due to wind. Shallow hypersaline water may also have thermodynamic properties that can significantly influence important processes in the water budget, such as evaporation and heat capacity. Previous unpublished work has also suggested that significant salt quantities may become bound into the sediment sub-strata. The role of this process in the salt budget should be clarified and quantified (Bate & Taylor, 2008; Vogel & Van Urk, 1975).

e) To investigate food web structures under wet cycle conditions, specifically the sources and role of detritus in the St Lucia system. Identification of the pulses that occur under different salinity regimes and knowledge of the factors driving them (e.g. when a macrophyte die-off occurs, driven by increasing salinity) are needed. Stable isotope analyses should be undertaken on a system-wide scale after major events. Knowledge of food web properties, such as trophic processes, enables inferences to be made about species interactions and ecosystem structure and function. The use of stable isotopes in ecological research has been recognized as an important tool towards this end. Since stable carbon isotopes ($\delta^{13}C$) are known to fractionate little between energy transfers, they are commonly used to quantify food sources and energy flow in aquatic systems. Stable nitrogen isotopes ($\delta^{15}N$) fractionate more and are typically used to infer trophic positions of consumers in a food chain (DeNiro & Epstein 1978, Peterson & Fry 1987). Stable isotope analysis should be taken on a system-wide scale, now that St Lucia is moving towards a wet state, in order to determine food web structure in a freshwater dominated phase. The study of Govender et al. (2011), which identified the food web structure in the different lake basins under drought conditions, could be replicated and compared to current conditions (i.e. freshwater dominated system). In this way, the source and role of detritus in the system can also be assessed.

f) To utilise changes in macrophyte vegetation as indicators of geomorphological change). Much more detail is needed on the macrophyte vegetation. This is the most sensitive indicator of geomorphological change (such as sediment accumulations) which would be evident if there is infilling (as expected if the system moves along the normal trajectory of evolution for a coastal lagoon), or flooding if its trajectory is reversed by sea level rise.

7.3 Methods/Approaches

7.3.1 Ecosystem shifts

The Quarterly monitoring surveys of the major physical and biological components of the benthic and pelagic environments need to continue as the system continues to move towards a wet state. The five representative stations that have been routinely sampled include the Estuary Mouth, Esengeni (Narrows), Catalina Bay and Charter's Creek (South Lake) and Lister's Point (False Bay). Where possible, both surface and near-bottom water physico-chemical measurements should be made with a YSI 6600 or similar water quality logger, fitted with temperature (°C), depth (m), salinity, dissolved oxygen (mg l^{-1}), pH and turbidity (NTU) probes. Surface and near-bottom water samples for the estimation of dissolved inorganic phosphorus and nitrogen (DIP and DIN, respectively) should also be collected at each site per sampling occasion. The biological components sampled should include: microalgae, zooplankton, meiofauna, benthic macrofauna and nekton (including prawns and fish). Additionally, hippopotamus, bird and crocodile counts should be taken as well, at least at yearly frequency. Quantitative analysis of these data will allow the assessment of the response of the biota to abiotic factors during wet conditions and eventually under open mouth state.

7.3.2 Resting stages

In order to investigate the various forms that different species adopt to survive unfavourable conditions, sediment should be collected from the lakes, particularly in those regions most prone to hypersaline development, e.g. False Bay and North Lake. The sediment can be collected with the use of a mini corer, separating the sediment into segments of approximately 1 cm each and resting stages can be extracted by employing methods similar to those used by Marcus (1989). Any eggs/cysts found can be incubated along a salinity gradient, in order to see when hatching occurs and identify any potential biodiversity that is hidden within the sediment.

7.3.3 Turbidity tolerance

Key estuarine taxa can be subjected to a range of naturally occurring turbidity levels (prepared using naturally occurring silt) in order to determine their effects on respiration, feeding and mortality rates. To measure respiration rates, individual animals could be incubated in sealed containers filled with O_2-saturated water from each turbidity treatment for a known period of time. Changes in oxygen consumption within each treatment should be recorded, in order to assess stress consumption. To investigate the effect of turbidity on mortality, a series of in vitro incubations could be performed, whereby individuals are subjected to varying turbidity levels over a period of time, with survival monitored frequently. In order to determine the effect of turbidity on feeding rates of key estuarine taxa, experiments could be set up to monitor the disappearance of food from each turbidity level. All three types of measurement have recently been employed at UKZN with good results (Cararsco et al. 2007, Carrasco et al. 2013b).

7.3.4 Salt budget

Various methods of investigating details of the salt budget may be used. Direct measurements of inter-basin fluxes at important control sections, such as the constriction at Fanie's Island may be undertaken. Numerical modelling (2D depth integrated) may be used to explore the effects of varying water levels and different wind conditions on water and salt exchanges between the basins. Salt distribution in sediments can be investigated using core sampling in the field. Furthermore it may be possible to employ modern isotope analytical methods to investigate the age of pore water recovered from cores and hence the fluxes between the sediment and the water column. Field or lab experiments can be used to investigate wind-driven entrainment of salt precipitates from exposed, desiccated surfaces.

7.3.5 Food webs

Samples of all the dominant and accessible biological components of the system (particulate organic matter, sedimentary organic matter, zooplankton, macrofauna, meiofauna, fish, macrophytes etc.) should be collected quarterly throughout the year at the five representative stations mentioned above. These samples should then be processed according to standard procedures (cf. Govender et al. 2011, Carrasco & Perissinotto 2010, 2011) and packaged for analysis of $\delta^{15}N$ and $\delta^{13}C$ signatures either at Isoenvironmental cc (Rhodes University) or the Stable Light Isotope Unit (Department of Archaeology, University of Cape Town). Using these signatures, it will be possible to gain insight into the trophic functioning of the St Lucia estuarine lake during wet and extreme drought conditions.

7.3.6 Macrophyte vegetation

Mapping and transect analysis are needed to understand the response of macrophytes to abiotic changes. Aerial photographs and ArcGIS should be used to map the different macrophyte habitats and compare with past vegetation maps. Permanent transects, consisting of fixed monitoring stations that can be used to measure change in vegetation in response to changes in salinity and inundation patterns, should be set up along an elevation gradient. Changes in the elevation profile will link the responses of the plants to geomorphological change. Percentage plant cover of each plant species in duplicate quadrats (1 m^2) can then be measured along the elevation gradient. For exposed sites other characteristics, such as sediment salinity, water content, depth to water table and water table salinity should be measured, while for submerged sites, depth and water turbidity are important parameters.

The different rates of colonisation and growth of the different species can be used to provide indicators of when changes occurred and how persistent they have been, e.g. mangroves may be indicative of events during the past 40-50 years, *Juncus* may reflect the past two decades and *Ruppia* the past year. These need to be accurately defined, in order to develop an index of stability and of change. Also, size classes need to be analysed, particularly of mangrove trees, as plant population dynamics are important but still poorly known. It is then important that this knowledge is synthesized in a modelling approach, so that the different rates of colonisation and growth of the species can be used to indicate when changes occurred and how persistent they have been. Such a modelling approach needs to include life-history information.

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8. THE WAY FORWARD

Ricky Taylor

8.1 Context

At the one-day workshop held at St Lucia, 50 involved people applied their minds to identify knowledge gaps and to discuss future research directions for the natural sciences at St Lucia. The essence of their deliberations was distilled into seven themes. For each theme a champion was identified whose job was to consolidate the theme. These champions have written the preceding chapters in this report which describe the rationale and context for each theme, the research aims, and some thoughts about the methodologies needed to undertake the research required for that theme.

This initiative comes at a time when the St Lucia ecosystem has been released from the stresses of a long and severe drought, assisted to some extent (especially in the Narrows) in recent years by a limited input of freshwater from the Mfolozi River system. It also comes at a time when our scientific knowledge, gained over the past 60 years, has been compiled and published by Cambridge University Press in the multi-author book entitled "Ecology and Conservation of Estuarine Ecosystems: Lake St Lucia as a Global Model' (Perissinotto et al. 2013). It also comes at the time when the iSimangaliso Project assessing the restoration of St Lucia, funded by the Global Environment Facility, is well underway. The climate is now ideal for new research initiatives at St Lucia.

This initiative also coincides with a period when several of the 'old guard' of experienced scientists, who have been the foundation for much of the research at St Lucia over the past few decades, are coming to the end of their scientific careers. It is time for a cohort of younger scientists to take over and, for this reason, a concerted effort was made to include young postgraduate students in the St Lucia Natural Science Workshop using sponsorship from the Water Research Commission.

The challenge now is to chart a way forward – a way that will promote the identified scientific investigations to fill the knowledge gaps needed to better conserve the St Lucia system. It is also a time to establish an enabling environment that is conducive to promoting research and everything associated with the production of rigorous science. We have seen how successful the synthesis of knowledge relating to the lower Mfolozi area has been – with the purpose of re-linking the Mfolozi and St Lucia systems (Bate et al. 2011). It is our firm hope that this report will help mould the next phase of natural scientific research at St Lucia.

8.2 Common threads

In the seven themes, described in the preceding theme chapters, there are a number of commonalities, including;

1. There is a need for **comprehensive baseline data** – good monitoring of hydrology and sediments, and good identification of species. There is a lot of value in having long-term data sets. We already have some, such as 60 years of salinity measurements, 40 years of groundwater records, 70 years of rainfall data, 50 years of fish monitoring, 30 years of bird counts and breeding records, 50 years of hippo counts and 30 years of crocodile counts. However, although there is a lot of data, much of it is patchy and without metadata.

   Derek Stretch, Robynne Lawrie-Chrystal and Katrin Tirok (pers. comm.) are currently putting together a model to show ecosystem changes. In pulling together this large database they are experiencing difficulties in “tying things together because data are patchy in space and time”. They are also finding that ”there is often little overlap in sampling methods and locations and that certain species have received far more research attention than others”. Based on the above, they recommend that “all scientists studying St Lucia need to work together coherently to collect data that can be used for more than one purpose or study”. Data collection is costly and needs to be done within the context of a conceptual model.

There is a need to have good metadata for all data sets. Well defined protocols should describe the methods used for the data collection. It is necessary to set and maintain standards for all data collection and to ensure consistency. With more and more remote collection of data (e.g. using images collected from space, using instruments that collect data remotely, loggers recording information from sensors and transmitters mounted on animals to detect movements and behaviours) the need is for strict protocols to calibrate instruments, to set them up properly, to collect and verify the data. Recently the South African Earth Observation Network (SAEON) has become involved with some of the monitoring in St Lucia and is a trend to be encouraged.

Good ecological science also depends on going back to the basics with species. Do we know what species we are working with? Too many promising studies fail because there is uncertainty about what species are being studied. Researchers should be encouraged to deposit voucher specimens in museum collections and species identifications need updated review. This has recently been done with the bivalves (Nel et al. 2012) and the crabs (Peer et al. in press) but needs to be done with all taxonomic groups.

2. St Lucia has a long history of research. However, much of it is in the form of isolated studies and there is a need to **synthesise** and integrate this information.

3. There is strength **in working in teams.** Scientists in teams support each other. The synergy within a co-ordinated team leads to efficient use of limited resources. Teamwork requires good understanding and communication. The two common threads in the most successful of the team programmes that have been conducted at St Lucia in the past are strong leadership and a focus on their goals. In the successful teams there is an intangible quality of 'generosity'. In these programmes the senior researchers have a willingness to share their knowledge and their data. Also, there is a generosity to give credit where this is due. This creates an openness that allows everyone to feel part of the team – not an isolated unit.

4. Where possible, these teams should be **interdisciplinary.** But there are few examples of true interdisciplinary programmes working. Often teams have a multidisciplinary composition but there is still little melding of approaches and ideas as each discipline tends to remain separated from the others.

5. **Modelling** is a good tool for interdisciplinary communication. The development of conceptual models can aid communication across disciplines. Conceptual models can be used to describe the current state of knowledge about complex systems. The strength of modelling is that it builds on existing scientific knowledge and explains assumptions. These then can be challenged by anyone.

6. Science focused on the wellbeing of St Lucia needs to look further afield than the estuarine lake system. Many of the problems affecting St Lucia have their origins in the **catchment**. Yet relatively little research has been done in the catchment areas – hence the emphasis on this topic in the current report.

7. We must **learn from the past** in order to understand the future. Some excellent research has been done on the dating of sediments and using pollen trapped in sediment deposits to inform us about past climates. This has provided insights into the rates of changes that are driving the system. From these we are able to predict possible future changes which may occur in response to global changes.

8. **Understanding of the extreme conditions** provides insights into average conditions. St Lucia is susceptible to extreme droughts and to large floods. The way science is funded and the slowness of the initiation of scientific projects make this difficult. So, a system of having contingency funding should be investigated to 'catch the moment'.
9. The use of **indicator species** as proxies for understanding environmental conditions can be useful – especially if good indicator species have been chosen and then are monitored to detect changes. We cannot understand the full system, but there are species that respond to different conditions. Use of these as indicators will inform us about conditions within the St Lucia system

10. Communication, the sharing of ideas, information, knowledge and data, can be improved with the use of the **Internet** and associated communication networks.

8.3 Guiding future research

How do we guide and foster research endeavours in the future? Science thrives in an environment conducive to good research. One requirement is to have an atmosphere where there are free interactions between involved scientists which promote the sharing of knowledge. The ability to freely engage with other scientists and the healthy critical comments of peers is necessary. A scientist must be encouraged to work in the field he/she is trained in and research at St Lucia requires well trained people in many disciplines. For interdisciplinary work the scientists should have a curiosity about disciplines other than what they are trained in, and hence can gain an understanding of what other research is being conducted.

This WRC report has been developed by people from many disciplines within the natural sciences and will hopefully act as a catalyst for developing the integrated science needed to provide the knowledge that will support the management of St Lucia. It is a document that should be used by researchers developing proposals for funding and by funding agencies as a guideline indication of the direction that research should be taking. However, it should be realised that it is still only a guideline, and not a prescription that should preclude innovative research directions. There must still be scope for individuals or teams to chart their own courses of scientific investigation. It must also be recognised that scientific thinking changes continually and so this sort of document does become outdated. Therefore, the ideas expressed in this document should not be set in stone.

Individuals have contributed so much in the past – and need to be encouraged. There will always be room for individual researchers focussing on a particular field, but more and more of the work is being done by teams. These teams can be small, from within a single unit within a university department, to multi-institutional partnerships. There is a lot of scope for the development of international programmes, especially where these bring expertise and technology into the country.

Teamwork often also improves the quality and rigour of the science, especially if there is good leadership and experienced scientists are mentoring and guiding the science. Whatever the scale and type of science being done, the most successful science that has been conducted at St Lucia in the past has been characterized by good leadership and a passion for science amongst the team members.

8.4 Who promotes the research?

There are four pathways along which research initiatives can be promoted:

a) By individuals or small teams

In the past individuals have contributed to a large extent to the scientific knowledge of the system – and must be encouraged to do so in the future. They must not be excluded in the movement towards team science and collaborations. The National Research Foundation (NRF) is one of the main funders for individual scientists (especially when they are NRF 'rated scientists').

In a number of cases individuals have formed part of very effective small teams. The best teams have been those that promote sharing and learning. A very effective formula is to set up teams of scientists who are at different stages in their careers – so that young scientists can learn from the more experienced ones and, in turn, can promote even younger scientists as they progress. This sort of multi-cohort team structure is good and can be improved upon if team members come from different institutions – thereby bringing different institutional cultures. The South African Research Chairs Initiative (SARChI) is one such route for the involvement of small teams of scientists and students at St Lucia.

b) As institutional programmes

These are usually reasonably large programmes set up by an institution or a consortium of several institutions. These research 'programmes' handle science at a larger scale than can be done by individuals or small teams. The type of direction this could take is having a group of highly-rated scientists establish a NRF Centre of Excellence. The establishment of such a programme would allow the participants to focus on much larger funding opportunities – especially those that have access to international funding.

c) As contracted research

Where a specific product is required, the research effort can be contracted out to specialists to undertake. This can be an efficient way to achieve a specified and well-defined objective. However it is a route where there is little leeway to follow interesting leads since the terms of reference are usually clearly defined. This is the sort of science that often results in 'grey-literature' reports and is usually not sufficiently challenged through a rigorous peer review process for journal publication.

Contracted research is often best suited to 'inventory science' rather than discovery science or hypothesis-based science. The funding for this is usually from within a government budget or from an international aid package.

d) By state officials mandated to do the work

The science that is best done by state employees from management agencies is long-term monitoring work, where consistent inputs are required; or science that has a very strong management focus. The funding for this would come from the department in which the official is based.

Funding is always needed and it is hoped that this document will become a first port of call for anyone wanting to develop research proposals to work in the St Lucia ecosystem. It is hoped that funding agencies will recognise that this document is a sound summary of what is needed (and give weight to what is in here) but not exclusively. There must be room for new approaches and avenues of investigation.

A problem with the present funding system is that funding cycles are typically 3-5 years. The dominant cycles affecting St Lucia are the wet-dry patterns which are about a decade in duration. So there is a mis-match between funding cycles and natural cycles. This is aggravated by the fact that much of the research being conducted at St Lucia is for higher degrees – and again the duration of the field component for a MSc or a PhD is only two to three years. There is always a need for more funding for research; however, the challenge is more often a shortage of suitably trained scientists than a lack of funding.

8.5 Products, communication and application of the science

There always will be a place for 'grey literature', but to have a solid science foundation it is necessary to publish findings in peer-reviewed journals and to present research findings at scientific symposia where these can be challenged by peers. Conferences and workshops directed at the research happening at St Lucia are important for knowledge dissemination, but symposia of the past that have not had published proceedings are the ones that have been forgotten.

The Internet opens new opportunities for communication. Its use should be developed to support ongoing science. Already much of the 'grey literature' relevant to St Lucia is housed on the SAEON web site for all to access. Another use would be to develop annotated checklists and species profiles for the main species in the system – with identification keys.

Then there is the communication of findings and integration of science into the day-to-day management implementation. This needs to be built into each project from the start and develop as the project progresses. Scientists need face-to-face contact with the managers as the informal discussions are often more effective than formal presentations and documents. In this age of too many meetings, workshops and symposia, and being swamped with documents, this becomes very important. Active scientists also need to communicate with other scientists and with the public.

Scientists need to be open, to develop a culture of sharing and helping other scientists. There is also a need to have the freedom to express ideas and opinions – and for scientists to be able to challenge one another. To keep the quality of science, it is also necessary to have highly-rated scientists as leaders.

8.6 Conclusions

There is no easy recipe for promoting science at St Lucia – it is more about the creation of an environment that supports science. But what is needed now is also a coming together of the natural sciences with people skilled in the social, economic and political disciplines to be able to understand the interactions of people and society with the long-term conservation goals of the St Lucia system. This was recognised in 2003 at a symposium linked to the World Parks Congress that was held at Cape Vidal. It was recognised then that there is an imbalance in research, with the much larger focus on the natural sciences than on the social sciences. In the intervening decade there have been considerable advances in the natural sciences and possibly less so in the social sciences – so that this imbalance continues. This needs to be rectified, not by having less focus and funding for the natural sciences, but by having a much greater focus on the social sciences, which have different avenues of funding and different support systems.

8.7 References

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List of Acronyms

ACRU Model	Agricultural Catchments Research Unit Model
AMS	Accelerator Mass Spectrometry
BP	Before Present
CG	Council for Geoscience
CITES	Convention on International Trade in Endangered Species
CLUZ	Conservation Land-Use Zoning
CSIR	Council for Scientific and Industrial Research
DDT	Dichlorodiphenyltrichloroethane
DEA	Department of Environmental Affairs
DELFT3D Model	Delft Institute 3D Model
DNA	Deoxyribonucleic acid
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EIS	Ecological Importance-Sensitivity
EZKN Wildlife	Ezemvelo KwaZulu-Natal Wildlife
GEF	Global Environmental Facility
GIS	Geographic Information Systems
GPS	Global Positioning System
IBA	Important Bird Area
IUCN	International Union for Conservation of Nature
KZN	KwaZulu-Natal
LAC	Limits of Acceptable Change
LGM	Last Glacial Maximum
MARXAN	Marine and Spatially Explicit Annealing
NMMU	Nelson Mandela Metropolitan University
NRF	National Research Foundation
OSL	Optically Stimulated Luminescence
PES	Present Ecological State
PFI	Percy Fitzpatrick Institute
PHVA	Population-Habitat Viability Analysis
PSD	Particle Size Distribution
PyTOPKAPI Model	Python Topographic Kinematic Approximation and Integration Model
RAMSAR	Ramsar Convention on Wetland Sites of International Importance
RDM	Resource Directed Measures
RU	Rhodes University
SAEON	South African Environmental Observation Network
SAIAB	South African Institute for Aquatic Biodiversity
SANBI	South African National Biodiversity Institute
SARChI	South African Research Chairs Initiative
SCADCO	St Lucia Scientific Advisory Council
SRTM DEM Model	Shuttle Radar Topography Mission Digital Elevation Model
TRMM	Tropical Rainfall Measuring Mission
UCOSP	Umfolozi Co-operative of Sugar Planters
UCT	University of Cape Town
UKZN	University of KwaZulu-Natal
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNIZUL	University of Zululand
WRC	Water Research Commission
WU	Wits University (University of the Witwatersrand)

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