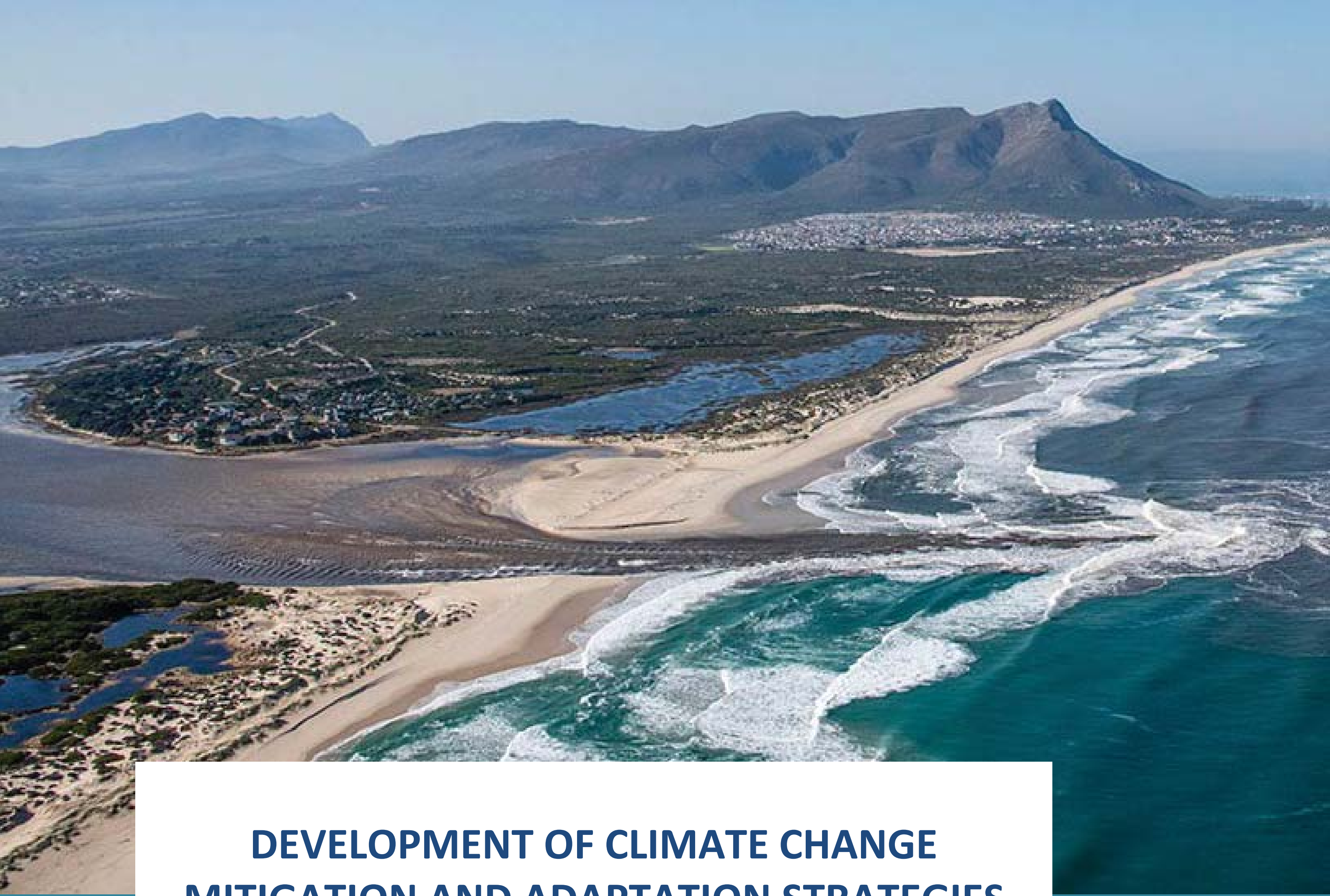
DEVELOPMENT OF CLIMATE CHANGE MITIGATION AND ADAPTATION STRATEGIES FOR SOUTH AFRICA'S ESTUARINE LAKES

L van Niekerk, S Taljaard, JB Adams, SJ Lamberth, SP Weerts, D Lemley, and T Riddin

Volume I: A Review of available information

WATER RESEARCH COMMISSION

TT 871/1/21



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COMPILED BY:

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WRC Report No. TT 871/1/21

February 2022

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This report emanates from a project titled *Development of Climate Change Mitigation and Adaptation Strategies for the Estuarine Lakes of South Africa* (WRC Project No. K5/2931) and forms part of a series of three reports. The other reports in the series are:

Van Niekerk L, Taljaard S, Adams JB, Lamberth SJ, Weerts SP, Lotter D, Lemley D, Riddin T. 2022. Development of Climate Change Mitigation and Adaptation Strategies for the Estuarine Lakes of South Africa. Volume II: Climate Change Vulnerability assessment and recommended Mitigation and Adaptation Strategies. (WRC Report No. TT 871/2/21)

Van Niekerk L, Taljaard S, Adams JB, Lamberth SJ, Weerts SP, Lotter D, Lemley D, and Riddin T. 2022. Volume III: Development of Climate Change Mitigation and Adaptation Strategies for the Estuarine Lakes of South Africa. Volume III: Vulnerability Assessment Appendices. (WRC Report No. TT 871/3/21)

Printed in the Republic of South Africa
ISBN 978-0-6392-0321-8

Title page: Historic breaching of the Bot/Kleinmond Estuarine Lake mouth after a flood – Jean Tresfon

ACKNOWLEDGEMENTS

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The following resource managers/specialists are thanked for their contribution to the Reference Group:

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LIST OF SYMBOLS AND ABBREVIATIONS

CPUE	Catch-per-unit-effort
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DWA	Department of Water Affairs (now DWS)
DWAF	Department of Water Affairs and Forestry now DWS)
DWS	Department of Water and Sanitation
EFR	Ecological Flow Requirement
EFZ	Estuary Functional Zone
EHI	Estuarine Health Index
EMP	Estuarine Management Plan
EWR	Ecological Water Requirement
MAR	Mean Annual Runoff
MLRA	Marine Living Resources Act (No. 18 of 1998)
MPA	Marine Protected Area
MSL	Mean Sea Level
NBA	National Biodiversity Assessment
NEMA	National Environmental Management Act (No. 107 of 1998)
NEMP	National Estuarine Management Protocol
NMU	Nelson Mandela University
NWA	National Water Act (No. 36 of 1998)
NWRS	National Water Resources Strategies
PES	Present Ecological Status
RDM	Resource Directed Measures
REI	River Estuary Interface

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1. INTRODUCTION

1.1 Background

Estuaries form an interface between the land and sea and are strongly influenced by runoff, wind, wave action, air and water temperatures from the land and sea. Ever-increasing anthropogenic impacts on estuarine systems are posing serious threats to the biodiversity and ecosystem services we derive from our national estuarine resources (e.g. carbon sequestration, flood attenuation, fisheries, provision of sustainable livelihoods, and eco-tourism). Climate Change is likely to add to, and possibly exacerbate existing pressures, accelerating degradation of estuaries. Therefore, timeous planning to mitigate and adapt to climate change has become critical for sustaining these valuable ecosystem assets.

Approximately 90% of South Africa’s nearly 300 estuaries (not considering the micro-estuaries) are small, **dynamic temporarily open/closed estuaries or linear, permanently open systems**. Over the past decade numerous studies have been undertaken on the biophysical function of these types of estuaries (e.g. Perissinotto et al. 2010; Whitfield et al. 2008 and 2012), providing valuable input to climate change strategy developments. However, a small percentage of the country's estuaries (< 4%) are **larger estuarine lake systems**, mostly evolved from drowned river valleys (Van Niekerk et al. 2020). Very few of these have been the focal point of long-term biophysical research studies that could inform climate change response strategies. While estuarine lakes constitute a small percentage of estuarine systems in terms of numbers (13 systems), collectively they cover more than 60% of the South Africa's estuarine habitat (Van Niekerk et al. 2013). Critical nursery habitats, such as submerged aquatic vegetation, only occur in 20% of South Africa’s of estuarine lakes making up a significant proportion of this habitat type (Adams et al. 2016). Despite their values, more than 84% of estuarine lake area already is in a poor ecological state because of anthropogenic pressures (Van Niekerk et al. 2013).

The physical properties of estuarine lakes suggest relatively low flushing rates, and the potentially stronger influence of *in situ* processes on estuarine characteristics (Taljaard et al. 2018). As a result, climate change strategies for these systems may be quite different from those of the other smaller, linear systems. For example, estuarine lakes generally have large surface areas/volumes, comparatively low mean annual runoff, and interrupted connectivity to the sea (e.g. mouths can close for extended periods). They are therefore less resilient to change as their biophysical processes function over long time scales (i.e. annual to decadal) and their re-setting mechanisms are relatively weak in comparison with the smaller systems. In general, estuarine lakes are very vulnerable to catchment and development pressures (Van Niekerk et al. 2019). This also makes them particularly vulnerable to the vectors of global change, including climate change (e.g. manifested in terms of shifts in seasonal rainfall, intensification of drought cycles, increase occurrence of floods, as well as increasing temperatures and evaporation).

1.2 South Africa’s Estuarine Lakes

Thirteen estuarine lakes systems have been identified along South Africa’s coast, namely Verlorenvlei, Zeekoevlei, Klein, Bot/Kleinmond, Heuningnes, Touw/Wilderness, Swartvlei, iMhlathuze, St Lucia, uMgobezeleni and Kosi (Figure1.1.) (Van Niekerk et al. 2013), spanning four biogeographical regions (Table 1.1). These lake systems mostly formed as a result of sea level changes between the late Pleistocene and Holocene (Whitfield, et al. 2017), some stemming from drowned river valleys (e.g. Swartvlei) and others from marine flooding (e.g. Wilderness) (Whitfield et al. 2017).

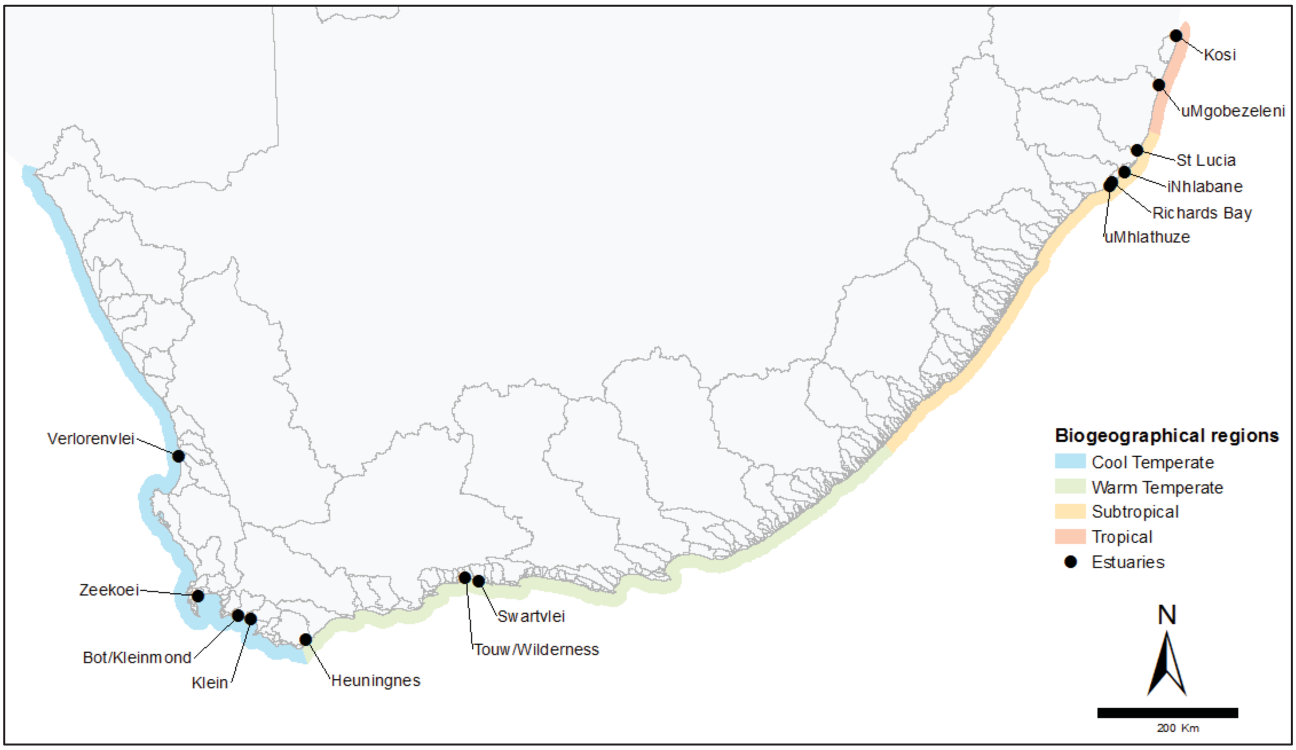

Figure 1.1 Location of South Africa's Estuarine Lakes

Together estuarine lakes comprise nearly 60% of South Africa's estuarine area (Van Niekerk et al. 2013) because they have large surface areas/volumes. These large systems therefore have low flushing rates, comparatively low mean annual runoff and their connection to the sea can be cut off for extended periods. Estuarine lake connectivity range from a near permanent open (e.g. Kosi), to predominantly closed (e.g. Bot/Kleinmond and St Lucia), while others open on an annual time scales (e.g. Swartvlei) (Russell and Randall 2017). The extent and duration of this connection to the sea also influence the salinity regime in these lake systems, ranging from fresh to hypersaline. As a result of restricted connectivity to the sea and low tidal amplitudes (15 to 20 cm) wind plays a more prevalent role in mixing processes compared with tides (Van Niekerk et al. 2019).

Table 1.1: Biogeographic distribution of South Africa's Estuarine Lakes (Van Niekerk et al. 2019)

ESTUARINE LAKE	BIOGEOGRAPHICAL REGIONS			
	Cool Temperate	Warm Temperate	Subtropical	Tropical
Verlorenvlei	●			
Zeekoevlei	●			
Bot/Kleinmond	●			
Klein	●			
Heuningnes		●		
Touw/Wilderness		●		
Swartvlei		●		
iNhlabane			●	
uMhlathuze			●	
St Lucia			●	
uMgobezeleni				●
Kosi				●

In fact, several of these lakes have been viewed as systems in transition from estuarine lakes to coastal lakes (Whitfield, et al. 2017) due to human interferences such as reduction in freshwater inflows, barrier at their outlets and inappropriate, low level development. For example, Sibaya, Cubhu and Mzingazi, used to be lakes that were connected to the sea (i.e. estuarine lakes) but have evolved in to coastal lakes over time through natural or anthropogenically induced loss connectivity from the sea (Weerts et al. 2014, Whitfield et al. 2017). Present day sediment processes in most South African estuarine lakes tend to be stable, with infilling occurring over long time scales and resetting limited to larger flood events. Sediment processes also are influenced by land use changes and low level human development (e.g. Eilandvlei in Touw/Wilderness lake system show such effects over the last 700 years – Reinwarth et al. 2013).

1.3 Existing Pressures on Estuarine Lakes

The low flushing rates and intermittent connection to the sea make South Africa's estuarine lakes more vulnerable to catchment and development pressures and as a result more than 84% of estuarine lake habitat already is in a poor condition from catchment and development pressures (Van Niekerk et al. 2019). This reduces their ability to provide key ecosystem services such as flood regulation, nutrient cycling, nursery habitat, and has compromised recreational and tourism benefits derived from these systems. Catchment development is increasing resulting in reduced inflow (either surface or groundwater) into many lakes, Kosi being a good example.

Table 1.2: Key pressures on South Africa's Estuarine Lakes

SYSTEM	PRESSURE																
	Overall Pressure Level	Reduced base flows	Reduced floods	Reduced groundwater input	Poor water Quality: Stormwater/floodplain drainage	Poor water quality: River water quality	Poor water quality: WWTW discharges	Reduced connectivity/ hydrodynamic functioning	Artificial mouth management/breaching	Loss/degraded riparian areas/ wetlands	Alien vegetation	Grazing in EFZ (sheep, cattle, goats)	Mangrove harvesting	Recreational activities impacting birds	High fishing pressure/ bait collection	Alien or translocated fish	Mining
Verlorenvlei	H	●		●		Agric		●	●	●		●			●*	●	
Zeekoevlei	VH	●			Urban	Urban	●	●	●		●			●		●	
Bot/Kleinmond	M	●				Agric	●		●		●			●	●*	●	
Klein	M	●			Urban	Agric	●		●		●			●	●*	●	
Heuningnes	H	●			Agric	Agric		●	●	●	●	●		●	●	●	
Touw/Wilderness	M	●						●	●		●			●	●	●	
Swartvlei	L	●				Agric		●	●		●			●			
uMhlathuze	VH	●	●		Agric	Agric/ Urban		●	●	●	●		●	●	●*	●	●
iNhlabane	VH	●	●					●		●	●	●			●*		●
St Lucia/uMfolozi	H	●	●					●			●		●		●*		
uMgobezeleni	L			●				●	●				●		●*		
Kosi	L	●		●							●		●		●*		

**Illegal gill netting*

Key pressures on South Africa's estuarine lakes include (Table 1.2):

- Base flow and flood reduction through abstraction, impoundments, and alien invasive plants in catchments;
- Groundwater utilisation and forestry;

- Artificial breaching or mouth stabilisation due to inappropriately or poorly planned coastal development;
- Wastewater discharges directly into, or just, above estuarine lakes;
- Poor water quality from the catchments and surrounding environment (stormwater and floodplain drainage), and low flushing rates, cause microalgal and macroalgal booms;
- Reduce connectivity and hydrodynamic functioning as a result of infrastructure, channelisation,
- Artificial mouth management and/or breaching, often at much lower than natural levels causing sedimentation (and in some cases causing premature mouth closure);
- Inappropriate resource utilisation (e.g. overexploitation of fish, mangroves and reeds);
- Biological invasions (alien invasive plants, invertebrates and fish);
- Recreational activities (boating, kite surfing) cause bird disturbance and noise pollution for soniferuous fish; and
- Mining impacting estuarine functioning and biota.

1.4 Expected influence of Climate Change on Estuarine lakes

Climate change is a measurable reality and South Africa is especially vulnerable to its impacts (DEA 2010, 2013), including estuarine lakes. Recently estuaries have been the focus of several comprehensive Climate Change Vulnerability Assessments (Day et al. 2008, 2011, Gillanders et al. 2011, Newton et al. 2014). Key drivers of change have been identified as (e.g. Duarte et al. 2013; Vizzini et al. 2013; Kerfahi et al. 2014; Milazzo et al. 2014; Ge et al. 2017; Rees et al. 2017; Laurent et al. 2017):

- Modification of terrestrial climatic (e.g. temperature and rainfall) and hydrologic processes;
- Changes in oceanic circulation;
- Ocean acidification;
- Sea level rise; and
- Increased sea storminess.

While global *temperatures* have increased by about 0.8°C over the last century, in response to the enhanced greenhouse effect, recent analyses indicate that South Africa has been warming at more than twice the global rate over the past five decades (Jones et al. 2012; Kruger and Sekele 2012; MacKellar et al. 2014; Engelbrecht et al. 2015; Kruger and Nxumalo 2016). The mean temperature of coastal waters has increased by 0.1°C per decade since the early 1970s (Schlegel and Smit 2016), although the trend is not uniform. Increases along the KwaZulu-Natal coast are among the highest in the Western Indian Ocean (Lima and Wethey 2012), while localized areas along the west and south coasts are cooling seasonally as a result of changes in upwelling patterns (Rouault et al. 2010, Lima and Wethey 2012).

Climate change in southern Africa will *change precipitation patterns*, which, in turn, will affect the quantity, quality, and seasonality of *hydrological regimes* to estuaries and exacerbate existing human modifications of river inflows (Alber 2002; USEPA 2009; James et al. 2013, Bunn 2016; SAWS 2017). Climate change may also manifest itself through changes in the frequency of occurrence of severe weather events (in addition to potential changes in the long-term averages of variables such as rainfall and temperature). On the subtropical and warm temperate biogeographical coasts, the combination of generally wetter conditions and heavy precipitation events will result in more runoff. While a decrease in rainfall in the cool temperate region, with the related minor increase in inter-annual variability, will result in a decrease in freshwater flows and an intensification of the wet-dry cycles, as shifts in precipitation are strengthened in the hydrological cycle in most instances (Hewitson and Crane 2006; Engelbrecht et al. 2009; 2011; Lumsden et al. 2009, James et al. 2013). An increase in extreme events is projected for the Southern, Eastern Cape and KwaZulu-Natal coasts during spring and summer, with a reduction projected for winter and autumn (e.g. Christensen et al. 2007; Engelbrecht et al. 2009; Engelbrecht et al. 2013).

South Africa's coastal climate is strongly influenced by *two large scale ocean currents*. The Agulhas Current, flowing along the east coast, is the strongest western boundary current in the southern hemisphere (Beal et al. 2011). Most of the inter-ocean transfer of heat and salt between the Indian and Atlantic oceans is associated with the Agulhas Leakage (Gordon et al. 1987; Matano and Beier 2003). Changes in Agulhas Leakage will also influence the ecosystems of the Benguela Current including its coastal climate, thus impacting river run-off and estuarine dynamics. Overall, a stronger Agulhas Current transport has been predicted due to global warming, which will affect inshore upwelling cells as well as shelf-edge upwelling which in turn may impact coastal and estuarine ecology along South Africa's coast (Backeberg et al. 2012). On the west coast, the Benguela Current is likely to intensify and lead to more intense upwelling due to the acceleration of the Supergyre (Saenko et al. 2005; Roemich 2007). How robust the upwelling trends in the Benguela Upwelling System will remain unclear (Hagen et al. 2001; Lutjeharms et al. 2001; Bakun et al. 2010; Rouault et al. 2010; Dufois and Rouault 2012).

Ocean acidification will ultimately result in a change in pH and oxygen in estuaries, with a related response in biotic processes such as community composition, nursery function and behavioural responses. However, natural variability in estuarine pH should be taken into account when the effects of ocean acidification are considered. Natural fluctuation in pH may play a large role in the development of resilience in estuarine biological populations (Sorte and Hofmann 2004). On the other hand, it may combine with the effects of ocean acidification to produce more extreme events that result in an even greater impact on the biota (Hofmann et al. 2011). The effects of ocean acidification in the short term will be negligible in comparison with the terrestrial signal (e.g. eutrophication resulting from urban runoff and agricultural return flow). Systems subjected to regular upwelling or increased upwelling, e.g. along the West Coast are likely to display the effects of ocean acidification first.

Present South African *sea level rise* rates are approximate: west coast +1.9 mm per annum, south coast +1.5 mm per annum and east coast +2.7 mm per annum (Mather et al. 2009; Mather et al. 2019). The effect of sea level rise, and related increase in tidal prisms, will be less apparent along the KwaZulu-Natal coastline, where except for estuarine lakes and bays,) the majority of estuaries are perched. However, it will be more apparent in estuarine systems along the Southern and Western Cape characterised by more extended coastal floodplains.

South Africa is a wave-dominated coast sensitive to *increased sea storminess*. In South Africa, increases in either intensity or frequency, or changes in seasonal storm intensity have been reported at a local scale albeit on a very short timescale (Guastella and Rossouw 2012; Harris 2010). Preliminary findings indicate that there may be long-term trends in the regional metocean climate (Theron 2007). Mori et al. (2010) predicted that mean wave height might generally increase in the regions of the mid-latitudes (both hemispheres) and the Antarctic ocean, while decreasing towards the equator. A more severe wave climate (or related oceanic wind climate) will result in more storm erosion, potentially more coastal sediment transport, and greater coastal impacts. However highly protected (e.g. Wild Coast) or very exposed (along the KwaZulu-Natal) estuaries are less likely to change character, whereas smaller estuaries along the Western, Southern and Eastern Cape may be very sensitive to this change.

Table 1.3 provides an overview of the expected influence of these climate change stressors on key estuarine processes. Of note is that estuarine habitats are already significantly degraded through other global pressures such as freshwater reduction, habitat destruction, nutrient pollution and overexploitation of living resources, which affects related ecosystem services (e.g. nursery function). These impacts reduce the capacity of estuaries to buffer the effects of change, be they natural or anthropogenic.

This study on estuarine lakes will focus specifically on the most critical *terrestrial climatic and hydrological vectors* associated with climate change, and its anticipated effects on the key estuarine processes, as well as the key biotic responses, and its consequences on the ecological health condition and important ecosystem services supplied by these systems.

Table 1.3: Vulnerability of key estuarine processes to various climate change stressors

ESTUARINE PROCESSES	STRESSOR				
	Terrestrial Climatic & hydrological processes	Ocean circulation	Ocean acidification	Sea level rise	Storminess
Coastal connectivity (alongshore)		●			
Land-sea connectivity (mouth state)	●			●	●
Salinity regime	●			●	•
Temperature	●	●			
Biogeochemistry (water quality)	●	●	●	•	
Biological cues (flow to sea)	●		•		

1.5 Aim and Objectives of Study

Within the above context, the aim of this study, therefore, is to develop **Climate Change Mitigation And Adaptation Strategies focusing on South Africa's estuarine lake systems** (focusing on terrestrial climatic and hydrological stressors) for consideration in resource allocation, planning and management (e.g. prioritising estuarine lakes Water Resource Classification under the National Water Act) and inclusion in related government policies. This will be achieved through the following objectives and associated tasks:

Objective 1: Conduct a literature review on South Africa's estuarine lake systems

An extensive literature review will be conducted to collate key data and information available on estuarine lake systems. This data and information will be critically reviewed to gain a better understanding of the present state, and biophysical dynamics of these systems, focusing on aspects such as river runoff, connectivity to the sea, salinity (and biogeochemical) states, as well as key biotic responses. This information will then be used to inform the conceptual models for estuarine lakes (see Objective 3)

Objective 2: Down-scale global model results of Climate Change scenarios

Available global/regional scale dynamic model outputs (with a focus on the terrestrial signal) will be downscaled appropriate for Climate Change assessments at the primary catchment scales. Key vectors of climate change that will be considered for downscaling as part of this project include (i) Shifts in seasonal rainfall on the primary catchment scale; (ii) Shifts in flood regimes on the primary catchment scale; (iii) Shifts in droughts on the primary catchment scale; and (iv)Terrestrial temperature regime shifts at the estuary scale.

Objective 3: Develop conceptual (biophysical) models for estuarine lakes

Using an available understanding of South Africa's estuarine lake systems (Objective 1), together with the experiential knowledge of the project team on climate change effects on other estuarine systems, conceptual models representing typical biophysical patterns in estuarine lakes will be constructed. Such conceptual modelling will assist in contextualising the effects of future climate change projection (see Objective 2), and other global change pressures.

Objective 4: Conduct Climate Change Vulnerability Analysis on estuarine lakes

Using the output from Objectives 2 and 3, a Climate Change Vulnerability Analysis will be conducted, framed in terms of changes in estuarine ecological health (or condition) as well as possible consequences in terms of key ecosystem services provided by these lake systems (e.g. fishery nursery function and production, carbon sequestration, flood mitigation).

Objective 5: Develop Climate Change Mitigation and Adaptation Strategies for South Africa's estuarine lakes

These strategies will be developed together with a group (2-4) of selected estuarine managers and planning authorities from key government departments (e.g. Water and Sanitation, Environment and Fisheries) in a workshop format to ensure relevance and buy-in from key managing authorities.

1.6 Purpose of this Report

This report comprises a scientific review of available information on South Africa's estuarine lakes, specifically on information that is considered relevant to inform science-based Climate Change Mitigation and Adaptation Strategies for these lakes.

This introductory chapter (Chapter 1) is followed by an overview of the approach and method that was adopted for this study to develop Climate Change Mitigation and Adaptation Strategies for estuarine lakes (Chapter 2).

Thereafter, an overview of relevant abiotic and biological characteristics of South Africa's estuarine lakes systems follows, including a summary of their present health condition (Chapters 3 to 14). Nine of the 13 estuarine lake systems in South Africa are discussed in detail. The remaining four (i.e. Zeekoevlei, uMhlathuze [now subdivided into uMhlathuze and Richards Bay estuaries], iNhlabane and uMgobezeleni) are only discussed briefly, either because a system has been highly modified or because relevant information the abiotic and biological characteristics are not readily available.

Finally, Chapter 15 critically reviews the patterns, differences and commonalities noted in and across the systems reviewed. This provides input for the development of the conceptual biophysical models, and ultimately for assessing responses to climate change.

2. APPROACH

This study focuses specifically on the anticipated *terrestrial climatic and hydrological vectors* of climate change on the functioning of estuarine lakes to inform climate change mitigation and adaptation strategies focusing on South Africa's estuarine lake systems. Specifically, this refers to expected changes in **atmospheric temperature** and **rainfall**.

The approach adopted for this assessment, therefore, was to select key abiotic and biological response indicators that could be used in studying future effects of these vectors of climate change in estuarine lakes based on such understanding inform the development of appropriate climate change strategies. The abiotic response indicators considered most appropriate in this regard were mouth dynamics (connectivity to the sea) and water levels (indicative of surface and/or groundwater water flows), salinity and water temperature. In terms of biological response indicators microalgae, macrophytes and fish were considered the most useful assemblages, and were also biota with the most information available.

2.1 Selection of Abiotic Response Indicators

2.1.1 Mouth dynamics and water levels

South Africa's coast is generally characterised by low tidal ranges and high wave energy, making it a wave-dominated coast (Cooper 2001). Therefore, the nearly 300 functional estuaries are predominantly microtidal systems (tidal range < 2 m) that are highly dynamic and shallow (average depth of 2-3 m). Owing to strong wave action and high sediment availability, more than 90% of these estuaries have restricted inlets that can close for varying periods of time when a sand bar forms across the mouth (Van Niekerk et al. 2013). The higher the wave energy at the mouth, the more constricted the mouth will be. Perched estuaries tend to have the most restricted mouths with a limited tidal range due to their elevation relative to sea level. In estuarine lakes there is therefore a continuum in the degree of mouth constriction, varying from open (e.g. Kosi Bay), constricted (e.g. uMgobezeleni) to perched (e.g. Verlorenvlei).

When an estuarine lake mouth is closed the inflowing freshwater from a river, or ground water, gradually fills the system (on condition that inflow exceeds evaporation and seepage losses). Under natural conditions, i.e. before coastal development took place, the water levels in the estuary would eventually exceed the height of the berm and a breaching would occur at levels often exceeding 3.0 to 3.5 m MSL. In exceptional cases, such as at steep beaches in KwaZulu-Natal, breaching can be caused by the berm collapsing before overtopping occurs.

Initially, the outflow of water from the estuary into the sea is via a shallow channel, but as water levels increase, ongoing scouring of the outflow channel occurs, and eventually, a very strong outflow can create a deep and wide channel between the estuary and the sea. The establishment of the natural outflow channel can take up to half a day or more to establish depending on the volume of water in the estuary and the additional river inflow. During a natural breaching, the maximum water level in an estuary is reached when the outflow through the mouth exceeds the river inflow. Under moderate to high river inflow conditions, this occurs a few hours after the actual breaching of the sand-berm. For example, studies show that for the Klein Estuarine Lake, the maximum outflows reached under high breaching levels (e.g. 2.63 m MSL), are equivalent to that of a 1:50 year flood.

During a major flood event, the water level in an estuary increases rapidly and the whole process described above occurs over a much shorter timeframe. However, as the outflow channel needs time to be properly established, it can still take several hours before the outflow exceeds the inflow from the river. This in turn translates into significantly higher water levels in an estuary under higher inflow conditions even hours after the actual breaching event, due to the constricting effect of the outflow channel. The greater the inflow, the longer it will take to reach the equilibrium between inflow and outflow. In the case of the Klein Estuarine Lake this means that the maximum water level reached may be up to a metre higher than the berm level during a flood event (CSIR 1999, 15 December

1998 breaching). Also, under flood conditions the water levels in the upper estuary will often be significantly higher than in the lower reaches as a result of the generally constricted nature of the upper reaches of most estuaries.

Estuaries typically undergo a sediment deposition-erosion cycle in which sediments are transported from the mouth into the lower estuary by the dominant flood tidal flows and wave action. These sediments are then periodically flushed out of the estuary by major floods and/or strong outflows during mouth breaching. Large amounts of sediments are scoured from the lower estuary and/or lake during such events. The lowest low tide level is achieved just after a breach. Over time a long-term equilibrium is reached between the flushing of sediments during a breaching, and the deposition of sediment by tides and wave action. This re-setting mechanism prevents estuaries from silting up in the long-term.

2.1.2 Salinity

The saline intrusion in an estuary is regulated by mouth state (period open), tidal amplitude (degree of connectivity), river inflow and bathymetry (size and shape) of an estuary (Prandle 2009). The salinity distribution and structure of an estuary may also be altered by anthropogenic actions such as dredging (deepening), barrier constructions (preventing salinity penetration) or flow modification (reduction in flow leads to increase penetration and an increase in flow to reduce penetration). In an open estuary saline intrusion involves a range of interactions, under an array of temporal and spatial scales (Prandle 2009): tidal cycle, neap-spring cycle, hydrological cycle, storm events, and variations in water density (temperature and suspended sediments). Lawrie and Stretch (2011a and 2011b) also showed that for lake systems the inlet configuration plays a key role in the salt balance, e.g. St Lucia/uMfolozi. For example, the longer an estuarine lake stays connected to the sea the more saline it can become.

Functionality in estuaries relies on salinity gradients, characteristically ranging from fresh upper reaches to brackish middle reaches, and saline lower reaches (Bate and Adams 2000). Reduced freshwater inflows may result in a reduction, or even complete elimination, of freshwater and brackish zones. If there is little, or no freshwater input in an open system, a reverse salinity gradient may develop as a result of high evaporation losses in mid and upper reaches (e.g. Klein) (Whitfield and Paterson 2003; James et al. 2013, Anchor 2015). In estuarine lakes extended periods of mouth closure (that can last for years) can result in either hyper or hypo-salinity, depending on freshwater flows and evaporation rates. For instance, under low flow conditions when evaporative losses often exceed inflow as a result of relatively large lake surface areas, hypersaline conditions are likely to develop (e.g. Bot or St Lucia). However, during closed mouth phases where freshwater inflows are low, but still exceed evaporative and seepages losses, reductions in salinity occur until such time as the mouth breaches. In the latter case, almost a complete loss of marine species will occur, with only euryhaline estuarine and freshwater species remaining (Whitfield 2005). In severe instances, mass mortalities of marine fish species trapped in these systems has been documented (Bennett 1985). Therefore, the biotic impacts of salinity shifts are linked to salinity preferences or tolerances. Reproduction may be interrupted in species that breed in estuaries, e.g. *Callichirus kraussi,* or mass mortalities of species unable to escape intolerable conditions can occur (Whitfield et al. 2006).

2.1.3 Temperature

Shallow-water aquatic systems such as estuarine lakes will exhibit greater sensitivity to temperature shifts than deeper waters (Rijnsdorp et al. 2009; James et al. 2013). Estuarine and marine species are adapted to and distributed within specific temperature ranges (Maree et al. 2000; Elliott 2002; Harrison and Whitfield 2006) and tend to be more stressed near the edge of their distribution (Sorte and Hoffman, 2004). Wooldridge and Deyzel (2012) showed that where species are at the edge of their temperature tolerance ranges, they can arrange themselves longitudinally according to the land-sea temperature gradient. As temperature changes, the geographical distribution of species, depending on their tolerances or preferences, may contract or expand, leading to new and unpredictable species interactions (Murawski 1993; Perry et al. 2005; Clark 2006; Harley et al. 2006; James et al. 2013). While many species of fish in estuaries are tolerant of extreme temperatures, changes in the distribution and abundance of especially the marine species in estuaries are likely to be linked to coastal (water) temperatures (James et al. 2013). Thermal windows are narrow in the early life stages of fish (eggs and larvae) and widen in juveniles and young adults (Pörtner and Knust 2007; Pörtner and Peck 2010). Range expansion may also be companied by behavioural changes. Expansion of, for example, spotted grunter *Pomadasys commersonnii* into the warm-cool temperate bioregion transition zone has culminated in stock separation, loss of return migration and the establishment of a spawning population in its new range (Lamberth et al. 2013). Less mobile or sessile species that are less able to evade or compete with encroaching species for resources, may face local or global extinction. The loss of species from an estuary that has become too warm may reduce species diversity in the short term with recovery depending on the mobility of new colonizers, their ability to tolerate higher temperatures and their tolerance of higher salinities in the marine environment. Shifts in coastal temperatures will also affect estuarine vegetation, e.g. a southward movement of tropical or subtropical communities (e.g. mangroves) into warm temperate habitats (e.g. salt marsh habitats) (Steinke 1999; Adam 2002; Gilman et al. 2008; Hoppe-Speer et al. 2015). Currently introduced mangrove communities are surviving in warm temperate estuaries along the Eastern Cape region and will most likely expand under predicted increases in temperature (Hoppe-Speer et al. 2015; Whitfield et al. 2016, Raw et al. 2019). Several mangrove-associated invertebrates have already shifted further than mangroves and colonised “surrogate” salt marsh and sedge habitat to the south. These include the tropical fiddler crab *Uca annulipes* and mangrove snail *Cerithidea decollate* in the Knysna Estuary which has become a new southernmost limit for both genera (Hodgson and Dickens 2012; Peer et al. 2015).

2.2 Selection of Biological Response Indicators

2.2.1 Microalgae

Microalgae form the base of food chains in estuaries. The group includes those living in the water column (phytoplankton) and those living on or in exposed intertidal or submerged surfaces (benthic microalgae). Phytoplankton biomass, using chlorophyll *a* as an index, indicates the nutrient status of an estuary (Snow 2007; Lemley and Adams 2019). Species composition also indicates the nutrient and hydrodynamic status of an estuary (Table 2.1). Dinoflagellates are typically abundant when the estuary is rich in nutrients and stratified. They occur in the middle reaches of an estuary where salinity is characterised by meso- to polyhaline conditions (5-30), whereas chlorophytes (green algae) and cyanophytes (blue-green algae) are common in nutrient-rich oligohaline waters (<5).

In saline estuaries phytoplankton cell size can also be used as a broad indicator of nutrient enrichment, with larger cells (e.g. diatoms, dinoflagellates) becoming more dominant during eutrophic conditions, while small cells (< 5 μm) are more efficient in oligotrophic environments (Guenther et al., 2015; Lemley et al., 2016). Further still, the dominance of a given size class can be used as an indication of energy transfer efficiency to higher trophic levels, where food webs may shift from long (microbial loop, i.e. small cells) to short (herbivorous, i.e. large cells) if ecosystems become over-enriched (Froneman, 2004; Lemley et al., 2018). Additionally, temperature alone can explain a large variance in the relative contribution of small cells to total phytoplankton biomass, regardless of trophic status or nutrient loading (Morán et al. 2010). Even at a much more localised scale, the thermal discharge of water from a nuclear power plant in the Gulf of Finland (Ilus and Keskitalo, 2008) supported the shift in community structure to one dominated by cyanobacteria. This suggests that given oligohaline and warm conditions, cyanobacteria are likely to become more prevalent in estuaries in the warm temperate and subtropical zone, where elevated temperature supports a higher oxygen demand through chemical and biological processes within the sediment. Benthic diatoms are known to respond to salinity and most references describe diatoms as freshwater, brackish or marine species (Bate et al. 2013). In addition, diatoms have proven to be useful indicators of trophic status, particularly in freshwater ecosystem studies (Taylor *et al*. 2007). As such, knowledge of diatom ecology is a vital component of estuarine management and it is therefore imperative that they, and phytoplankton, are included in Resource Directed Measures (RDM) studies. Bate et al. (2013) identified 333 diatom taxa in 27 estuaries from Olifants Estuary on the west coast to St Lucia Estuary on the east coast. Of these, 25 taxa were exclusively found in the cool temperate estuaries (Olifants and Great Berg estuaries), and 124 taxa were exclusively found in the 16 warm temperate estuaries.

Table 2.1: Summary of the indicator properties of each of the phytoplankton functional groups

TYPE	TYPICAL CONTROLLING FACTORS	REFERENCES
Chlorophytes (green algae)	Freshwater conditions (< 5); Low residence time (high flow); High N:P, but low Si	Domingues *et al*., 2005; Paerl *et al*., 2006; Barbosa *et al*., 2010; Paerl *et al*., 2010; Domingues *et al*., 2011; Kotsedi *et al*., 2012; Kaselowski & Adams, 2013; Lemley et al., 2017; Lemley et al., 2019
Cryptophytes	Freshwater and brackish conditions (0-18); Warm temperatures	
Cyanophytes (cyanobacteria/blue-green algae)	High optimum temperature; High nutrient inputs; Low N:P, and low Si High residence time (low flow)	
Bacillariophytes (diatoms)	Ubiquitous (freshwater to marine); High N:P ratio, and high Si; Spring and winter blooms	
Dinoflagellates	High residence time (low flow); Stable, stratified conditions; Warm temperatures (spring and summer); High nutrients (N & P)	
Euglenophytes (euglenoids)	Freshwater conditions (< 5); High nutrients (N & P); Warm temperatures	
Prymnesiophytes	Freshwater to brackish conditions (0.5-10); Alkaline conditions (> 8.5); High inorganic and organic nutrients (N & P)	
Raphidophytes	Brackish conditions (5-25); Stable, stratified and open-mouth conditions; High nutrients (N & P); Warm temperatures (spring and summer)	

2.2.2 Macrophytes

Lake systems support very valuable estuarine habitats. Submerged aquatic vegetation provides critical nursery habitat for fish and invertebrates. This vegetation promotes recruitment, survival and growth for fishes and crustaceans thus supporting a valuable ecosystem service in the form of the provision of nursery areas. This has been classified as a supporting service; however, some studies have also linked the nursery function of certain habitats to food provisioning services (Liquete et al. 2013). This is because nursery habitat is fundamental for maintaining fisheries as the life cycles of a diverse range of species is supported. Only 20% of South African estuaries contain submerged aquatic vegetation with large areas occurring in the estuarine lakes; namely Kosi (652 ha), St Lucia (431.5 ha), Swartvlei (219 ha) and Klein (180 ha) (Adams et al. 2016). The seagrass *Zostera capensis* is a key species but other plants such as *Ruppia cirrhosa, Stuckenia pectinata* and *Chara* spp. are dominant in estuarine lakes because of the brackish and fluctuating salinity conditions (Adams et al. 2016). Table 2.1 described the main habitats and macrophyte groups in South Africa's estuaries. Intertidal and supratidal salt marshes are the dominant macrophyte habitats in temperate estuaries whereas reeds, sedges and mangroves are prevalent in Subtropical and Tropical systems where there is higher rainfall and runoff. Availability of fine sediment, suitable sediment salinity gradient and some degree of tidal flushing creates an ideal habitat for the development of salt marsh in temperate estuaries (Adams 2020). This is unique vegetation consisting mostly of herbaceous halophytes (plants tolerant of salinity). An additional macrophyte habitat is swamp forest that is confined to Subtropical and Tropical estuaries.

Table 2.2: Macrophyte habitats recorded in Estuarine Lakes (spp. examples in italics)

HABITAT	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES
SUBMERGED MACROPHYTES	Plants that are rooted in both soft subtidal and low intertidal substrata and whose leaves and stems are completely submerged for most states of the tide. Submerged macrophytes tend to occur in permanently open estuaries, particularly Eelgrass (*Zostera capensis*) whereas *Ruppia cirrhosa* prefers the less saline and sheltered conditions of estuarine lakes and temporarily open/closed estuaries. *Stuckenia pectinata* (Ribbon Weed, Fennel Pondweed) prefers fresher conditions (salinity below 10) and therefore occurs in closed systems or in the upper reaches of estuaries. Submerged macrophytes are important primary producers in estuaries providing a source of food, refugia and nursery for invertebrates and fish. They play an important role in biogeochemical processes including oxygenating the water column during the growing season through photosynthesis, improving water clarity, nutrient trapping and recycling. The distribution and abundance of submerged macrophytes is threatened by a decline in water quality and smothering from macroalgal blooms and invasive aquatic plants.
SALT MARSH	A suite of herbaceous vascular plants that are adapted to endure the extremes of salinity, desiccation and tidal flooding characterizes salt marshes. Common genera are *Sarcocornia*, *Salicornia, Triglochin, Limonium* and *Juncus*. Halophytic grasses such as *Sporobolus virginicus* and *Paspalum* spp. are common. Salt marsh plants show distinct zonation patterns along tidal inundation and salinity gradients. Zonation is well developed in estuaries with a large tidal range, e.g. Berg, Knysna and Swartkops estuaries. Intertidal salt marsh occurs below mean high water spring and supratidal salt marsh above this. *Sarcocornia pillansii* is common in the supratidal zone and large stands can occur in estuaries such as the Olifants. Salt marsh vegetation stabilizes the sediment protecting the banks of an estuary from eroding away. They are important filters of sediment and pollutants as well as zones of nutrient production and retention.
REEDS AND SEDGES	Reeds, sedges and rushes are important in the freshwater and brackish zones of estuaries. Because they are often associated with freshwater input, they can be used to identify freshwater seepage sites along estuaries. The dominant species are the common reed *Phragmites australis* and sedges *Schoenoplectus*, *scirpoides* and *Bolboschoenus maritimus*. Like salt marsh, reeds and sedges protection the banks of estuaries from erosion. They also provide important habitat for birds, invertebrates, fish and food for detritivores. Due to their high productivity *Phragmites*-dominated marshes are widely used in artificial wetlands for the treatment of polluted water.
MANGROVES	Mangroves are trees that establish in the intertidal zone in permanently open estuaries along the east coast of South Africa north of East London where water temperature is usually above 20°C. The White Mangrove (*Avicennia marina*) is the most abundant, followed by the Black Mangrove (*Bruguiera gymnorrhiza*), followed by the Red Mangrove (*Rhizophora mucronata*). Mangrove forests protect the coastline acting as buffers against severe weather. They are extremely productive habitats that are home to a diversity of fish and invertebrate species. Mangroves are also important for filtering and improving water quality. They also have a high recreational, cultural and tourism value. More recently the value of mangrove forests as a carbon sink has been recognized. Mangroves are threatened by overutilization such as the harvesting of mangrove wood for building material, and for removal for aquaculture and slash and burn cultivation. At Kosi Bay mangroves are intensively harvested for the construction and maintenance of traditional fish traps. Harvesting results in stunted growth and coppicing of the trees. Climate change driven sea level rise and temperature changes has the potential to change the distribution range of mangrove species.
SWAMP FOREST	Swamp forests are freshwater ecosystems associated with estuaries in the subtropical and tropical regions, including species such as *Barringtonia racemosa*, *Hibiscus tiliaceous*, *Ficus trichopoda* and *Syzigium cordatum*. In systems with little submerged macrophytes they play an important role in detritus input in the form of leaf litter. This habitat plays an important role in riparian erosion control and flood attenuation.
MACROALGAE	Macroalgae can be free floating or attached to rocks and other substrates. Filamentous macroalgae often form algal mats and increase in response to nutrient enrichment or calm sheltered conditions when the mouth of an estuary is closed. Typical genera include *Ulva* and *Cladophora*. Marine genera in estuaries are *Codium, Caulerpa, Gracilaria* and *Polysiphonia*. Increased nutrient loads due to agricultural runoff and wastewater input have resulted in increased incidences of macroalgal blooms.
SAND AND MUD BANKS	This habitat provides a possible area for microphytobenthos to inhabit.
OPEN WATER AREA	This is the habitat associated with the water column of an estuary and is measured as water surface area. Serves as a possible habitat for phytoplankton.
FLOODPLAIN	This is a mostly grassy area that occurs within the estuary functional zone. It also includes dune vegetation at the mouth and riparian vegetation along the middle and upper reaches of the estuary.

Submerged aquatic vegetation changes rapidly in response to changes to water level, turbidity, nutrients and salinity; and is therefore a good indicator of the trophic state of an estuary. However, this has not been well documented for South Africa's estuarine lake systems and requires investigation. For example, when the mouth does breach water level in the lake can drop by extreme levels (> 1.5 m) resulting in the die back of submerged macrophytes and associated biota, e.g. Bot/Kleinmond Estuary (Lamberth 2008). Extended periods of mouth opening (for example in the Swartvlei after the 2007 floods), resulted in a 99% loss of biomass of submerged macrophytes and a 95% loss of waterbird biomass (Russell and Randall 2017). This is because the dominant *Stuckenia pectinata* and Charophytes have an upper salinity tolerance of 15. Saline water intrusion was above this (775 days open with salinity peaking at 27.6) (Russell and Randall 2017). Despite the low species diversity in lakes, their rate of expansion can take place very quickly. After a significant die back of submerged vegetation in the Wilderness Lakes between 1979 and 1981, mean biomass per m^2 doubled over a one year period (Weisser, et al. 1992). However at the same time in the adjacent Swartvlei Lakes, a similar die back did not see the full recovery of submerged macrophytes even after 10 years (Howard-Williams and Davies 1979).

2.2.3 Fish

Estuaries provide extremely important habitat for fish in southern Africa. The vast majority of coastal habitat in southern Africa is directly exposed to the open ocean, and as such is subject to intensive wave action throughout the year (Field and Griffiths 1991). Estuaries in southern Africa are thus disproportionately important relative to other parts of the world, in that they constitute the bulk of the sheltered, shallow water inshore habitat in the region. Juveniles of many marine fish species in southern Africa have adapted to take advantage of this situation and have developed the necessary adaptations to enable them to persist in estuaries for at least part of their life cycles. There are at least 100 species that show a clear association with estuaries in South Africa (Whitfield 1998). Most of these are juveniles of marine species that enter estuaries as juveniles, remain there for a year or more before returning to the marine environment as adults or sub-adults where they spawn, completing the cycles. Several other species also use estuaries in southern Africa, including some that can complete their entire life cycles in these systems, and a range of salt-tolerant freshwater species and euryhaline marine species. Whitfield (1994, 2019) has developed a detailed classification system of estuary associated fishes in southern Africa. He recognized five major categories of estuary associated fish species and several subcategories.

Table 2.3: Classification of South African fish fauna according to their dependence on estuaries (modified from Whitfield 1994)

CATEGORY	DESCRIPTION
I	Truly estuarine species, which breed in southern African estuaries; subdivided as follows:
Ia	Resident species which have not been recorded breeding in the freshwater or marine environment
Ib	Resident species which have marine or freshwater breeding populations
II	Euryhaline marine species which usually breed at sea with the juveniles showing varying degrees of dependence on southern African estuaries; subdivided as follows:
IIa	a. Juveniles dependant of estuaries as nursery areas
IIb	b. Juveniles occur mainly in estuaries, but are also found at sea
IIc	c. Juveniles occur in estuaries but are more abundant at sea
III	Marine species which occur in estuaries in small numbers but are not dependant on these systems
IV	Euryhaline freshwater species that can penetrate estuaries depending on salinity tolerance. Includes some species which may breed in both freshwater and estuarine systems. Includes the following subcategories:
	a. Indigenous
	b. Translocated from within southern Africa
	c. Alien
V	Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments

Fish species in categories I, II, and V as defined by Whitfield (1994) are all wholly or largely dependent on estuaries for their survival and are hence the most important from an estuary conservation perspective. The degree of estuarine dependence varies intraspecifically and between assemblages in the different biogeographical regions (Lamberth 2008). Some such as silver kob *Argyrosomus inodorus* have no estuary association in the warm temperate bioregion but occur in all predominantly open west coast systems (Lamberth 2008). Similarly, the degree of estuary association shown by the Knysna sand goby *Psammogobius knysnaensis* appears to decline from east to west and, in the latter region, is mostly confined to the surf-zone. However, this *psammophyllic* species is more widely distributed within (sandier) systems on the west coast.

Fish that breed in estuaries and/or estuary residents comprise 10%-28% of estuarine fish assemblages on the cool temperate west coast as opposed to 4%-18% for those on the Warm-temperate east coast or 25% for those in the south coast transition zone between the two biogeographical regions. Excluding these species, obligate estuary-dependent marine fish such as white steenbras *Lithognathus lithognathus* comprise only 11% of estuarine fish assemblages in the cool temperate region compared to 22% on the warm temperate east coast. This is most likely a function of the few estuaries and lower probability of recruitment success on the west coast. Including estuary residents, obligate and partially dependent species, up to 48% of cool temperate and 61% of warm temperate estuarine fish assemblages comprise species that have some degree of estuary association.

Subtropical and tropical estuaries support the greatest diversity of fishes, with close to 160 species reported with some regularity (Whitfield 2019). Of these 24% are species that breed in estuaries, 53% are estuary-dependent marine fishes, 19% are marine stragglers and 5% are freshwater species that are tolerant of elevated salinities. Across systems there is a high degree of heterogeneity in these percentages, driven primarily by estuarine category (temporarily open/closed estuaries vs permanently open systems).

Approximately 80 fish species are exploited in South African estuaries (Lamberth and Turpie 2003). Catch diversity increases eastward with 20, 30 and 40 species caught in the Cool-Temperate west coast, south coast transition zone and warm temperate east coast respectively. However, a few taxa, namely mullet Mugilidae, kob *Argyrosomus japonicus*, elf *Pomatomus saltatrix* and spotted grunter *Pomadasys commersonnii* comprise the bulk (>90%) of the catch. Participation in estuarine fisheries ranges from approximately 1000 fishers in the cool temperate bioregion to 10 000-20 000 in the warm temperate region to more than 70 000 in subtropical KZN. Total landed mass ranges from 1 040 t per annum from cool temperate systems to 1 170 t in the warm temperate region to 1 170 t in subtropical KZN and 350 t in tropical region. Coastwise, estuary-associated species comprise 85% of the catch of the commercial beach-seine and gillnet fisheries and 10% of the commercial and recreational boat line fisheries. Accounting for different degrees of estuary-association among fish as well as differences in the value of individual fisheries, it is estimated that estuaries contribute 25% of the value of South African inshore marine fisheries (Lamberth and Turpie 2003). The total value of estuarine fisheries and estuary contribution to marine fisheries is R1.8-2 billion per annum (2014 rands adapted from Lamberth and Turpie 2003).

3. VERLORENVLEI

3.1 General Features

Verlorenvlei (Figure 3.1) surface area is estimated to be 198 000 ha with an average water area depth between 2 and 3 metres with a maximum depth of 5 metres (Robertson 1980). A small inlet channel of about 2.6 km connects the lake to the sea. The entire channel is very shallow (about 0.5 m deep), tending to inhibit free water exchange.

During the dry summer months, the mouth is usually closed by a sandbar overlying a rocky sill and the channel may be reduced to a few series of stagnant saline pools. The bar is formed by wave action and a south-going longshore current in combination with frequent onshore winds. When good rains provide sufficient water, the lake and lower estuary fill, and the bar is overtopped. The outflowing water scours the sandbar away thus permitting some tidal interaction. Verlorenvlei normally functions as a freshwater system as the mouth is perched and only allows occasional seawater inflow during high spring tides and stormy conditions at sea.

The Verlorenvlei River feeds the system through a series of wetlands at Redelinghuys. Noble and Hemens (1978) estimate the mean annual runoff at 102 million m^3. The Sandveld Reserve Study revised this estimate down to 89 million m^3 (DWAF 2003). This does not consider any direct contributions of groundwater into the system. An estimated 12 000 m^3/day groundwater is contributed to the Verlorenvlei G30E catchment (DWAF 2003).

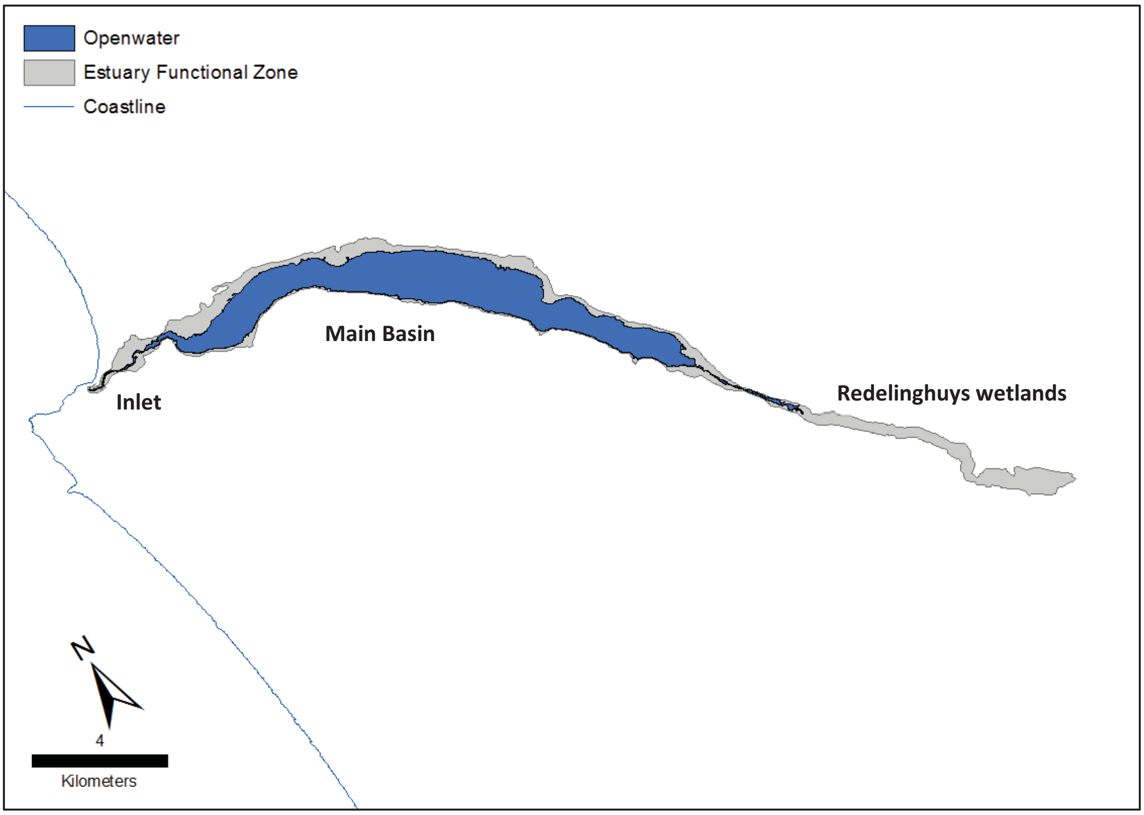

Figure 3.1 Verlorenvlei: EFZ and openwater area

3.2 Zonation and Abiotic States

Zonation of the Verlorenvlei is provided in the 2009 Estuarine Management Plan (Van Niekerk et al. 2009) comprising three zones. A small channel (~2.6 km) in the lower estuary connects the larger lake (or basin) to the sea (Zone A in Figure 3.2). The entire channel is very shallow (about 0.5 m deep). The lake (Zone B) has an average depth of between 2 and 3 metres with a maximum depth of 5 metres (Robertson 1980). The Verlorenvlei River feeds the system through a series of wetlands at Redelinghuys (Zone C) that back floods under closed mouth conditions.

Figure 3.2 Verlorenvlei: Zonation

No abiotic states have been identified for the Verlorenvlei system in previous studies.

3.3 Abiotic Response Indicators

3.3.1 Mouth dynamics and water levels

This lake is located on the west coast in a winter rainfall zone. During the dry summer months, the mouth is usually closed. In winters with good rains, the system fills, and the bar is overtopped. The outflowing water scours the sandbar away thus permitting some tidal interaction. Tidal exchange continues until the velocity of the outflowing water decrease sufficiently to allow the accretion of sand to form a new bar at the mouth. During storms and high spring tides the sea washes over the sandbar. Seawater is reported to penetrate the main basin as far as Verloren Farm (Robertson 1980; Van Niekerk et al. 2009).

There are four major obstructions to tidal exchange in the lower vlei (Zone A): the mouth; a rocky sill (that used to be a causeway); a causeway below the railway bridge and the road crossing to Elands Bay. In addition to the constrictions in the lower estuary, there are also two causeways in the upper vlei (Zone C) at Grootdrift and Redelinghuys that also pose a constraint to circulation.

Mouth: The rocky barrier at the mouth (~1 m MSL) is covered by a 1 to 2 m thick sand layer. Since the mean high tide is about 0.8 m MSL, overwash from the sea can only occur during high spring tides and storm surges. Evidence of overwash is clearly to be seen as dried kelp wrack on the sand spit near the mouth or decaying kelp in the lower mouth area (Sinclair et al. 1986). When open the mouth is perched, with freshwater running out to sea on the ebb tide and seawater entering the lower estuary in a very limited manner on the flood tide, i.e. the mouth acts as a natural constriction to tidal flows.

Rocky sill 500 m from the mouth: The concrete causeway that used to run across the channel in the lower estuary has been removed and the underlying bedrock exposed. This allows for free outflow of water from the vlei, but still acts as a natural obstruction to tidal flows. Seawater is only expected to penetrate beyond this point during high spring tides and storm surges. Although this rocky sill represents a hydraulic constriction to tidal flows it is now deep enough to allow for the recruitment of invertebrates and fish into the system, e.g. juvenile steenbras recorded in 2008.

Railway bridge crossing: The railway bridge crossing is situated about 1 km from the mouth and used to provide also for a maintenance road that ran along the Sishen/Saldanha railway line across the riverbed. The road was raised 1 m above the riverbed on a crude rubble and clay causeway until removal in 2012. It prevented a free connection to the vlei and reduced the nursery function of the system. The causeway was temporarily reinstated during 2015 as part of upgrade works on the main road crossing further upstream but has since been removed.

Road crossing: The main road to Elands Bay from Dwarskersbos crosses the uppermost narrow section of the channel (2.6 km upstream of the mouth) via a recently upgraded 275 m embankment about 2 m above the lakebed level. The 2014/15 road upgrades installed new box culverts which allow free flow of water on the southern bank of the channel. Although this constriction does not pose a major constraint to flow under normal conditions, it does prevent normal circulation and, in the past, has contributed to the substantial vegetation growth in the lower vlei (Zone B). The culverts also are a constriction under flood conditions and contribute to backflooding of adjacent land.

Grootdrift causeway: The causeway hinders the natural meandering of the channel and flow to the upper vlei (Zones B and C). The causeway only allows limited flow through four sets of culvert structures, retarding both up- and downstream flow. The result is more stagnant conditions and a related increase in sedimentation and vegetation growth.

Redelinghuys causeway: Similar to the Grootdrift causeway, the Redelinghuys causeway also restricts flow and reduces free movement of water in the upper channels, resulting in sedimentation and increased vegetation growth in the upper Verlorenvlei. An effort should be made to increase the flow through the causeway.

The water levels recorded at DWS gauging station DWS Gauge G3T001 from 1993 to 2019 are shown in Figure 3.3. Low water levels are shaded in red on the graphs. Note however that the recorder "bottoms out" and cannot record values below 0. The highest water level on record was during the July 2008 flood, when Verlorenvlei was able to breach on its own. Measurements at the DWS gauge plate indicated that it was 3.284 m. Relative high-water levels also occurred in 1996, 2006, 2013, and 2014. After the mouth was illegally artificially breached in September 2014, the water level continued to rise for several days due to the construction works on Elands Bay Road bridge and the associated coffer dam. Water level continued to rise until 7th/8th September and only dropped below the 29th of July level on 18th October 2014. More concerning is the increasing incidences of very low water levels in the vlei, with 2000, 2003, 2004, 2015, 2016 to 2019 being the lowest on record. Under these extremely low water levels large parts of Verlorenvlei are dry at times (DWS Gauge G3T001, Van Niekerk et al. 2019).

Lower water levels in the lake have resulted in fish kills and a loss of birdlife. In February 2019 there was a fish kill of large fish in the system, coincident with very low water levels. The kill comprised about 90% flathead mullet *Mugil cephalus*, 5% Mozambique tilapia *Oreochromis mossambicus*, 3% carp *Cyprinus carpio* and 2% other. Small dead fish comprised 99% estuarine round-herring *Gilchristella aestuaria*. Surprisingly, no harder *Chelon richardsonii* were recorded. This is usually the dominant fish species in Verlorenvlei. Harders are very resilient to poor water quality, often feeding on Microcystis and other blue-green algae, so they may have been hiding out in the deeper areas of the vlei (Van Niekerk et al. 2019).

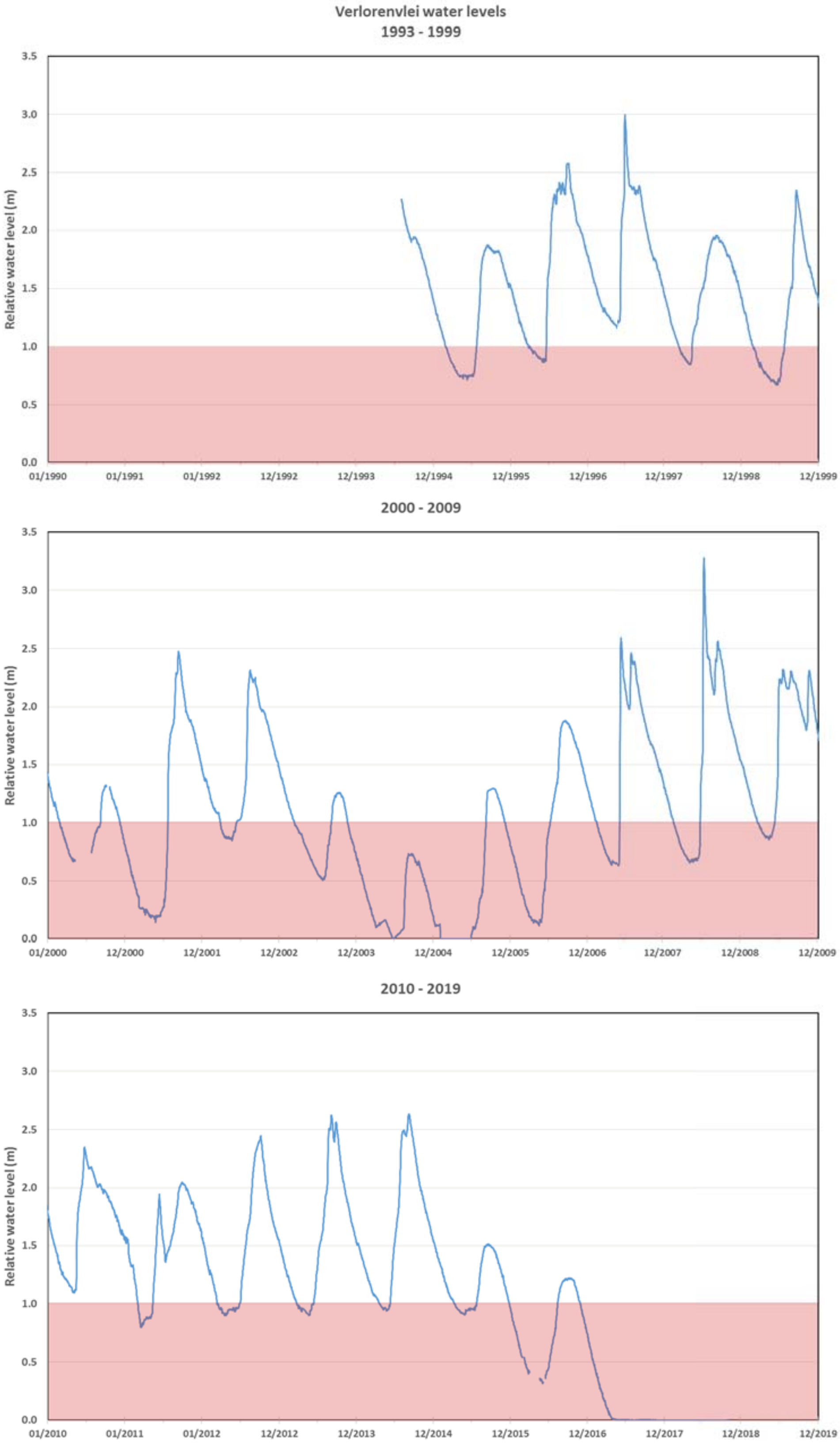

Figure 3.3 Verlorenvlei: Relative water levels at DWS Gauge G3T001 for 1993 to 2019, with extremely low levels indicated by red shading. Note water level recorder does not record values less than 0 m

Figure 3.4 Verlorenvlei: Low water levels in 2019 (Source: F Strange)

Figure 3.5 Verlorenvlei: Fish kill – Feb 2019 (Source: F Strange)

During the low water level fish kill event salinity was markedly elevated from the usual 1 to 2 in the vlei to 16 to 19. Oxygen levels were 6 to 8 mg/ℓ (daytime saturation levels 76 to 120%), but this was probably due to *Microcystis* photosynthesis and wind mixing. Night oxygen levels were likely to be much lower due to algal respiration and fish would have had to surface breathe. pH was high at 7.9 to 8.4 which may indicate some ammonium toxicity in the system. Water temperatures were 18 to 24°C, which was fairly normal for the time of year. Overall, the fish kill was likely a combination of exhaustion from repeatedly having to surface breathe at night and high pH/ammonium toxicity (Van Niekerk et al. 2019).

Overall, artificial breaching lowers the water level, and reduces the reservoir of water that buffers the system against droughts and water quality issues thus putting the ecology of the Ramsar site under pressure.

3.3.2 Salinity

Salinity data on Verlorenvlei is summarised in Figure 3.6 (Robertson 1980; Grindley et al. 1980; DWAF 2003; Van Niekerk et al. 2009). Verlorenvlei normally functions as a freshwater system: the mouth is perched and only allows occasional seawater inflow during high spring tides and stormy conditions at sea. When water levels in the vlei are high, there is a continuous discharge to the sea maintaining freshwater dominated conditions as was observed in September 1985, September 2002 and November 2008.

When the water level in the lake declines, the outflow to the sea no longer occurs creating a stagnant water body in the lower reaches. During these low water levels, the shallower areas – downstream of the road crossing – can become more saline, and even hypersaline when interchanges of freshwater between the larger vlei and these shallow regions are no longer sufficient to counterbalance salt build-up associated with occasional overwash and evaporation. Such conditions were evident in 1978/79 (Figure 3.6) when a drought resulted in a marked drop in water levels and when the old causeway and railway service road were still present, preventing proper exchange between the shallower lower estuary and the larger basin.

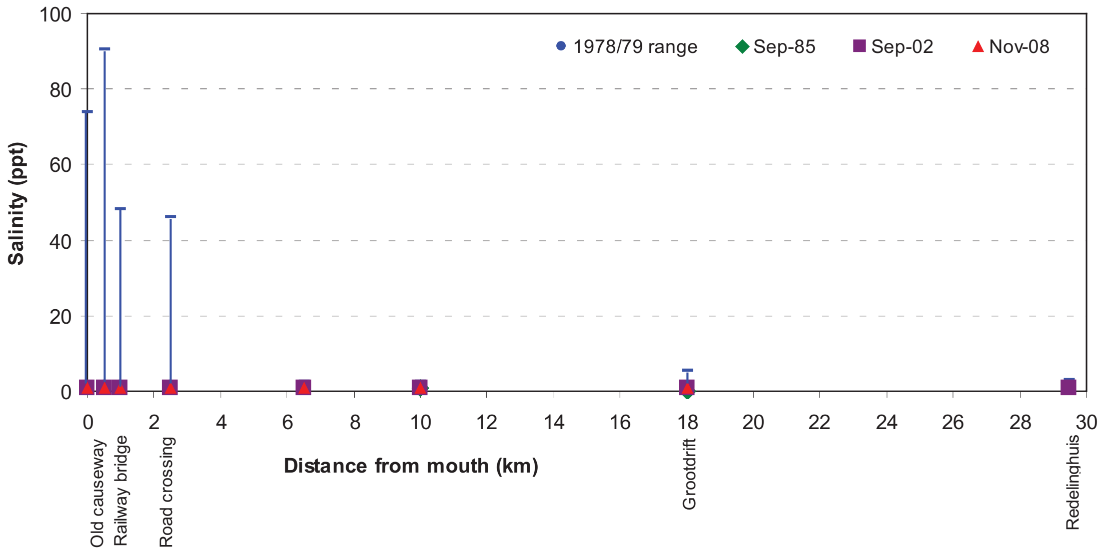

Figure 3.6 Verlorenvlei: Summary of salinity measurements during the 1978 to 2008

3.3.3 Temperature

Water temperature data for Verlorenvlei are summarised in Figure 3.7, depicting monthly temperature ranges measured in the lower estuary and lake over the period 1978 to 2008 (Robertson 1980; Grindley et al. 1980; DWAF 2003; Van Niekerk et al. 2009).

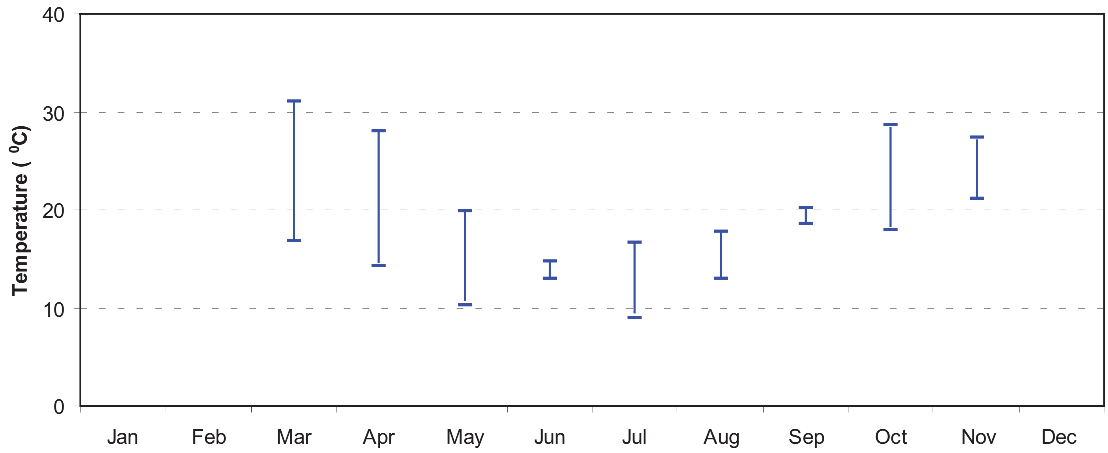

Figure 3.7 Verlorenvlei: Monthly temperature ranges (1978-2008)

The temperature regime in Verlorenvlei shows a clear seasonal pattern, with summer temperatures being markedly higher than those in winter. The temperature within the system also shows diurnal variation, depending on the time of day and the prevailing air temperature, as reflected in the wide range of temperatures recorded within months. For example, during warmer months, the morning the water temperature can be relatively low (below 20°C) but can reach 30°C at mid-day as the air temperature rises, especially in the shallower areas that are protected from wind mixing.

3.4 Biological Response Indicators

3.4.1 Microalgae

Sinclair et al. (1986) found microalgae blooms, including cyanobacterial species such as *Microcystis aeruginosa*, to occur in Verlorenvlei during spring. The Sandveld RDM Study reported that the phytoplankton assemblage was representative of a eutrophic system even though the lake was phosphorus-limited during the assessment period. The microalgal assemblage is indicative of freshwater/oligohaline conditions, mainly comprised cyanobacterial taxa belonging to the genera *Anabaena, Lyngbya, Anabaenopsis, Merismopedia, Microcystis*, with minor contributions from chlorophytes (*Scenedesmus*) and bacillariophytes (*Cyclotella*, *Nitschia*). The algal assemblage was indicative of an elevation in trophic status that has been in place for some time and probably reflects eutrophication-associated alterations to the lower levels of the foodweb (e.g. depauperate zooplankton) (DWAF 2003). A similar cyanobacterial bloom was observed in the lower and middle reaches of Verlorenvlei in November 2008. While certain species of cyanophytes are toxic to animal life, there have been no reports of toxic instances in Verlorenvlei. Large masses of filamentous green algae, including *Chaetomorpha* and *Cladophora*, are common in the inlet channel, particularly between the railway bridge and the lower causeway, where the water is often stagnant and hypersaline (Sinclair *et al.* 1986).

3.4.2 Macrophytes

Verlorenvlei exhibits a transition from salt-tolerant macrophyte species near the mouth to freshwater species further inland. Salt tolerant species include *Sarcocornia natalensis, Scirpus maritimus* and *Juncus kraussi.* Extensive beds of emergent aquatic macrophytes occur along the margins of the vlei with *Phragmites australis*, *Typha latifolia* and sedges as dominants. Downstream of Redelinghuys (Zone C) there are wide and open wetlands with patches of mixed sedges and reed communities along the course of the Verlorenvlei River over a distance of 11 km. Dense reedbeds are present in the upper part of the lake (Sinclair et al. 1986). There has been a substantial increase in *Typha* and *Phragmites* growth especially in the lower and upper reaches of Verlorenvlei since the 1930s. During the late 1980s *Myriophyllum spicatum*, a submerged macrophyte, dominated large areas of the lake where the water is less than 2 m deep (Sinclair et al. 1986). This submerged macrophyte was not present during the 2003 Sandveld study or during the 2008 field visit (personal observation). The reason for the switch between macrophytes and microalgal blooms after the late 1980s is not clear and is something that needs further investigation. The water lily, (*Nymphaea capensis*), a species that is becoming rare in South Africa as a result of wetland destruction, occurs in small numbers in the system.

3.4.3 Fish

A total of 14 fish species from 9 families has been recorded from Verlorenvlei and a further two are expected to occur (Harrison et al. 2000, Sinclair et al. 1986, Robertson 1980, Poggenpoel 1996, DWAF 2003) (Table 3.1). Four (25%) of these are entirely dependent on estuaries to complete their lifecycles. One, the estuarine round-herring *Gilchristella aestuaria*, breeds and spends its entire lifecycle in the estuarine environment whereas three, the white steenbras *Lithognathus lithognathus*, flathead mullet *Mugil cephalus* and freshwater mullet *Myxus capensis* are dependent on estuaries as nursery areas for at least their first year of life. In addition, *Myxus capensis* and to a lesser extent, *Mugil cephalus* are facultative catadromous species that require estuaries as transit routes between the marine and freshwater environment. A further three (19%) species namely the harder *Liza richardsonii*, white stumpnose *Rhabdosargus globiceps* and Knysna sand-goby *Psammogobius knysnaensis* are at least partially dependent on estuaries. In all, 44% of the fish species recorded, or expected to occur, in Verlorenvlei can be regarded as either partially or completely dependent on estuaries for their survival. All 9 (56%) of the remaining species are euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance. Three of these, the Cape galaxias *Galaxias zebratus*, Cape kurper *Sandelia capensis* and Berg River Redfin *Pseudobarbus bergi* are endemic to the southwestern Cape. Six, the Mozambique Tilapia *Oreochromis mossambicus*, carp *Cyprinus carpio*, banded tilapia *Tilapia sparrmanii*, smallmouth bass *Micropterus dolomieu*, largemouth bass *Micropterus salmoides* and tench *Tinca tinca* are introduced species.

Table 3.1: Verlorenvlei: List of all species recorded by DWAF 2003 (a) by Harrison et al. 2000 (b), Sinclair et al. 1986 (c), Robertson 1980 (d) and Poggenpoel 1996 (e). The species are classified into five major categories of estuarine dependence as suggested by Whitfield 1994. Introduced species indicated by an asterisk*

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE CATEGORY	RECORDED BY
Anabantidae	*Sandelia capensis*	*Cape kurper*	*IV*	*d*
Centrarchidae	*Micropterus dolomieu*	*Smallmouth bass*	*IV*	*c*
	Micropterus salmoides	*Largemouth bass*	*IV*	*c*
Cichlidae	*Oreochromis mossambicus*	*Mozambique tilapia*	*IV*	*a,b,c*
	Tilapia sparrmanii	*Banded tilapia*	*IV*	*b*
Clupeidae	*Gilchristella aestuaria*	*Estuarine round herring*	*Ia*	*a,b,c*
Cyprinidae	*Cyprinus carpio*	*Carp*	*IV*	*a,b,c*
	Pseudobarbus burgi	*Berg River redfin*	*IV*	*d*
	Tinca tinca	*Tench*	*IV*	*c*
Galaxiidae	*Galaxias zebratus*	*Cape galaxias*	*IV*	*a,d*
Gobiidae	*Psammogobius knysnaensis*	*Knysna sandgoby*	*Ib*	*expected*
Mugilidae	*Liza richardsonii*	*Harder*	*IIc*	*a,b,c,e*
	Mugil cephalus	*Flathead mullet*	*IIa*	*a,b,c,e*
	Myxus capensis	*Freshwater mullet*	*Vb*	*expected*
Sparidae	*Lithognathus lithognathus*	*White steenbras*	*IIa*	*b,e*
	Rhabdosargus globiceps	*White stumpnose*	*IIc*	*e*

Six (38%) of the estuarine fish and three (19%), of the freshwater fish recorded in Verlorenvlei, are South African or southwestern Cape endemics (Smith and Heemstra 1986; Skelton 1993). In all, the fish assemblage of Verlorenvlei with its high proportion of endemics and low diversity is typical of estuarine lakes on the west and southern coasts of South Africa comprising freshwater species or estuarine species tolerant of low salinities (Van Niekerk et al. 2009).

In 2002 a total of 16 600 fish representing 5 species from 4 families were recorded using seine and gillnets (DWAF 2003). *Liza richardsonii* (89%) and *Gilchristella aestuaria* (10%) dominated numerically, providing 99% of the total catch. In terms of mass, *Oreochromis mossambicus* (64%) dominated followed by *Liza richardsonii* (18%), *Cyprinus carpio* (10%), *Mugil cephalus* (6%) and *Gilchristella aestuaria* (2%). The distribution of the species caught during the spring 2002 survey was largely a reflection of the estuarine-dependence category to which they belong. *Gilchristella aestuaria*, which breeds only in estuaries (also freshwater populations) is largely confined to the river-estuarine interface (salinity 0-10) of most estuaries. In Verlorenvlei it was fairly evenly distributed and occurred from the mouth to Redelinghuys 25 km upstream. However, there were higher densities in the lower and upper reaches of the vlei compared to the middle reaches. *Mugil cephalus*, a facultative catadromous species, were confined to the middle and upper reaches of Verlorenvlei but, according to locals, substantial catches are often had at Redelinghuys 25 km upstream.

Liza richardsonii is equally at home in the marine and estuarine environment. The bulk of estuarine populations are usually distributed in the lower and middle reaches of estuarine systems (20-35) but there is often a second peak in abundance on the upstream side of the 0 to 10 zone. A few individuals may venture far into freshwater where they may become isolated and survive for several years. In Verlorenvlei high fish densities occurred in the mouth region and head of the vlei and medium densities in the middle reaches. *Oreochromis mossambicus* is a freshwater species tolerant of a wide range of conditions. It survives in salinities of 0-100 and has been recorded in temperatures of up to 42°C (Whitfield 1998). It is also opportunistic in “taking advantage” of degraded habitats from which other fish have been excluded. The optimum temperature range for *O. mossambicus* is 20-35°C whereas its tolerance of lower temperatures is positively correlated with brackish water (Whitfield 1998). Adult *O. mossambicus* were caught throughout the middle and upper reaches of Verlorenvlei. Except for a few adults the bulk of the *L. richardsonii* catch comprised juveniles of 20-100 mm in length recruiting into the system. A bimodal size frequency distribution suggests that there had been at least two spawning events in the marine environment within the four months prior to sampling. In turn, the low proportion of adult *L. richardsonii* suggests that there had been a mass exodus from the system that probably occurred with the onset of winter rains and the first breaching of the estuary mouth. Similar to *L. richardsonii*, the low numbers of *M. cephalus* suggest that most of the adults left with the first winter rains. This behaviour is characteristic of this species throughout the west and south coast as evidenced by adults appearing in marine samples from April-May onwards. Juvenile recruitment may have been occurring at the time of sampling and there may have been a few juvenile *M. cephalus* mixed with the *L. richardsonii* as the young of these and other mullet species are notoriously difficult to tell apart. Most of the *G. aestuaria* caught in 2002 were young of the year and probably were spawned the previous summer. This species can spawn within its first year, but individuals examined suggested that this had yet to occur. *Gilchristella aestuaria* spends its entire lifecycle in estuaries but is equally at home in most freshwater environments provided the pH is not too low. Adults respond to high winter flows by swimming upstream whereas spawning usually occurs at the head of estuaries to prevent eggs and young from being swept out to sea. The majority of *O. mossambicus* caught were large territorial males defending nests. Only two juveniles were caught both nearer to the mouth. Except for the juveniles all those caught had numerous open lesions (up to 36) over their bodies. Superficial examination revealed males to have more lesions than females. The most likely cause is that territorial males frequently fight leaving bite-marks that are easily infected with one or more parasites that exist in the water column. The females' lesions are probably incidental resulting from the actions of overzealous males.

The ability of fish to recruit into an estuary varies between species and can only really be gauged by their relative abundance or presence/absence within a particular system. Mullet species such as *L. richardsonii* and *M. cephalus* as well as *L. lithognathus* are known to recruit through wave overwash into temporarily open/closed systems. In addition, mullet species also recruit by swimming from standing wave to standing wave in systems where there is a strong outflow. Indeed recruitment, into isolated coastal lakes and estuaries that seldom open, only occurs during floods or years of higher flow. In all, the high abundance and presence of *M. cephalus* and *L. richardsonii* as opposed to the absence of *L. lithognathus* in Verlorenvlei may be at least partially explained by their being much more adept at recruiting into the system. Timing is also important to permit fish recruitment an estuary has to be open during the appropriate period. Recruitment also depends on spawning behaviour and the estuarine dependence category to which a fish belongs. By example, *Liza richardsonii* is a partially estuarine dependent species that spawns throughout the year with peaks in the summer months. Juveniles are equally at home in estuaries and the marine environment and can remain in the surf-zone until such time as an estuary opens with a chance of recruitment. *L. lithognathus* on the other hand is entirely dependent on estuaries for its first year of life and has a relative short spawning season. Its' recruitment window is thus very short and if an open estuary is not found within that period the larvae or juveniles will die. The recruitment window is probably 2 of 3 months, August-October of each year depending on when spawning took place and the proximity of the estuary encountered to the spawning ground. In Verlorenvlei, water abstraction has resulted in the mouth staying open for shorter periods and closing earlier than it did historically. The recruitment opportunities for *L. lithognathus*, therefore, have been greatly reduced.

3.5 Present Ecological Health

The Verlorenvlei Estuarine Lake system is an important estuary from a biodiversity perspective (Importance rating score = 72) and a conservation priority (Turpie and Clark 2007; Van Niekerk et al. 2019a). Verlorenvlei is a proclaimed Ramsar site (No. 525) and the vlei itself is owned by the state. The Verlorenvlei, however, does not have any statutory protection, although it is included in the subset of estuaries identified as requiring protection to conserve South Africa's estuarine biodiversity estate in the National Estuary Biodiversity Plan (Van Niekerk et al. 2019). The Verloren Estuarine Lake system is in a heavily degraded state. Table 3.2 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system.

Table 3.2: Verlorenvlei: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Significant reduction in base flow and groundwater to the estuary.					●	
Hydrodynamics	Reduce inflow/groundwater is reducing opportunities for open conditions. Illegal artificial breaching is practised from time to time. Reduce connectivity due to constricting causeways and bridges.				●		
Salinity	Increased hypersalinity in lower reaches, but the main water body was always fresh.		●				
General Water Quality	Nutrient enrichment from agricultural activities in catchments. Possible toxins from herbicides and pesticides.					●	
Physical habitat	Stabilisation of meandering channels due to bridges and causeways. Harding of riparian banks in places. Habitat loss due to infilling of channels. Low lying developments in EFZ.			●			
Microalgae	Microalgae blooms occur regularly in the system. *Microcystis* have been identified (unpublished DAFF).					●	
Macrophytes	Significant reed growth due to enrichment and low water levels, loss of riparian vegetation due to farming activities and roads, grazing of salt marsh and reeds. Regular burning of reeds.				●		
Invertebrates	Change in community composition. Reduce recruitment opportunities as a result of premature closure.				●		
Fish	Change in community composition, i.e. less estuarine species. Reduce recruitment. Alien fish occur in high densities. Pathogens and diseases due to poor water quality and/or microalgae blooms.					●	
Birds	Reduce bird numbers due to loss of habitat and prey.			●			
ESTUARY HEALTH	**HEAVILY DEGRADED with a downwards trajectory. However, functionality is relatively intact and opportunities for rehabilitation exists.**				⦿		

4. ZEEKOEVLEI

4.1 General features

Zeekoevlei is a U-shaped lake (Figure 11.1), divided into North and South basins. Its surface area is estimated at 2.56 km^2. Most freshwater inflow is into the North basin via two rivers, Big and Little Lotus, while the outflow to the sea is from the southwestern corner of the South basin through the Zeekoe Canal. The vlei is also fed by an extensive aquifer (Brown and Magoba 2009). Rondevlei, lying directly to the west, is considerably smaller than Zeekoevlei, covering an area of approximately 0.45 km^2. Its surface inflow is mainly from the road canals, and its outflow to the Zeekoe Canal is in the south-east corner. A natural link existed between the two vleis until 1943, at which time it was closed permanently and an outlet from Rondevlei was constructed to connect to the Zeekoevlei outlet canal (Brown and Magoba 2009).

At present, outflow from the vleis is concentrated in a narrow canal through the dunefield at the mouth. The mouth of the canal is fixed by the Baden Powell Drive Road bridge. The system often partially dams up behind the 2 to 3 m high beach bar forming a shallow longshore 'lagoon'. Because of the high elevation, the 'lagoon' is usually perched and non-tidal. At times the meandering of the beach canal threatens road infrastructure, and the canal is straightened by the City of Cape Town, which significantly reduces the backwater area.

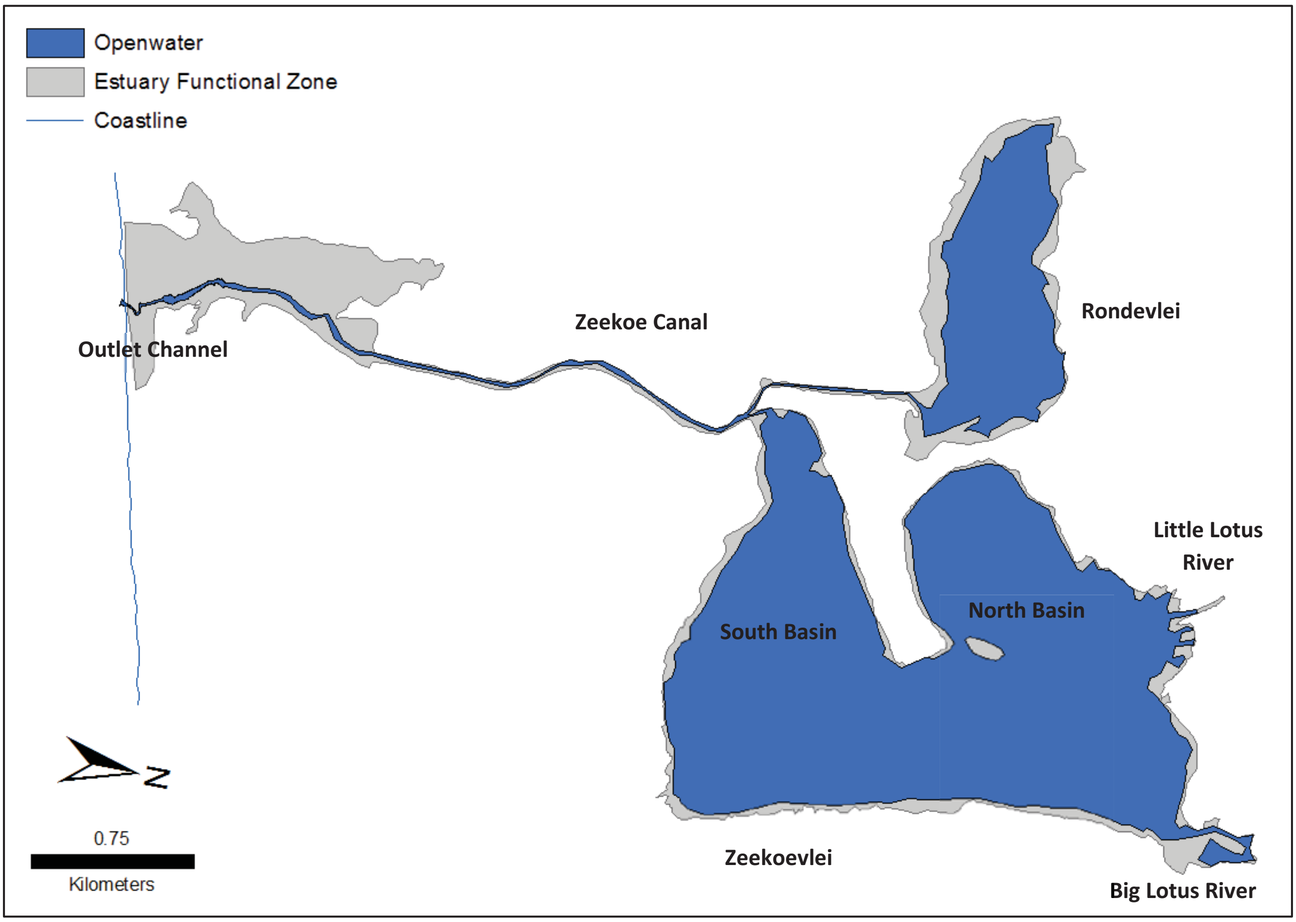

Figure 4.1 Zeekoevlei: EFZ and open water area

The Zeekoevlei and Rondevlei in their natural state would have functioned similarly to an estuarine lake taking a year or more to fill up and breaching once water levels were high enough to facilitate a cut-through of the coastal dune system. The resultant high outflow would have scoured a deep and wide outflow channel that could have remained open for 3 to 6 months at a time. After breaching saline water would have penetrated the system freely.

The system would have been tidal during the open phase (possibly 10-20 cm on average). After a prolonged open period, mouth closure would have occurred that initially would be associated with low water levels and even seasonally drying out of parts of the system. With persistent and increased inflows during the winter months, a period of elevated water levels would have followed. The mouth of the system would have migrated significantly from its present fixed position. Old maps also show an outlet from Zeekoevlei to the sea, but this closed during the first quarter of the last century. In the past, water levels fluctuated greatly and in summer large marginal areas of the vlei became dry white sandflats. The water was brackish and formed a salt crust where it evaporated on the shore. Under present conditions, two weirs (at Rondevlei and Zeekoevlei) and the constricted channel obstruct flow and prevent natural fluctuations in water level. The Cape Flats Wastewater Treatment Works discharges effluent into the channel below the weir. The elevated inflows ensure that the mouth of the Zeekoevlei is now permanently open (Bickerton 1982).

To reduce the amount of pollution entering the lake system during summer low-flow diversion weirs were constructed in the Lotus River catchment (Bickerton 1982). In 1997, a management scheme was initiated to improve water quality in Zeekoevlei that involved opening the sluice gates at the Zeekoevlei weir in late summer to draw down the water levels of the vlei. The previously solid weir was altered through the construction of six openings that permitted adjustment of water levels in the vlei, allowing for the release of up to 3 x10^6m^3 from Zeekoevlei (~1.2 m drawdown). The first drawdown improved the functioning of the vlei through a reduction in the phytoplankton and improved light penetration. Drawdowns have taken place each year since then but the initial success in promoting a clear water phase has not been achieved again. The sluice gates on the weir were upgraded in 2007 so outflow mostly comprises contaminated bottom water.

4.2 Present Ecological Health

The Zeekoevlei Estuarine Lake system is in a severely degraded state. Table 11.1 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 4.1: Zeekoevlei: Present ecological health

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Significant reduction in high flows and increase in baseflows.				●		
Hydrodynamics	Reduce connectivity due to weirs. Mouth nearly permanently open to the sea due to waste water input. The meandering channel often artificially straitened reducing backwater areas. Collapsible weir drawdown once a year to flush lake. Largely cut-off from the catchment.						●
Salinity	Nearly completely fresh. No connectivity with the sea due to weirs and increased base flows (waste water input).					●	
General Water Quality	Nutrient enrichment from catchments (stormwater). Low oxygen events have been recorded.						●
Physical habitat	Canalisation and rerouting of channels. Harding of riparian banks in some areas. Habitat loss due to infilling. Low lying developments.						●
Microalgae	System is nearly permanently in a eutrophic state.					●	
Macrophytes	Significant reed growth due to enrichment, fresher conditions and low water levels. Significant loss of riparian vegetation due to urban development.					●	
Invertebrates	Change in community composition. Reduce recruitment opportunities. Large riverine species are now present.						●
Fish	Change in community composition, i.e. little to no estuarine species. Reduce recruitment. Alien fish occur in high						●

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
	densities. Pathogens and diseases due to poor water quality and/or microalgae blooms.						
Birds	Change in community composition. Reduce bird numbers of 'estuarine type' species due to loss of habitat and human disturbance.				●		
ESTUARY HEALTH	**SERIOUSLY DEGRADED, but has increased in health in last decade due to restoration actions. Little natural functionality intact due to urbanisation.**					⊙	

5. BOT/KLEINMOND

5.1 General Features

Low flow conditions could cause the expansion of reeds and sedges into the water column further reducing flow. The Bot/Kleinmond Estuarine Lake (Figure 4.1) is located on the south-western coast of South Africa some 110 km south-east of Cape Town (Koop 1982). The Bot and Kleinmond are connected via a natural overflow channel through the Lamloch swamps at a water level of 1.7 m MSL. When the joint system is breached at the Kleinmond mouth, the Bot loses water at about 310 000 m³ a day or approximately 0.11 m a week (Willis 1985). The Bot mouth is mostly closed (or "blind") since it is cut off from the sea by a belt of coastal dunes. The valleys between the dunes are sufficiently low in some places to permit occasional overtopping by waves from the sea during exceptionally high tides. The coastal dune belt is prograding landward because of the deliberate stabilization of the sand by vegetation mainly *Acacia cyclops* (Bally 1985).

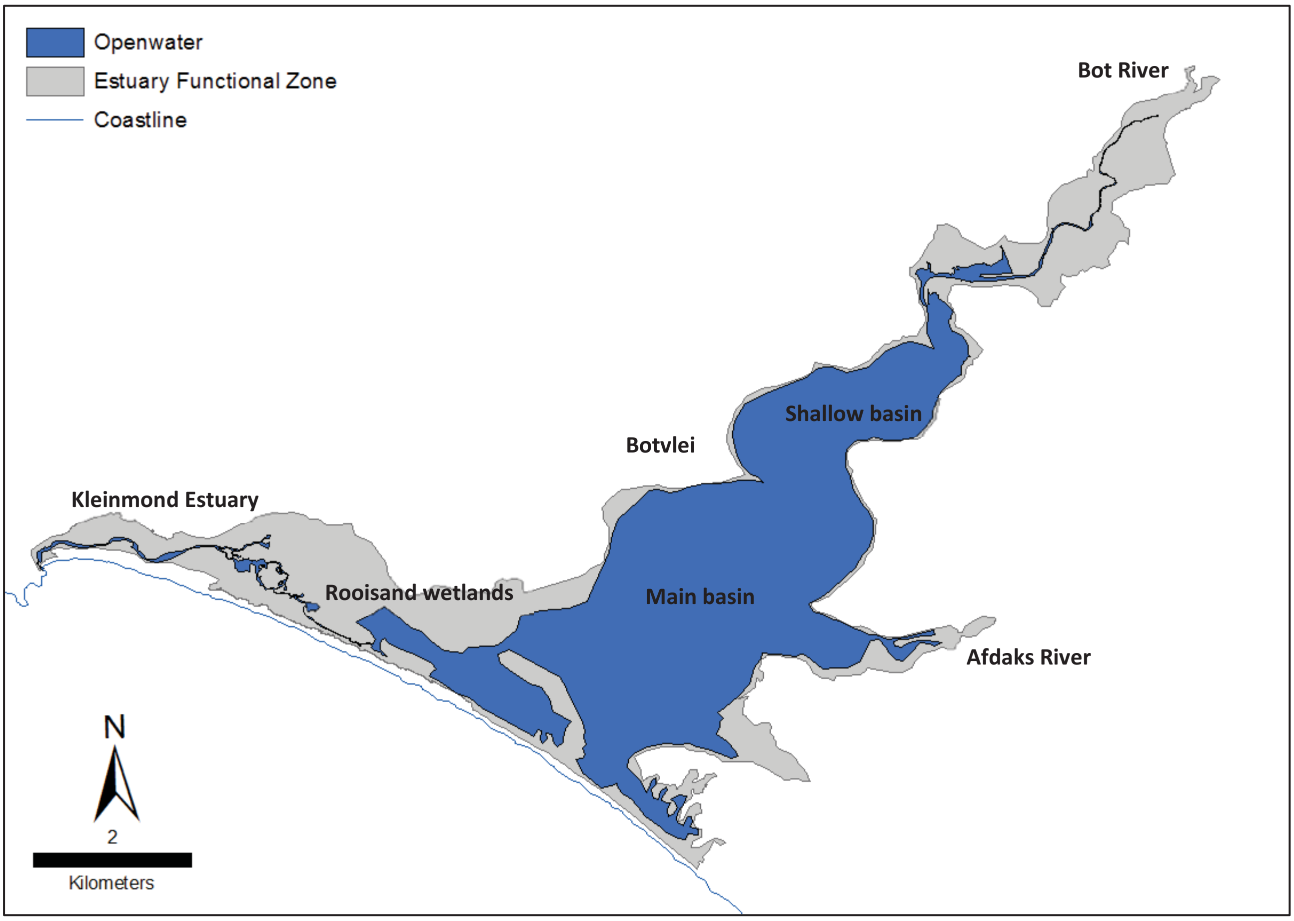

Figure 5.1 Bot/Kleinmond: EFZ and openwater area

The Bot is normally breached at Meerensee, creating a deep tidal mouth, between 80 and 110 m wide and 2.0-2.5 m MSL deep. The mouth stays open for two to four months after a breaching. Outflow during a breaching varies between 250 and 400 m³/s (Fromme 1985a, 1985b). The water level in the system varies from about 2.7 m MSL shortly before a breaching to about 0.0 m MSL after a breaching (Koop 1982).

In the past the Kleinmond was frequently breached (often artificially), draining up to one metre of water from the Bot, which is a critical loss in terms of future potential breachings of the Bot itself.

The Bot River catchment is situated in the south-west of the Breede Water Management Area in the Western Cape Province. The main inland urban areas in the study area are the towns of Botrivier and Caledon and the coastal towns of Kleinmond and Hawston. The major sub-catchments flowing into the lake system include the Bot and the Afdaks rivers into the Bot, as well as Lamloch River into the Kleinmond. There are no large dams in the study area. The largest registered dam is Twaalffontein with a capacity of 0.68 million m^3, however, there are several very small dams or water bodies scattered throughout the catchment area. The present MAR is 72 million m^3, which is a 20% decrease compared to the natural MAR of 89 million m^3 (Van Niekerk et al. 2010).

5.2 Zonation and Abiotic States

The Bot/Kleinmond systems form a relatively shallow coastal lake, roughly 10 km long and a maximum width of about 2 km with a mean depth of -1.5 m MSL (Willis 1985). The Bot and Kleinmond are connected via a natural overflow channel through the Lamloch swamps at a water level of 1.7 m MSL. As per the 2010 EWR study Van Niekerk et al. (2010) the Bot was sub-divided into five distinct zones using bathymetry (size and shape) and salinity distributions as indicators of more homogenous sections (Figure 4.2).

- **Zone A: Upper** – This zone of the Bot is a narrow, confined channel (~3 m deep) opening up into the wider, shallow middle basin (~1 m deep).
- **Zone B: Middle** – This zone comprises a smaller, shallow basin with depths varying between 0.5 to 1 m, depending on water levels in the system.
- **Zone C: Lower** – This zone of the Botvlei represents the large, main basin with depths varying between 2 to 3 m, depending on water levels in the system.
- **Zone D: Rooisand wetlands** – This area comprises a wetland connecting Bot with the Kleinmond. This zone becomes exposed when water levels in the Botvlei are low. When this area is inundated water depth is on average about 0.5 m.
- **Zone E: Kleinmond** – This zone comprises the much smaller tidal Kleinmond estuarine section.

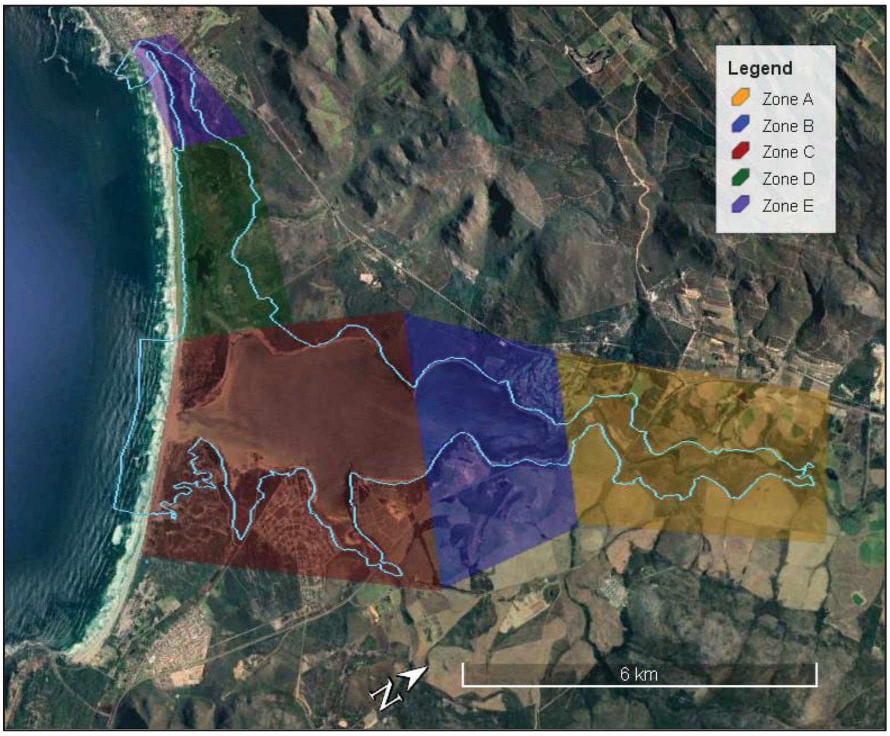

Figure 5.2 Bot/Kleinmond: Zonation

Van Niekerk et al. (2010) identified four characteristic 'abiotic states' for the Bot, largely linked to mouth condition, tidal exchange and salinity distribution (Table 4.1). These are primarily determined by river inflow patterns, water levels and duration since last breaching.

Table 5.1: Bot/Kleinmond: Abiotic states

STATE	NAME	WATER LEVEL (m MSL)	DURATION (years)
1	Mouth is closed, marine dominated to hyper saline (salinity >25)	< 1.0	Closed < 1 year
2	Mouth is closed, brackish (salinity ~ 10-25)	1.0-2.5	Closed between 1-3 years
3	Mouth closed, freshwater dominated (salinity < 10)	1.5-3	Closed more than 3 years
4	Mouth is open, marine dominated as a result of strong tidal exchange.	0.0-1.0	Open for ~ 4 months of the year

Under the natural MAR regime, the system was in the open marine state for about 56% of the time which has now been reduced to 44% of the time (Van Niekerk et al. 2010) (Figure 4.3).

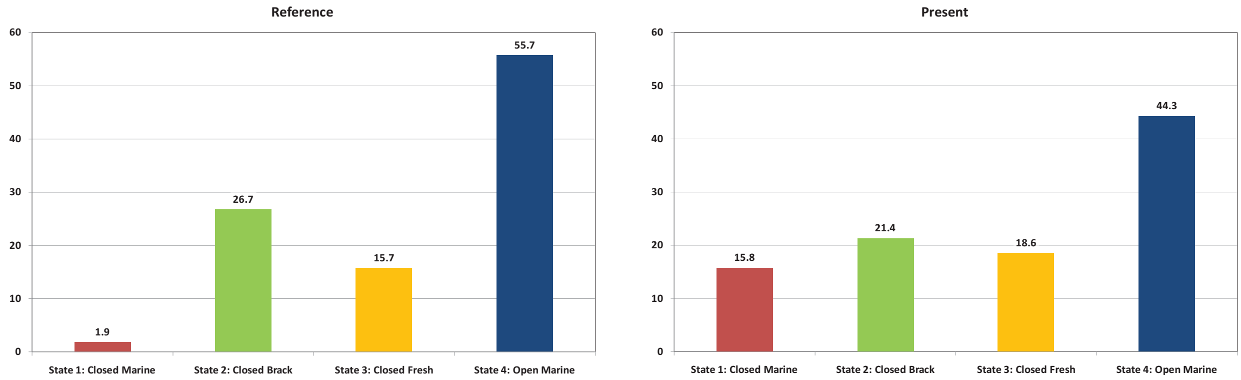

Figure 5.3 Bot/Kleinmond: Annual occurrence of the various abiotic states under the Reference and Present state for Bot

5.3 Abiotic Response Indicators

5.3.1 Mouth dynamics and water levels

The Bot mouth is mostly closed and at present is breached artificially approximately one to two times every three years. The Bot is normally breached at Meerensee, creating a tidal mouth between 80 and 110 m wide and 2.0-2.5 m MSL deep. The mouth stays open for two to four months after a breaching. Outflow during a breaching varies between 250 m^3/s and 400 m^3/s (Fromme 1985a, 1985b). The water level in the estuary varies from about 2.7 m MSL shortly before a breaching to about 0.0 m MSL after a breaching (Koop 1982). This drastic change in water levels and exposure of the marginal areas, resulting from an artificial breaching, is seen by some as a huge shock to the system and therefore to be avoided (Branch et al. 1985; Morant and Quinn 1999). However, it should be realised that breachings and sudden changes in conditions also occurred naturally. After a breaching sea-water intrusion increases salinities to 35 throughout the estuary (Bally and McQuaid 1985; Willis 1985).

The Bot mouth is mostly closed (or 'blind'), since it is cut off from the sea by a belt of coastal dunes. The valleys between the dunes are sufficiently low in some places to permit occasional overtopping by waves from the sea during exceptionally high tides. The coastal dune vegetation is now extending landward as a result of the deliberate stabilization of the sand by vegetation mainly *Acacia cyclops* (Bally 1985). The Bot and Kleinmond are connected via a natural overflow channel through the Lamloch swamps at a water level of 1.7 m MSL. When the joint system is breached at the Kleinmond mouth, the Bot loses water via this channel at about 310 000 m^3 a day or approximately 0.11 m a week (Willis 1985). In the recent past, the Kleinmond was frequently breached (often artificially). Such a breaching can drain up to one metre of water from the Bot, which is a critical loss in terms of future potential breachings of the Bot itself. In the last decade, CapeNature has made a determined effort to prevent artificial breaching of the Kleinmond, which in turn has allowed the Bot to return to a more natural state.

When closed the water level in the Bot depends on the balance of the inflow (+) and the outflow (-). The inflow is dependent on rainfall and the run-off from the catchment and the outflow on what flows through the Kleinmond mouth, seepage and evaporation. Figure 4.4 illustrates the three important levels on which conclusions (Van Niekerk et al. 2005; Van Niekerk et al. 2010):

- At levels of ~1.7 m MSL the Bot and Kleinmond are connected
- The natural breaching level of Kleinmond is ~2.5 m MSL (based on the level that the berm of the Kleinmond breached naturally in 2000
- The natural breaching level of Bot is estimated at ~3.0 m MSL.

The interaction between the two systems occurs in the following manner. At about 1.7 m MSL the two systems become connected via the outflow channel. If the Kleinmond is then open, water flows from Bot to Kleinmond and out to sea. The Bot can only open if the river inflow is greater than the outflow through the Kleinmond mouth. The total amount of water required to breach the Botvlei is thus strongly dependant on the amount lost to the Kleinmond. The greater the volume of water lost through the Kleinmond mouth, the greater the volume of water needed for the Bot to breach. Therefore, premature openings at Kleinmond reduce the possibility of breachings at Botvlei considerably and are a critical factor for the Bot not breaching as often as it should.

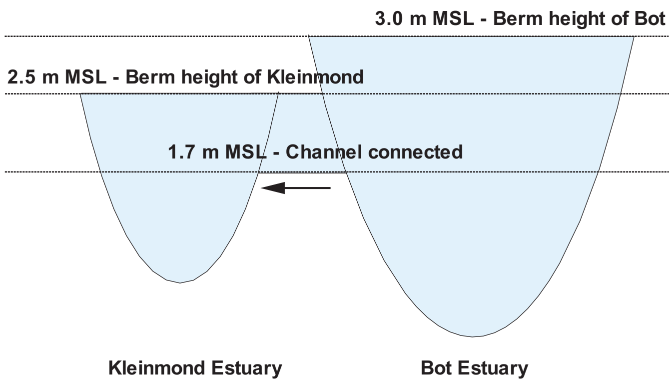

Figure 5.4 Bot/Kleinmond: Important water level features

An analysis of the water level recorder in the Bot (G4R003) from 1979 to 2009 indicates that (Van Niekerk et al. 2010):

- Breaching occurs most frequently in late winter – with more than 30% of past breaching having occurred in August;
- System stays open for approximately 4 months after breaching;
- System closes at a water level of approximately 0.6 m MSL.

The outflow to Kleinmond is 310 000 m^3/day (~3.5 m^3/s or 9 million m^3/month) occurs when the Kleinmond and Bot connect during periods when water level in the system is high. An analysis of the water level data showed no rapid decreases in water levels between 1.7 and 2.0 m MSL indicating that somewhat lower flows occur (estimated at 1.5-2 m^3/s or 5 million m^3/month) at these levels. At 0.5 m MSL the Bot has an estimated volume of 15 million m^3, while at 3 m MSL the volume of water behind the berm is about 45 million m^3. This indicates that the Bot requires about 30 million m^3 to breach on average levels. The evaporative requirement of the Bot is approximately 9 million m^3 in summer, but at higher water levels, when the surface area is significantly larger, it can be as high as 12 million m^3. During breaching, the water level in the Bot decreases from 2.75 to 0.0 m MSL in a few hours. This is equal to about 31 289 800 m^3 of water lost from the system during a breaching. At about 3 m MSL the volume of the system is estimated to be about 45 million m^3, with the surface area varying between 10 000 000 m^2 at closure to 13 000 000 m^2 before a breaching (Van Niekerk et al. 2010).

5.3.2 Salinity

Salinities in the Bot vary seasonally, being highest just after closure and during summer and autumn. Salinities tend to decrease in winter due to dilution by river water. Superimposed on this pattern is a progressive reduction in salinity from year to year if the mouth remains closed (Bally and McQuaid 1985).

Four salinity regimes are proposed for the Bot (Van Niekerk et al. 2010) (Figure 4.5):

- State 1: Mouth is closed, marine dominated to hypersaline (salinity >25)
- State 2: Mouth is closed, brackish (salinity ~ 10-25)
- State 3: Mouth closed, freshwater dominated (salinity < 10)
- State 4: Mouth is open, marine dominated because of strong tidal exchange.

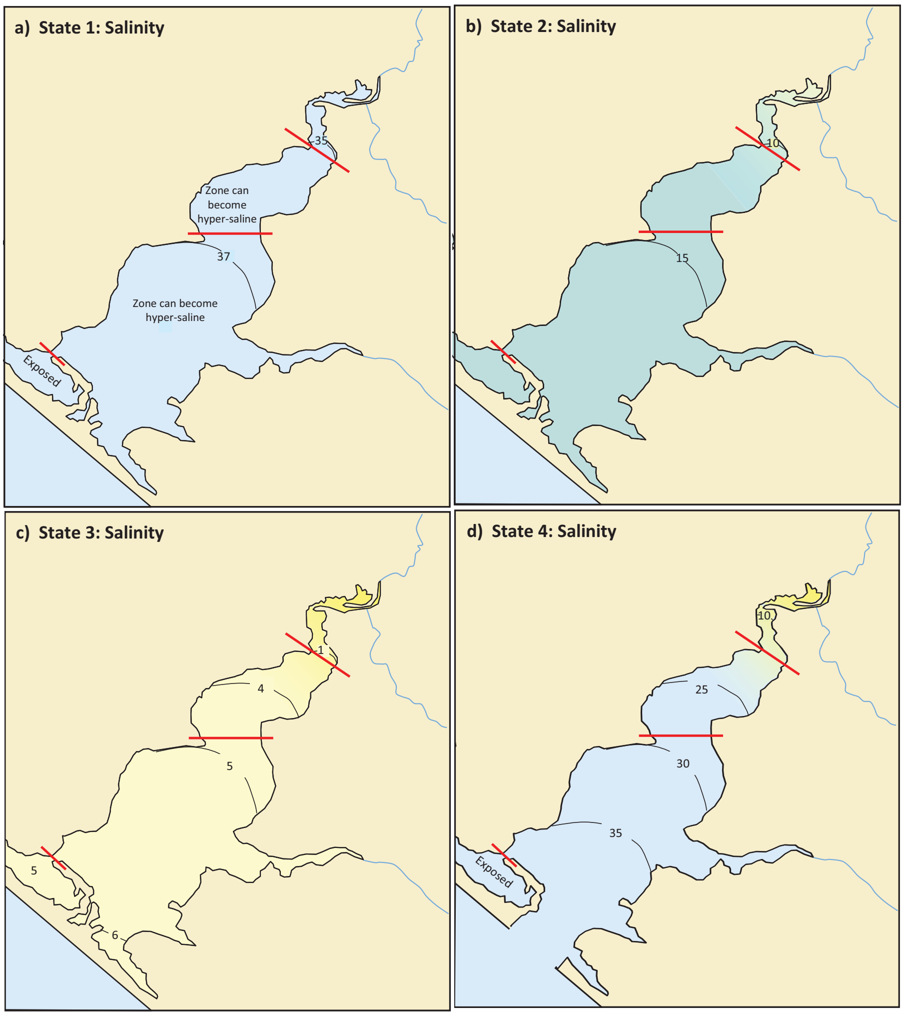

Figure 5.5 Bot/Kleinmond: Salinity distribution in various abiotic states

State 1 usually occurs just after closure or in late summer during periods of no or low river inflow when salinity in the system remains high (>25). Salinities in the upper reaches are often higher than those nearer the mouth (probably as a result of evaporation during summer) (Koop 1982). During State 1 the system can become hypersaline. Salinities as high as 47 have been measured during this state (Bally and McQuaid 1985). During State 2, the system becomes less saline. This is the typical state after closure when winter rainfall and runoff have a chance to increase the influence of freshwater into the system. The system becomes fresher and depending on factors such as the amount of rain, the period for which the system has been closed and the extent of overflow into the Kleinmond, salinities during this state usually range between 25 and 10. Because the system is quite shallow with strong wind mixing, vertical stratification is negligible. Although some degree of longitudinal stratification may exist, it is usually not very strong and more prominent in the narrow upper reaches. State 3 typically occurs after the system has been closed for ~2 years and after significant freshwater inflows during the rainy season. The system becomes largely freshwater-dominated with salinities <10. Because the system is quite shallow with strong wind mixing, vertical stratification is negligible. Although some degree of longitudinal stratification may exist, it is usually not very strong and more prominent in the narrow upper reaches. State 4 represents the open mouth condition following a breaching event. The mouth is wide open, resulting in strong tidal intrusion, and the system rapidly becomes marine-dominated. Salinities in the system are high (>25), except in the narrow upper reaches where salinities can remain low (<10) depending on the volume of river inflow. At the onset, when river inflow may still be significant, horizontal salinity gradient can be very strong, i.e. 35 near the mouth versus 0 near the head of the system, fluctuating with the tide. As river inflow decreases the system becomes more marine dominated up to a stage, just before closure, when salinities throughout the system may be close to that of seawater, i.e. 35. Although vertical stratification may be significant during the earlier stages of this State, i.e. when river inflow is still significant, it is likely to decrease as the State progresses (owing to the shallow basin and strong wind mixing). Because the system is quite shallow with strong wind mixing, vertical stratification will not remain significant although it can be present at the onset of this State.

5.3.3 Temperature

Based on available literature the temperature variations in the Bot show a strong seasonal signal, with average winter and summer temperatures being 11.9°C and 23.6°C, respectively (Bally and McQuaid 1985; Van Niekerk et al. 2010) (Figure 4.6).

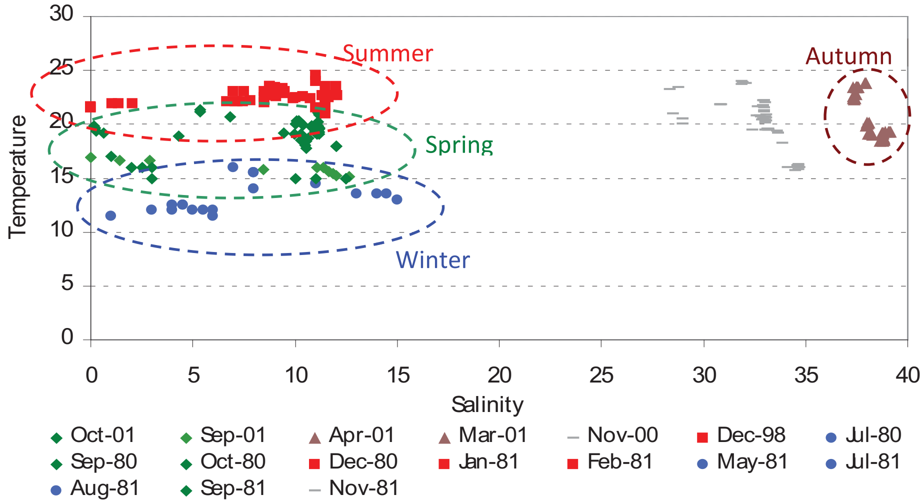

Figure 5.6 Bot/Kleinmond: Typical seasonal temperatures

In most states, the temperature regime in the Bot therefore largely depends on seasons. State 4 may, however, be an exception. Should this State occur during summer months, the temperature of seawater intruding during flood tides will be much lower than the normal summer temperature, and even more so during upwelling when seawater temperature can go down to about 13°C (as has been observed in the Palmiet Estuary) (Taljaard 1986). No measured data could be found to illustrate this for the Bot.

5.4 Biological Response Indicators

5.4.1 Microalgae

The microalgal groups present in the Bot are listed in Table 4.2. For the 2010 EWR study (Van Niekerk et al. 2010), very little data were available on phytoplankton biomass. However, some estimations were needed to predict the responses to different scenarios and therefore predicted cut-offs for low, medium and high biomass were identified and used (Van Niekerk et al. 2010).

Table 5.2: Bot/Kleinmond: Microalgae groupings and defining features

MICROALGAL GROUPS	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES
Benthic microalgae	Benthic diatoms contributed 7% of total system annual primary production (Bally *et al*. 1985). Epiphytic communities would also be important on the emergent and submerged plants. MPB community generally consists of euglenophytes, cyanophytes and bacillariophytes (diatoms). Diatoms are generally dominant in the microphytobenthos. Loss of emergent or fully submerged macrophytes and macroalgae will represent a loss of epiphyte habitat.
Phytoplankton	Phytoplankton also contributed 7% (782 t dry mass/a) to total system annual primary production (Bally *et al*. 1985). Mean water column chlorophyll *a* was 1.9 ug/ℓ, with a range of 0.35 to 5.96 ug/ℓ. This is low by comparison with other South African estuary types. Although phytoplankton are not the dominant primary producers, when estuarine lakes become eutrophic, they change from one stable state to another, i.e. clear water system with submerged macrophytes to a turbid, nutrient-rich system with phytoplankton blooms. Given the lack of vertical salinity gradients and typically low salinity levels, bacillariophytes (diatoms), dinoflagellates, cyanophytes, chlorophytes, cryptophytes and euglenophytes are the dominant phytoplankton groups.

5.4.2 Macrophytes

Macrophytes in the system (Bot only) covers a total area of 15 600 382 m^2 (Table 4.3). The vegetation map for 2009 is shown in Figure 4.7 (Van Niekerk et al. 2010).

Table 5.3: Bot/Kleinmond: Macrophyte habitats and functional groups in the Bot (spp. examples in italics)

HABITAT TYPE	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES	AREA (m^2)
Open surface water area (less macroalgae)	Indicates available habitat for phytoplankton	6 389 214
Intertidal sand and mudflats	Indicates available habitat for intertidal benthic microalgae	770 311
Submerged macrophyte beds	*Ruppia cirrhosa, Potamogeton pectinatus, Chara* sp.	4 763 677
Macroalgae (50% of submerged area)	*Cladophora* sp., *Chaetomorpha* sp., *Ulva intestinalis*	2 381 838
Intertidal and supratidal salt marsh	*Cynodon dactylon, Sarococornia natalensis, Bassia diffusa, Triglochin* spp., *Salicornia* sp., *Plantago crassifolia, Cotula coronopifolia, Sporobolus virginicus, Juncus kraussii, Juncus littoralis, Sarcocornia decumbens*	693 494
Reeds and sedges	*Phragmites australis, Bolboschoenus maritimus, Typha capensis, Cyperus thunbergii, Cyperus textilis, Ficinia nodosus*	601 847

Bally et al. (1985) reported that there is a shallow littoral unvegetated zone up to 1 m width around the Bot. Bally et al. (1985) also reported that submerged macrophytes occurred to a maximum depth of between 2.5 to 3 m, depending on light availability. However, analysis of old aerial photographs (1938, 1961, 1973 and 1981) never show submerged macrophytes extending across the main water body of the Bot. Submerged macrophyte beds appear to be limited to the edges probably due to wind and light limitations. In the afternoon wind turbulence suspends sediments reducing water transparency. For this reason, a lower depth limit of 1.5 m below the prevailing water level was used to calculate the available submerged macrophyte area in relation to the water volume (Van Niekerk et al. 2010).

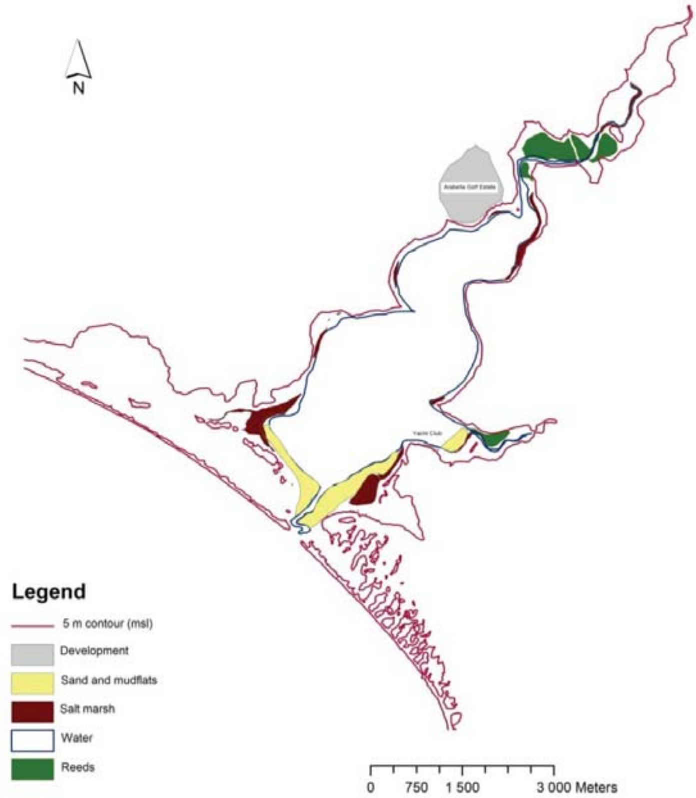

Figure 5.7 Bot/Kleinmond: Vegetation map of the Bot (based on Google Earth 2009 imagery)

A water level to area/volume relationship was used to calculate available submerged macrophyte area and volume. This equation was calculated using the bathymetric x, y and z points provided by CSIR (Van Niekerk et al. 2004). The data were projected from Gauss Conform, Lo19 to WGS_1984_Transverse Mercator and then interpolated using Kriging under spatial analysis of ArcGIS 9.3.1 ™. The available submerged macrophyte habitat for a specific water level was calculated using a model built in ModelBuilder (Figure 4.8). Model Builder is an application used to create, edit and manage models in ArcGIS 9.3.1™. Models are workflows that string together sequences of geoprocessing actions such as extracting a selected water level from a bathymetric map, with the output of one action becoming the input of another. It, therefore, creates a workflow of a sequence of tools or processes. The model can also be used to determine available habitats for other trophic levels. For example, how much area is flooded by 30 cm water, the habitat wading birds use.

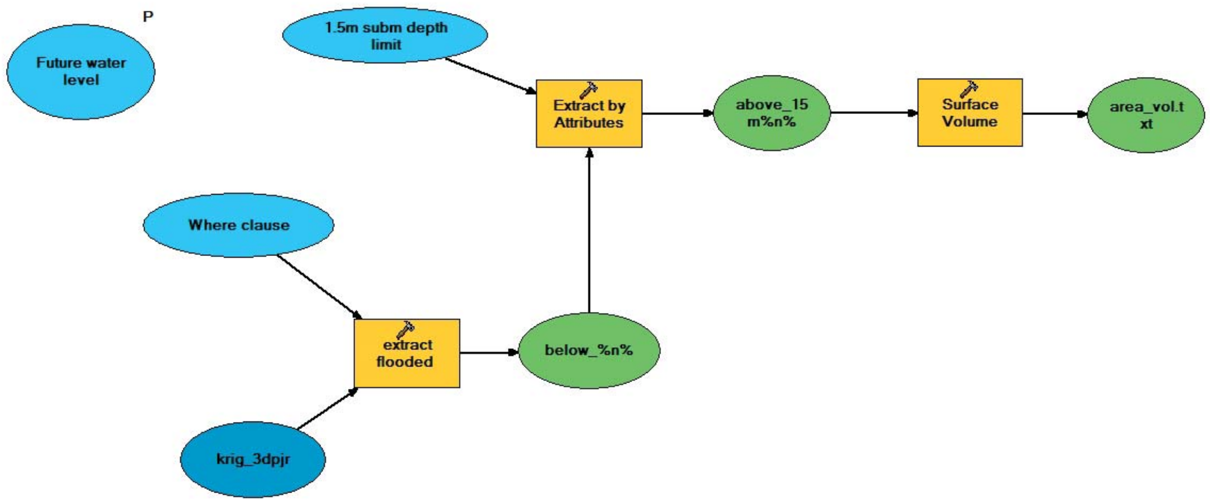

Figure 5.8 Bot/Kleinmond: Model of available area and volume for submerged macrophyte habitat in Bot under different water level scenarios. Grey ovals represent parameter inputs (e.g. future water level), dark blue ovals represent input layers (krig_3dpjr = bathymetric map), green ovals represent intermediate and final outputs and yellow rectangles represent processes (e.g. extract flooded area and area/volumetric calculation)

Total submerged macrophyte area was 4 763 677 m^2 at 2 m MSL (Figure 4.9). Maximum biomass was achieved at a water level of 2 m MSL and declined at higher or lower water levels due to the bathymetric shape of the Bot. The main submerged macrophyte species is *Ruppia maritima* (representing 87% of total submerged macrophyte area, Bally et al. 1985). Other species include *Stuckenia pectinata* (5% of total submerged macrophyte area, Bally et al. 1985) and the macroalga *Chara* sp. (8% of submerged macrophyte area). *Chara* sp. also occurs in patches near the head of the Bot and in the Lamloch Swamp. *Stuckenia pectinata* occurs in dense isolated patches in the upper reaches of the Bot. Although not reported previously by others, *Zostera capensis* has been recorded in the Bot over the last few years (Lamberth pers. comm.) and was observed in the field in March 2011. This may indicate an increase in saline conditions.

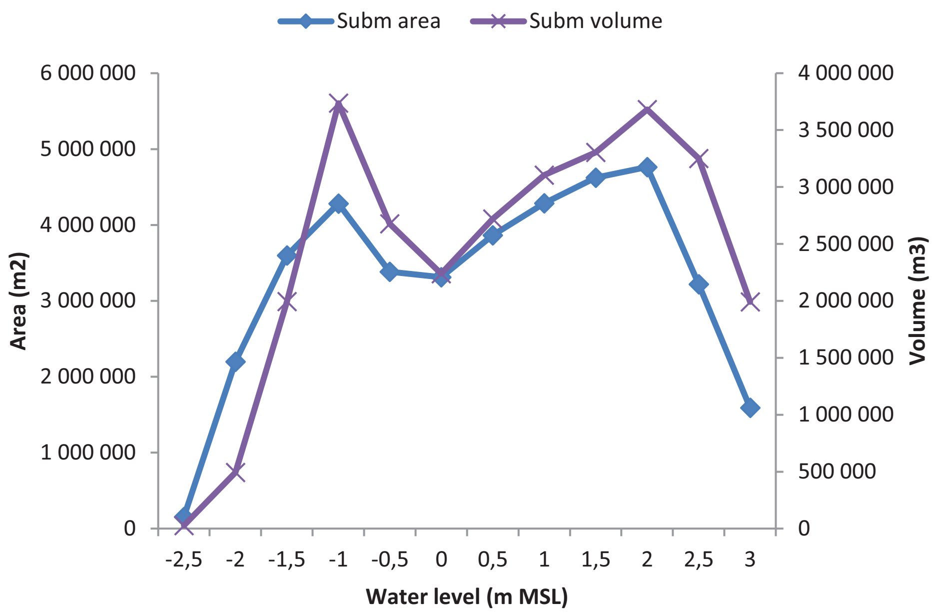

Figure 5.9 Bot/Kleinmond: Model of submerged macrophyte available area and volume under different water levels. Subm = submerged macrophytes which include *Ruppia maritima*, *Stuckenia pectinata* and *Chara* sp. Depth limit was taken at 1.5 m below prevailing water level

Water column salinity determines macrophyte species composition in the Bot; *Ruppia maritima* occurs at salinity between 0-45, Charophytes at 0-20 and *Stuckenia pectinata* at <15. Submerged macrophytes contribute 72% to the total annual primary production in the Bot (7987 t DW/a) (Bally et al. 1985). *Ruppia maritima* contributes 4411 t or 710 $g/m^2/a$. *Stuckenia pectinata* contributes 1253 t or 4125 $g/m^2/a$ and *Chara* sp. 1449 t or 2230 $g/m^2/a$. Light is also an abiotic driver of submerged macrophytes in the Bot. Infilling from sedimentation in the catchment may also reduce available habitat due to the high presence of fine particles (mud and silt), particularly in the northern section of the Bot. Stable water level for 2 months is required for submerged macrophytes to develop from seed reserves (Riddin and Adams 2009). Peak submerged macrophyte biomass will develop after 9 months if the water level is stable (Vromans 2010).

Salt marsh occurs predominantly in the Lamloch area near the head of the Kleinmond and in isolated areas around the main water body of the Bot, with a total area of 693 494 m^2. Salt marsh includes intertidal and supratidal habitat as they could not be mapped separately using the current images. The main species are *Sporobolus virginicus, Juncus kraussii, Juncus acutus, Sarcocornia natalensis* and *Sarcocornia decumbens*. When water level increase above 1.7 m MSL these areas are inundated and can become submerged for prolonged periods. Under these conditions they become heavily epiphytized. Salt marsh dies back when inundated for more than 3 months but recovers rapidly, within 1 to 2 months of water level dropping to expose habitat. No values for the contribution of salt marsh to the total annual primary production of the Kleinmond are available. There has been localised loss of salt marsh at the Rooisand area due to bank destabilisation and in patches along Zone B due to development (Van Niekerk et al. 2010).

Reeds and sedge habitats are characterised by *Chondropetalum tectorum* in the Lamloch area and in isolated patches in the littoral zone around the Bot being replaced by *Scirpus nodosus* in sandier areas and *Juncus acutus* near the head of the system. At the head of the Bot dense stands of *Phragmites australis* and *Scirpus littoralis* reed swamps occur in marginal waterlogged areas. Small patches of reeds and sedges also occur along the edges of the Bot, for example near the Afdaks River and in Lamloch Swamp. The reeds are important as they absorb nutrient input from the land (e.g. fertilizers) and also act as sediment traps. Reeds and sedge cover an area of 601 847 m^2 (Bally et al. 1985). There have been localised losses of reed and sedges due to road construction at the head of the Bot and at Afdaks River. When water level is low (State A and D) and under conditions of nutrient input, reeds will expand in areas where there is freshwater seepage.

Macroalgae in the Bot are common opportunistic species that occur in estuaries worldwide mainly in response to eutrophication. They proliferate initially when salt marsh becomes inundated and begins to decompose. The area coverage was taken as 50% of the submerged macrophyte habitat as they can form dense mats in these areas. When the water level drops these mats are deposited on the shoreline vegetation. The epiphytic macroalga *Cladophora* sp. forms on submerged aquatic vegetation. It can break free and forms dense mats along the shoreline. It has no definite growth cycle, appears unpredictable and can occur for several months at a time. Because of this drifting nature, biomass is highly erratic (Bally et al. 1985).

Four of the nine possible national macrophyte habitats occur in the Bot, only mangroves and swamp forest are absent. The large submerged macrophyte beds are important as they have diverse faunal communities associated with them. 10% of the *Ruppia* beds are estimated to be eaten by coots and 10% by fish (associated epiphytic fauna on the leaves of *Ruppia*). Loss of this habitat after an artificial breach has been estimated to result in a loss of 25 000 coot. Salt marsh have low plant species richness because they typically occur in habitats that are stressful environments. Reeds at the mouth host several bird species.

Submerged macrophyte area cover varies with seasonal water level. When the mouth breaches, 60 to 80% of macrophyte beds are lost through exposure (Bally et al. 1985). Increased frequency of mouth breaching may eventually lead to a long-term reduction in submerged macrophyte area due to exposure and inadequate time for beds to develop once closed. Salt marsh expands when water level is low (State 1) and will continue to grow even when inundated, as long as it is not covered for more than 2 to 3 months. Salt marsh expands rapidly into exposed areas when water level drops and 100% cover can be achieved within 1 to 2 months. Ephemeral pans adjacent to the main water body in the northern parts will dry out during the summer months and under lowered water levels. Increased sediment salinity due to evaporation may result in a temporal loss of species. Dune stabilisation along the Hawston coastline has led to a buildup of sand at Sonesta (Meerensee area), reducing/preventing natural breaching. Increased sedimentation in the lower reaches may also reduce the tidal elevation range, thereby restricting salt marsh zonation.

5.4.3 Fish

Species composition and estuary-dependence

A total of 41 fish species from 24 families have been recorded from the Bot (Bennett 1985, 1989; Bennett et al. 1985; Branch et al. 1985; Lamberth unpublished data in Van Niekerk et al. 2010). Nineteen (46%) of these are entirely dependent on estuaries to complete their lifecycle. Eight of these breed in estuaries and include the estuarine round-herring *Gilchristella aestuaria*, Bot River klipvis *Clinus spatulatus*, Cape halfbeak *Hyporhamphus capensis*, Cape silverside *Atherina breviceps*, Knysna sand-goby *Psammogobius knysnaensis*, three *Caffrogobius* species and pipefish *Syngnathus temminckii*. Seven species, dusky kob *Argyrosomus japonicus*, white steenbras *Lithognathus lithognatus*, leervis *Lichia amia*, Cape moony *Monodactylus falciformis*, flathead mullet *Mugil cephalus*, freshwater mullet *Myxus capensis* and Cape stumpnose *Rhabdosargus holubi*, are dependent on estuaries as nursery areas for at least their first year of life. A further three, African mottled eel *Anguilla bengalensis*, Madagascan mottled eel *A. marmorata* and longfin eel *A. mossambica* are obligate catadromous and use estuaries as transit routes between the marine and freshwater environment. In addition, *Mugil cephalus* and *Myxus capensis* may be regarded as facultative catadromous species.

Ten (24%) of the fish species, including harder *Liza richardsonii*, groovy mullet *Liza dumerilii*, elf *Pomatomus saltatrix* and white stumpnose *Rhabdosargus globiceps*, are at least partially dependent on estuaries. A list of all fish species recorded in the Bot according to Bennett (1985, 1989); Bennett et al. (1985); Branch *et al*. (1985) and Lamberth (unpublished data) is provided in Table 4.4. Estuarine dependence categories, adapted from Whitfield (1994), can be regarded as either partially or completely dependent on estuaries for their survival.

Most of the 12 remaining species are marine species, e.g. piggy *Pomadasys olivaceum* and wildeperd *Diplodus cervinus*, which occur in, but are not dependent on estuaries. Four species, the indigenous Cape galaxias Galaxias zebratus and introduced carp *Cyprinus carpio*, largemouth bass *Micropterus salmoides* and Mozambique tilapia *Oreochromis mossambicus*, are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance.

Table 5.4: Bot/Kleinmond: List of all fish species recorded in the Bot (Bennett 1985, 1989, Bennett et al. 1985, Branch et al. 1985; Lamberth unpublished data)

FAMILY NAME	SPECIFIC NAME	COMMON NAME	DEPENDENCE CATEGORY	RECORDED BY
Anguillidae	*Anguilla bengalensis*	African mottled eel	Va	B
	Anguilla marmorata	Madagascar mottled eel	Va	B
	Anguilla mossambica	Longfin eel	Va	B
Ariidae	*Galeichthys feliceps*	Barbel/white seacatfish	IIb	a,b
Atherinidae	*Atherina breviceps*	Cape silverside	Ib	a,b
Carangidae	*Lichia amia*	Leervis/garrick	IIa	a,b
	Trachurus trachurus	Horse mackerel	III	A
Centrarchidae	*Micropterus salmoides*	Largemouth bass	IVc	a,b
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IVb	a,b
Clinidae	*Clinus spatulatus*	Botriver klipvis	Ia	a,b
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	Ia	a,b
Cyprinidae	*Cyprinus carpio*	Carp	IVc	a,b
Engraulidae	*Engraulis capensis*	Anchovy	III	A
Galaxiidae	*Galaxias* sp.	Cape galaxias	IVa	B
Gobiidae	*Caffrogobius gilchristi*	Prison goby	Ib	a,b
	Caffrogobius nudiceps	Barehead goby	Ib	B
	Caffrogobius saldanha	Commafin goby	Ib	B
	Psammogobius knysnaensis	Knysna sand-goby	Ib	a,b
Haemulidae	*Pomadasys olivaceum*	Piggy	III	a,b
Hemiramphidae	*Hyporhamphus capensis*	Cape halfbeak	Ib	a,b
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa	a,b
Mugilidae	*Liza dumerili*	Groovy mullet	IIb	a,b
	Liza richardsonii	Harder/ southern mullet	IIc	a,b
	Liza tricuspidens	Striped mullet	IIb	a,b
	Mugil cephalus	Flathead mullet	IIa/Vb	a,b
	Myxus capensis	Freshwater mullet	IIa/Vb	B
Ophichthidae	*Ophisurus serpens*	Sand snake-eel	III	A
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc	a,b
Rhinobatidae	*Rhinobatos annulatus*	Lesser guitarfish	III	a,b
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa	a,b
Soleidae	*Heteromycteris capensis*	Cape sole	IIb	B
	Solea bleekeri	Blackhand sole	IIb	a,b
Sparidae	*Diplodus cervinus*	Zebra/wildeperd	III	a,b
	Diplodus sargus	Dassie/blacktail	IIc	a,b
	Lithognathus lithognathus	White steenbras	IIa	a,b
	Lithognathus mormyrus	Sand steenbras	III	B
	Rhabdosargus globiceps	White stumpnose	IIc	a,b
	Rhabdosargus holubi	Cape stumpnose	IIa	a,b
	Sarpa salpa	Strepie	IIc	a,b
Syngnathidae	*Syngnathus temminckii*	Longsnout pipefish	Ib	a,b
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III	a,b
		Total	**41 species**	

Species that breed in estuaries and/or estuarine residents comprise 20% of the Bot fish fauna as compared to 26-27% for the permanently open Berg and Olifants estuaries on the West Coast and between 4-18% for all estuaries on the southwest (Cape Agulhas to Cape Point), east and KwaZulu-Natal coasts (Bennett 1994; Lamberth et al. 2008). Entirely estuarine dependent species comprise 46% of the Bot fish fauna which is slightly lower than the 54% for all south-coast estuaries but high compared to 26, 25, 22 and 21% for west, southwest, east and KwaZulu-Natal coasts respectively (Bennett 1994; Lamberth and Whitfield 1997; Harrison 1999). Partially estuarine dependent species comprise 20% of the Bot fish fauna, which is lower than the 29-40% for the west coast but within the 27-18% range for southwest, east and KwaZulu-Natal coast estuaries (Bennett 1994, Lamberth et al. 2008). Non-estuary-dependent marine species comprise a relatively low proportion (20%) of the fish species recorded and most, e.g. gurnard *Chelidonichthys capensis* and anchovy *Engraulis japonicus* can be construed as rare vagrants which seldom enter estuaries, their occurrence in the temporarily open/closed Bot largely a function of their chance proximity to the mouth when it was open.

Based on their distributional ranges given by Smith and Heemstra (1986), 20 (49%) of the fish recorded in the Bot are southern African endemics including the Botriver klipvis *Clinus spatulatus* which has an extremely limited range being confined to the Bot and nearby Klein. The Bot is a relatively large temporarily open/closed system and accounts for 12% of the total estuarine fish nursery area from False Bay to Port Alfred. Its importance lies in its size and its situation in a region of high endemicity within the warm temperate, cool temperate transition zone.

Abundance

Gillnet sampling is usually targeted at the adults and sub-adults of the larger fish species whereas seine-nets are aimed at catching juveniles and the smaller fish species. A total of 314 573 fish representing 20 species from 14 families were caught in 164 seine hauls in the Bot from 2000 to 2010. A further 2912 fish representing 15 species from 7 families were caught in 50 gillnet sets during the same period. The seine catches compare well with those of Bennett in the early 1980s who caught 14 species and had a catch-per-unit-effort of 1 225 fish/haul versus 1918 fish/haul in the more recent data. Abundance of the dominant estuary-breeders *G. aestuaria, A. breviceps* and *C. spatulatus* was similar during both time periods whereas juveniles of estuary-dependent marine species such as *L. richardsonii* were more abundant from 2000 to 2010. This is most likely due to the prolonged mouth closure and reduced recruitment from the sea during the 1980s study. The much higher numbers of benthic weed-loving species, e.g. *C. gilchristii* and *S. temminckii* in the 1980s corresponds with a massive *Rhuppia, Cladophera/Enteromorpha* and *Zostera* biomass at that time. Gillnet catches of large estuary-dependent fish, e.g. *L. lithognathus* were much higher in the 1980s probably due to the prolonged mouth closure, fish growth and the relative absence of illegal gillnets compared to the present day. The exception is *L. richardsonii* where past and present catches are similar. Although targeted by the illicit fishery, fishing effects on *L. richardsonii* are buffered by it being the only species that recruits in any substantial numbers through the Kleinmond and Lamloch swamps into the Bot. There has also been a substantial increase in the number of freshwater fish mostly due to the introduction of alien species and to lower salinities arising from prolonged periods of mouth closure. Despite this, the fish assemblage of the Bot is typical of that of temporarily open/closed estuaries, being dominated numerically by estuary-breeders and subject to highly variable recruitment by estuary-dependent marine species. This said, survival of the latter has been severely compromised by illegal netting and, despite some years of good recruitment, their contribution to the fish assemblage remains low. Overall, reduced recruitment, alien fish and illegal netting have reduced abundance to about 70% of reference, a figure that would be lower were it not for the buffering of the numerically dominant estuary breeders (Van Niekerk et al. 2010).

Seasonality

Resident estuary-breeders, whether they are livebearers (e.g. *C. spatulatus*) or release eggs (e.g. *G. aestuaria*), reproduce throughout the year with peaks in the spring and summer. Breeding also tends to be concentrated in the dry season to prevent eggs and larvae from being flushed out to sea. Flushing may also be countered by spawning at the head of the estuary and in the freshwater reaches (e.g. *G. aestuaria*) or by producing adhesive eggs (e.g. *A. breviceps*). Estuary-residence and year-round breeding maintain fairly constant biomass and availability to piscivorous predators throughout the year. The peak spawning and recruitment period for obligate estuary-dependent marine species (e.g. *L. lithognathus*) is spring to early summer and, under natural conditions, coincides with higher flow and mouth-opening in the Bot and other estuaries in the southwestern Cape. Partially estuary-dependent fish (e.g. *L. richardsonii*), peak in early summer but will recruit opportunistically throughout the year as happens when the overflowing Bot allows recruitment via Kleinmond and the Lamloch Swamps. If breaching occurs, adults leaving the system may become reproductively active and contribute to another spawning peak in late summer (Van Niekerk et al. 2010).

Catadromous (glass) eels enter the Bot (and other systems) mainly in summer, at night on high spring tides, under strong river flow and when the mouth is open. There is a good chance that most of the recruitment into the Bot catchment occurs via the Kleinmond where overflow and opening are more frequent. Upstream migration of elvers is enhanced by high flow and inundated marginal areas. Adult return migration to the sea (8-20 years later) is cued and facilitated by floods and high flow.

Connectivity with other estuaries and the marine environment

The Bot, together with the Klein, account for 25-30% of the available estuarine fish nursery area from Cape Point to Port Alfred. It is crucial that at least one of these two estuaries is open to the sea during the spring/early summer recruitment window each year. With the exception of some drought years, the Klein usually opens annually under natural conditions. Recent droughts and eutrophication (2010/11) have seen that system and its fish under severe stress from hypoxia and high-water temperatures with mass mortalities occurring. The Bot, which has opened during this time period, would have provided some level of mitigation by allowing recruitment of juvenile fish and larvae and the export of adult fish to recruit into the marine fisheries. The latter function was probably negated by the gillnet catches (Van Niekerk et al. 2010).

Connectivity between the Bot and Klein is highlighted by the fact that *Clinus spatulatus* only occurs in these two systems and nowhere else. On the other hand, the *G. aestuaria* population in the Bot is probably the most genetically isolated one of this species along the entire South African coastline (Norton MSc thesis). This can be at least partly explained by its life-history characteristics but also by the fact that fish recruitment into Walker Bay and its estuaries is limited compared to other bays in South Africa, mostly due to its relative isolation and currents bypassing the bay, deflecting further out to sea. This may also be a factor in the recruitment of estuary-dependent marine species as it may limit the estuary recruitment window more than elsewhere along this country's coastline.

5.5 Present Ecological Health

The Bot/Kleinmond system is in a moderately degraded state. Table 4.5 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 5.5: Bot/Kleinmond: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Significant reduction in low flows.			●			
Hydrodynamics	Bot berm has been stabilised (increasing height). The system does not reach a natural breaching level due to flow reduction and increase berm height. Artificially breached at Bot, but with a highly regulated schedule. Artificial breaching at Kleinmond has been stopped. Increase in the closed mouth conditions.			●			
Salinity	Salinity range from nearly fresh (when outflow occurs through Kleinmond) to hypersaline (<45) (when outflow occurs through Bot). Bot breaching hypersalinity conditions on the increase due to reduced freshwater inflow.		●				
General Water Quality	Nutrient enrichment from catchments and waste water. Low oxygen events have been recorded in the upper reaches.				●		
Physical habitat	Some harding of riparian banks in some areas. Habitat loss due to infilling. Some low lying developments.		●				

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Microalgae	Microalgal blooms have been detected in the system due to enrichment.			●			
Macrophytes	Some loss of riparian vegetation due to urban development. Some reed growth due to enrichment near the golf course.		●				
Invertebrates	Some change in community composition, but largely estuarine species in the system. Reduce recruitment opportunities.		●				
Fish	Some change in community composition, i.e. loss of marine species. Reduce recruitment. Significant reduction in abundance due to overfishing (illegal gill netting). Some invasive alien fish.				●		
Birds	Some change in community composition. Some reduction in bird abundance due to human disturbance, reduction of prey species and loss of habitat.		●				
ESTUARY HEALTH	**MODERATELY DEGRADED with a downwards trajectory. However, functionality is relative intact and opportunities for rehabilitation exist.**			⊙			

6. KLEIN

6.1 General Features

The Klein Estuarine Lake (Figure 5.1) is situated more or less midway between Cape Point and Cape Agulhas on the south-west coast within the Cool Temperate biogeographic region of South Africa. The lake comprises a single longitudinal system directly linked to the sea. The main basin, below the riverine inflow, is shallower and more confined in its lower 2 km. The estuarine lake is mainly fed by the Klein River, with the much smaller Voëlgat River flowing into the main basin.

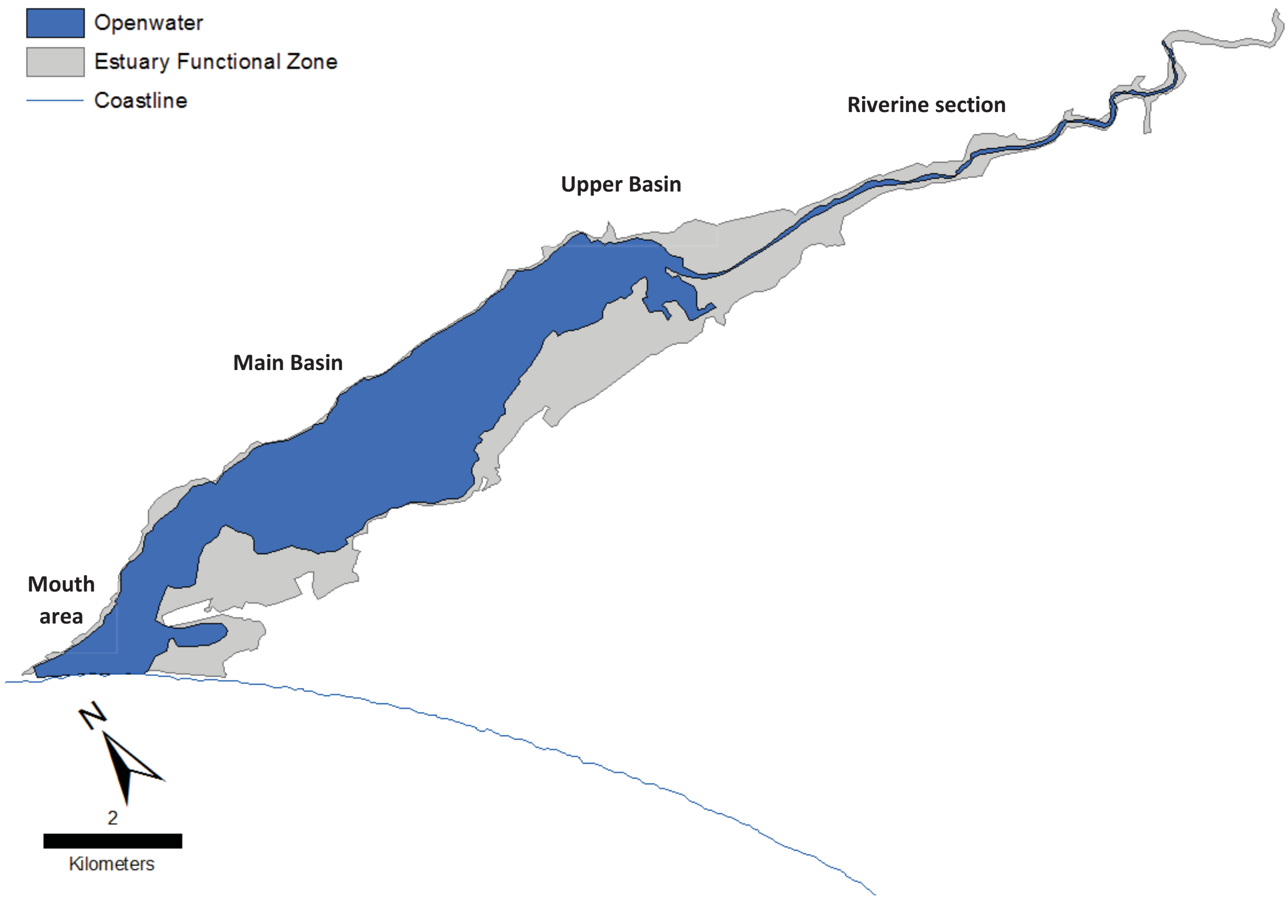

Figure 6.1 Klein: EFZ and openwater area

The Klein River catchment is in the south-west of the Breede-Overberg Water Management Area in the Western Cape Province. The main nearby urban areas are the inland town of Stanford and the coastal town of Hermanus. The Klein River and its main tributaries, the Hartebees, Steenbok and Karringmelk rivers initially flow through well-developed agricultural land, which consists mainly of dryland agriculture and vineyards with some commercial irrigation (centre pivots). The total quaternary catchment area is 820 km^2 (Anchor 2015). There are no major dams within the Klein catchment, however, there are numerous farm dams that are used to supply water for irrigation. The largest is Tolbos Dam with a capacity of 238 million m^3. Many dams appear to be used for off-channel storage. Thus, the present flood regime for the Klein River is judged to be very similar to natural. It is estimated that flood flows are about 87% like natural conditions. However, the present MAR has decreased more significantly and is estimated at 77% of natural. This reduction is clearly manifest in the increased occurrence of low and zero flow conditions, which now occur about 30% of the time. Average monthly flows in the low flow period (Dec-Mar) are now 50% of that under natural conditions. As an estuarine lake system, the Klein is sensitive to any change in inflows.

The Klein is bounded to the north by the Kleinriviersberge composed of Table Mountain Group, while its southern shore is composed of coastal limestone (calcretes). Fringing the southern shore of the estuary, are lithified dunes covered by a calcrete cap. These calcretes are replaced on the seaward side by modern sand dunes. These dunes progress in a general west to east direction and form dunes up to 30 m high, at intervals of 300 to 500 m. Stabilisation of the dunes with *Acacia cyclops* (Rooikrantz) and indigenous dune vegetation during the 1940s has prevented any further movement of the dunes in modern times. A vegetated dune has been artificially created to the east of the estuary mouth that affects the mouth dynamics of the system.

Several alluvial fan deltas occur along the northern shore, where rivers discharge their loads from the mountains into the estuary. The largest of these deltas is formed by the Voëlgat River, which enters the estuary west of Kettle Point. The alluvial fan deltas introduce poorly sorted sediments along the northern margin of the system, with coarse sands and gravels deposited nearshore and fines deeper in the estuary.

6.2 Zonation and Abiotic States

The Klein Estuarine Lake system comprises four relative homogenous zones (parts) that behave differently under different mouth states and associated water levels: a shallow mouth area (A), a deeper main waterbody (B), shallow upper reaches (C) the deeper riverine (D) section (Figure 5.2) (Anchor 2015).

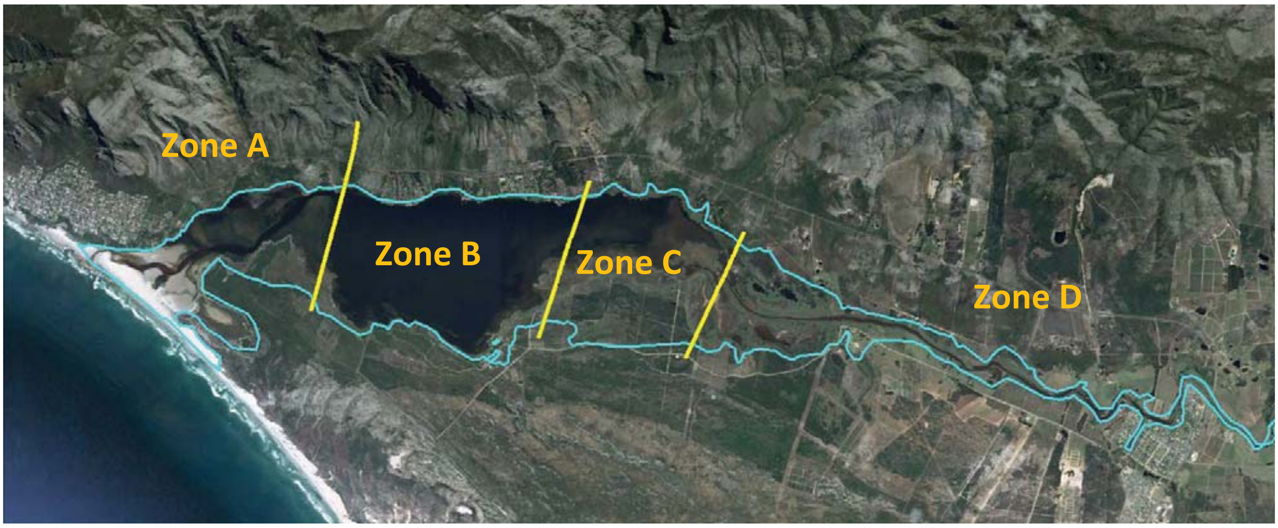

Figure 6.2 Klein: Zonation

Table 5.1 summarises the key features of each zone (Anchor 2015).

Table 6.1: Klein: Key feature of zones

FEATURE	ZONE A MOUTH	ZONE B MAIN WATER BODY	ZONE C SHALLOW UPPER	ZONE C RIVERINE
Open water area (ha) under closed mouth conditions	295	542	247	70
Depth (m) when open	0.5-1.0 (Mostly dry when open)	2.0-3.0	0.5-1.0 (Very shallow to dry when open)	2.0-3.0

Because the Klein system is not driven by seasonal river inflow patterns, but rather by inter-annual flow patterns, the relationship between "river inflow" and abiotic states can best be described in terms of water levels. Five distinct abiotic states have been identified, resulting in the following combination of conditions occurring in the estuary (Anchor 2015) (Table 5.2).

Table 6.2: Klein: Abiotic states

STATE	NAME	DESCRIPTION
State 1	Open, marine	The mouth of the estuary is open, with the system under tidal conditions. Salinity in Zone A to C is greater than 30, and is around 20 in Zone D.
State 2	Open, gradient	The mouth of the estuary is open, with the system under tidal conditions. Salinity in Zone A to B is generally greater than 30 and is around 25 and 10 in Zone C and D, respectively.
State 3	Closed, marine	The mouth of the estuary is closed, with the system at water levels below 1.6 m MSL. Salinity in Zone A to C is greater than 30, and is around 25 in Zone D.
State 4	Closed, brackish	The mouth of the estuary is closed, with the system at water levels greater than 1.6 m MSL. Salinity in Zone A to C is between 15 and 20, while in Zone D is between 10 and 15.
State 5	Closed, hypersaline	The mouth of the estuary is closed, with the system at water levels below -1.0 m MSL. All zones in the estuary are hypersaline (salinity 40 to 75). (Note: this is a hypothetical state that does not occur under the Reference or Present conditions.)

The probability of occurrence of the various abiotic states under Reference and Present conditions is indicated in Figure 5.3. On average occurrence of State 1: Open marine has declined from 21% to 14%, while State 3: Closed, marine has increased in occurrence from 45% under reference conditions to 61% at present (Anchor 2015).

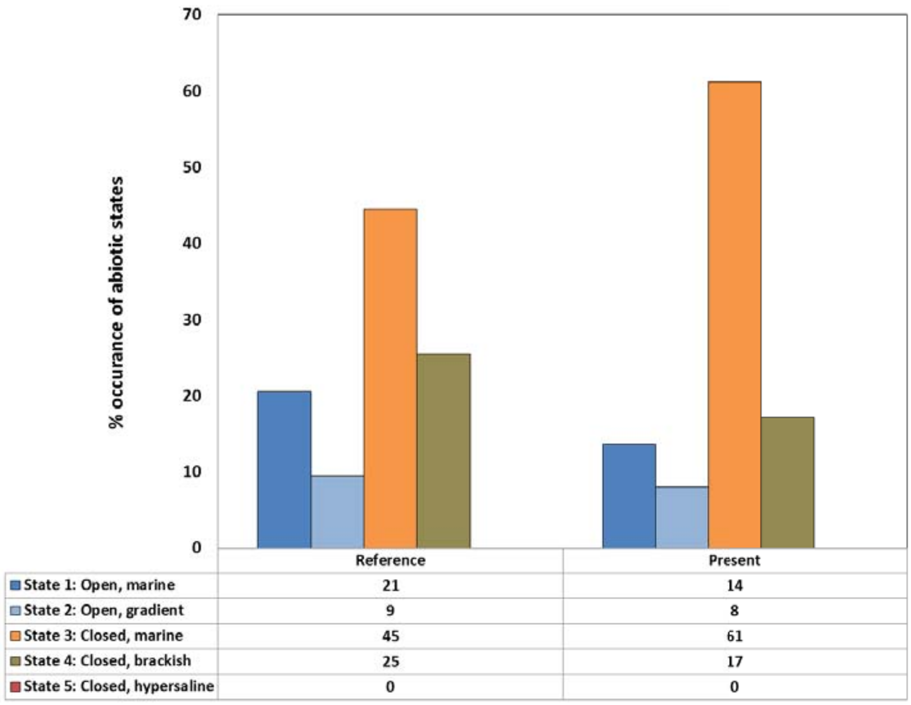

Figure 6.3 Klein: Percentage occurrence of abiotic states under Reference and Present state. Colour coding indicates the likely occurrence of different abiotic states (State 1: Open marine, 2: Open gradient, 3: Closed marine, 4: Closed brackish, 5: Closed hypersaline)

6.3 Abiotic Response Indicators

6.3.1 Mouth dynamics and water levels

Normally floods play a significant role in scouring sediments from estuaries, but in the case of the Klein, the effect is somewhat moderated due to the large surface area of the system that attenuates floods in the main water body. Thus, the scouring impact of floods is mostly confined to the riverine reaches (Zone D) and the lower mouth reaches (Zone A), with Zone B and C acting as sediment dispositional areas. Besides river flow, the main hydraulic driver in the estuary is the tide. During neap tides, maximum velocities are low with very little transport of water or sediments, while both velocities and transport increase towards spring tides. During low river flow periods, the net sediment transport in the estuary relies on a subtle balance between dominant flood and the ebb tide flows. More sediment enters the mouth on the flood tide than can leave on the ebb (Anchor 2015).

Mouth breaching and floods are the only mechanisms for removing sediment from the system, with the near annual mouth breaching being the more important factor in maintaining the equilibrium in the lower reaches of the system. Changes in river inflow and artificial breaching have resulted in major changes in the mouth condition, water level, water column structure (stratification), salinity distribution, and water quality in the Klein estuary.

During the early 1900s humans started settling along the banks of Klein system. To prevent properties from being flooded, the practice of artificially breaching the mouth of the estuary was instituted. Initially, artificial breaching was undertaken by teams of workers using spades. Later, mechanical equipment such as bulldozers became available, enabling artificial breaching at even lower levels (De Decker 1989). Before human development took place, i.e. under natural conditions, breaching of the Klein Estuary would only occur when the water level inside the estuary exceeded the height of the sand berm at the mouth. During the closed phase, the berm could have built up to levels exceeding 3 m above mean sea level. Under natural conditions, the water levels in the estuary would eventually exceed the height of the berm and a breaching would occur at levels often exceeding 3.0 to 3.5 m MSL.

Initially, the outflow of water from the estuary into the sea would be through a shallow channel, but with a gradual increase in water levels, on-going scouring of the outflow channel occurs, and eventually, a very strong outflow would have created a deep and wide channel between the estuary and the sea. The establishment of the natural outflow channel can take up to half a day or more to establish depending on the inflow. When breaching occurred at natural levels (up to metre higher than at present) a much larger volume of water would have flowed out to sea over a much longer period, which in turn, would have removed significantly larger volumes of sediments from the middle and lower reaches of the estuary. During a breaching event, the maximum water level in an estuary is reached when the outflow through the mouth exceeds the river inflow. Under moderate to high river inflow conditions, this occurs a few hours after the actual breaching of the sand berm.

CSIR (1999) showed that for the Klein Estuary, the maximum outflow reached under high breaching levels (e.g. 2.63 m MSL) is equivalent to that of a 1:50 year flood. Large amounts of sediments are scoured from the lower estuary and vlei during such events. Under natural conditions, breaching events of this nature and concomitant significant scouring of sediment would have occurred nearly every year. Over time a long-term equilibrium is reached between the flushing of sediments during breaching and the deposition of sediment by tides and wave action under open conditions, which would have prevented the estuary from silting up.

The main difference between an artificial and natural breaching event is that in the case of artificial breaching, a channel is excavated which allow outflow to begin at a lower water level than would naturally be the case. During artificial breaching, an outflow channel is excavated through the berm at a pre-determined water level. After the channel has been prepared, it is opened to the sea and outflow begins. Under artificial breaching, outflow volumes exceed inflow volumes faster than for natural breaching as the initial scouring processes are replaced by the artificial channel, ultimately translating to lower water levels, i.e. under the same size flood event the maximum level reached under natural breach levels is higher than under artificial breach conditions. Artificial breaching at lower than natural breaching levels, reduce the volume and duration of water flow out to sea, which in turn reduce sediment scouring. This disturbs the long-term erosion/depositional cycles in estuaries as the same amount of marine sediment will still be deposited inside an estuary wave action, while less is removed during an artificial breach than under natural water levels. In the long-term this results in increased sedimentation in the lower estuary.

Under open tidal conditions, water levels in the Klein are substantially lower than when it is closed, ranging between +0.5 and +1.0 m MSL (DWS Station G4R004 with raw data corrected with -1.47 m to obtain water levels to MSL (CSIR 1997).

In 1997 and 1998 the mouth was artificially breached at water levels of +2.65 and +2.63 m MSL, respectively, which resulted in a considerable increase in the maximum outflow rates during these breaching events. According to available information, no significant damage to property resulted at these breaching levels (CSIR 1998, CSIR 1999), however, it was concluded that problems could have occurred if the waves had been higher in the main waterbody. During these breaching events, observations were made of the effects of high-water levels under windy conditions on low-lying properties along the vlei edge where the large open water body lends itself to the generation of significant waves. Sandbags and straw bales were installed to protect these properties. Since then, the mouth has been breached again several times at water levels similar to or even higher than those of 1997 and 1998. A summary of breaching water levels between 1979 and 2015 is presented in Anchor (2015) which shows the maximum water levels recorded for each event. There has been a notable upwards trend over the last three decades. An analysis of the Klein Estuary water levels for 35 years (1980-2015) indicates (Figure 5.4):

- Average breaching level is 2.32 m MSL, with the lowest breaching recorded at 1.71 m MSL and the highest at 2.81 m MSL. (Note that in most cases the Klein Estuary is breached artificially and that this does not represent natural breaching levels, which would have occurred at much higher water levels.)
- Average level at which the Klein Estuary mouth closes is 0.6 m MSL.
- Very weak correlation between “breaching water level” and “days open after breaching” indicating that several other factors also play a key role in maintaining a prolonged open mouth state. For example, observations have shown that mouth position plays a significant role in assisting with the mouth remaining open. The occurrence of high waves during aseasonal coastal storm events has also resulted in unexpected closures.

On average the Klein Estuarine Lake remains open between 3 and 4 months after breaching, with a minimum period of 18 days and a maximum open period of 12.5 months. The system remains closed for about 7 months of the year on average. The longest period of closure was 25 months, associated with the 2010/11 drought. The estuary also remained closed for more than a year in 1990/91 and 2003/05. The highest frequency of breaching occurs between June and September, with a peak near early spring.

During a major flood event, the water level in the system increases rapidly and the whole process described above occurs over a shorter timeframe. However, as it takes some time for the outflow channel to establish under natural conditions, it can still take several hours before the outflow exceeds inflow from the river. This in turn translates into significantly higher water levels in the system under higher inflow conditions even hours after the actual breaching event, due to constricting effect of the outflow channel. The greater the inflow, the longer it will take to reach the equilibrium between inflow and outflow, which means that the maximum water level reached in the Klein Estuary can be up to a metre higher than the berm level (CSIR 1999, 15 December 1998 breaching).

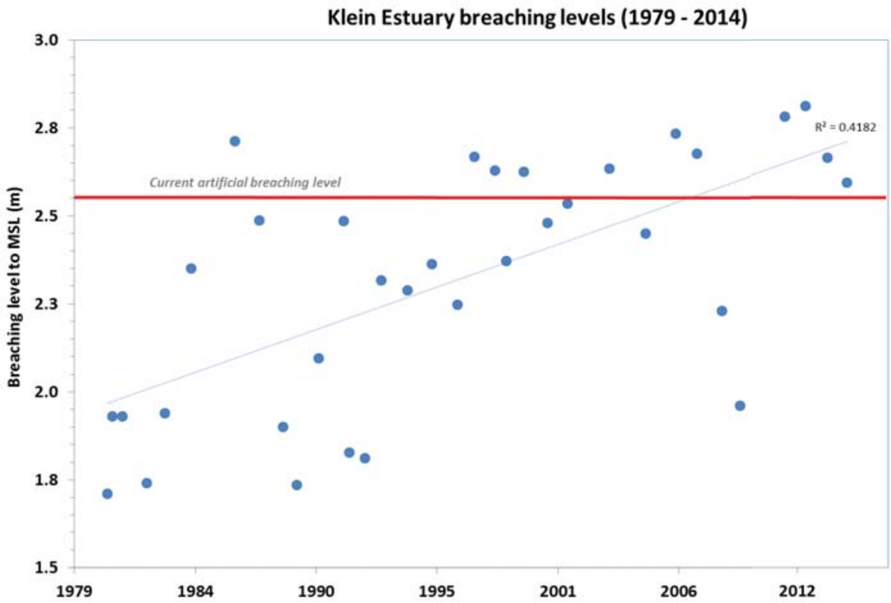

Figure 6.4 Klein: Summary of breaching water levels between 1979 and 2014

However, while artificial breaching can moderate maximum water levels (i.e. not increase to natural levels) under low to moderate inflow conditions (freshettes and small floods), the flood attenuation effect is significantly less under major flood conditions. Under high inflow conditions, the water levels in the upper estuary are significantly higher than in the lower reaches as a result of the constraints imposed by the channel.

The flood attenuation effect provided by the large water body of the vlei is significantly reduced in the upper reaches, e.g. the upper reaches are only about 50 m wide in comparison with the vlei which is 650 m to 1500 m wide. Therefore, when a flood comes through, the lack of storage area results in a significant increase in water level in the upper reaches in comparison with the vlei which can distribute the same volume of water over a much larger surface area than is the case for the upper reaches.

6.3.2 Salinity

Table 5.3 provides a summary of 25 salinity profiles taken in the Klein Estuary over a 15-year period. The observed salinity data was averaged for zones A to D. From this dataset it is clear that the Klein Estuary is strongly marine dominated, with salinity between 30 and 38 recorded for both the open and closed mouth phases. The data set also shows very little stratification, attributed to very effective wind mixing under open and closed mouth conditions. Stratification is mostly confined to Zone D under higher flow conditions (Anchor 2015).

If a sound connection with the sea is established following breaching, near marine conditions (30-35) establish themselves within a month or two of breaching. Under extended open mouth conditions, coupled with the limited base flows, hypersalinity (36-39) can develop in the upper reaches of Zone B and Zone C. After a few months, physical processes will cause mouth closure in the late summer or early winter. Several observations indicate that runoff is generally still low during this period, leading to medium to low water levels (<1.8 m MSL) while maintaining the high salinity values (30-35). If closure occurs early in summer, hypersalinity may even develop during this state (36-39). Later, when seasonal winter rainfall elevates the water levels above 1.8 m MSL, salinity decreases to below 20. Only under significant inflow conditions, generally associated with mouth breaching, does a full salinity gradient develop from Zone A to D (A=25-30, B=10-20, C=15-5, D=1). However, these conditions are only maintained for a few weeks at a time, before the systems start reverting to the more dominant open marine condition.

Table 6.3: Klein: Summary of average observed salinity across zones vs. mouth state and water levels (1999-2014)

NO	DATE	SALINITY				WATER LEVEL (m MSL)	MOUTH STATE	DAYS SINCE…
		Zone A	Zone B	Zone C	Zone D			
1	19-Dec-99	14	16	8		0.67	Open	84
2	05-Feb-00	35	35	36	16	0.57	Open	131
3	29-Mar-00	31	32	32	18	0.88	Closed	29
4	19-Apr-00	32	32	32	14	0.92	Closed	50
5	05-Jun-00	29	30	30	14	0.99	Closed	97
6	**02-Jul-00**	29	28	19	11	**1.14**	**Closed**	**124**
7	**28-Aug-00**	**19**	**18**	**18**	**17**	**2.03**	**Closed**	**181**
8	07-Nov-00	34	26	15	15	0.49	Open	8
9	02-Mar-01	34	36	36	22	0.53	Open	123
10	06-Apr-01	35	36	36	28	0.62	Open	158
11	30-Dec-01	34	34	33		0.61	Open	95
12	04-Jun-02	32	32	32			Open	251
13	**29-Mar-03**	**17**	**16**	**15**	**3**	**1.55**	**Closed**	**180**
14	**15-Feb-10**	**19**	**19**	**19**	**16**	**1.69**	**Closed**	**184**
15	27-Sep-11	25	23	16	2	1.91	Open	20
16	25-Oct-11	34	31	28	13	1.91	Open	48
17	29-Feb-12	37	38	33	26	0.50	Closed	60
18	21-May-12	35	37	32	25	0.50	Closed	142
19	**31-Jul-12**	**22**	**22**	**21**	**14**	**1.50**	**Closed**	**213**
20	28-Aug-12	24	9	6	1	0.69	Open	14
21	11-Sep-12	30	15	13	1	0.96	Open	28
22	19-Sep-12	28	17	9	1		Open	36
23	14-Nov-12	25	16	15	1	0.83	Open	92
24	19-Mar-13	26	23	16	3	0.867	Closed	117
25	06-Oct-14	32	22	20	19	0.867	Open	101

However, similar low salinity conditions can also develop when the entrance channel is too restrictive to allow for effective tidal flushing, i.e. the inlet channel is too narrow and shallow (breaching at low water levels or not aligned with historical channels) or too extended (western position add an addition 500 m to inlet length) as a result of inappropriate breaching practices. However, under this condition, these lower salinities will persist, resulting in a limited/slow increase in salinity over time. Marine conditions (salinity >30) throughout the system may not even be achieved as the mouth tends to close prematurely under these conditions.

6.3.3 Temperature

Temperatures in the Klein Estuary exhibit a strong seasonal signal with the highest temperatures in summer (23-28°C) and lowest during winter (12-17°C), based on measurements collected during 7 surveys between 2010 and 2013 (DAFF, CSIR and Overberg Municipality, unpublished data in Anchor 2015) (Figure 5.5).

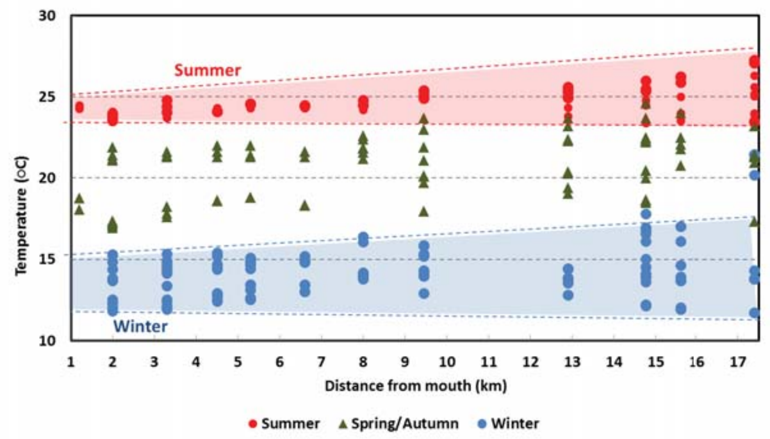

Figure 6.5 Klein: Seasonal temperature patterns based on available data (2010-2013)

This would have been like the Reference condition. During the open mouth state especially in summer, temperatures in the lower estuary can decrease significantly (14-15°C) because of upwelling at sea, when colder seawater enters the estuary during high tide, as was observed in February 1989 (Anchor 2015).

6.4 Biological Response Indicators

6.4.1 Microalgae

Microalgae in the Klein estuary are divided into two groups – benthic microalgae and phytoplankton (Anchor 2015).

Benthic microalgae: Benthic diatoms are likely to be important in large shallow sand and mudflat areas. Epiphytic communities would also be important on the emergent and submerged plants. MPB community generally consists of euglenophytes, cyanophytes and bacillariophytes (diatoms). Diatoms are generally dominant in the microphytobenthos. Loss of emergent or submerged macrophytes will represent a loss of epiphyte habitat.

Phytoplankton: There are indications of phytoplankton blooms (Chl-*a* > 20 ug/ℓ). There is likely to be competition for nutrients from macroalgae under closed mouth conditions. If coastal/estuarine lakes become eutrophic they change from one stable state to another, i.e. clear water system with submerged macrophytes to a turbid, nutrient-rich system with phytoplankton blooms. Given the prevalence of brackish and marine conditions, bacillariophytes (diatoms), dinoflagellates, cyanophytes and cryptophytes are the expected dominant phytoplankton groups.

Chlorophyll data from 2012 shows that phytoplankton blooms (Chl-*a* > 20 ug/ℓ) do occur. At present, nutrients are not limiting for microalgal growth and phytoplankton blooms occur frequently depending on water retention time. Phytoplankton biomass has increased, especially in the upper reaches, because of reduced base flow and an increase in closed mouth conditions and nutrient input. As a result, cyanophytes have increased in the system.

6.4.2 Macrophytes

Macrophytes have been mapped (Anchor 2015) by De Decker's (1989), Russell (2003) and Turpie and Clark (2007) (Figure 5.6). The Klein Estuary has a large open water channel comprising roughly half of the estuarine functional zone. During open mouth conditions, the estuary drains increasing the available habitat of sand/mud banks and rocky outcrops. Saltpans would have developed in low lying areas in the middle reaches. Salt marsh was abundant on the southern banks but less so on the northern bank as this bank was steeper and less suitable for establishment. *Salicornia meyeriana* was limited to a small patch south of the estuary mouth. Reeds and sedges, mainly the common reed, *Phragmites australis,* fringed the middle and upper reaches of the estuary where salinity was suitable for establishment. *Phragmites australis* was also abundant at the Klein River inlet. Several epiphytic microalgae and submerged macrophyte species also inhabited the estuary. These species are restricted to fringing areas where the water depth did not exceed 1.5 m. Summary data on the extent in the distribution of different macrophytes groups on the Klein Estuary is presented in Table 5.4 (Anchor 2015).

Table 6.4: Klein: Summary of important estuarine habitat

HABITAT TYPE	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES	AREA (2014) (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	741.6
Sand and mud banks	Intertidal zone consists of sand/mud banks that are regularly flooded by freshwater inflows. This habitat provides a possible area for microphytobenthos to inhabit. Saltpans located in the middle reaches of the estuary were Included in this habitat type.	79
Macroalgae	Marine algae*, Ectocarpus fasciculatus, Polysiphonia* sp., *Porphyra capensis* and *Ulva capensis* appear to be restricted to the rocky fringes on the southern bank in the mouth region.	Not visible Estimated 92
Submerged macrophytes	*Ruppia maritima, Stuckenia pectinata* and *Zostera capensis* are abundant in the shallow open water areas fringing the deeper channel. Although not clearly visible from aerial photographs the estimated cover is based on mapping from Turpie & Clark (2007). According to De Decker (1989) *Ruppia* favours the shallow, less saline areas of the middle and upper reaches, while *Zostera* occurs in the deeper more saline water of the middle and lower reaches near the mouth.	11 mapped Estimated 92
Salt marsh	Intertidal species include *Sarcocornia natalensis*, *Salicornia meyeriana, Cotula coronopifolia, Cotula filifolia, Triglochin bulbosum* and *Paspalum vaginatum*. *Limonium scabrum, Sporobolus virginicus, Plantago carnosa* and *Samolus porosus* were found in the upper intertidal zone whereas *Sarcocornia pillansii*, *Stenotaphrum secundatum* and *Opreum frutescens* were the dominant supratidal species.	170
Reeds and sedges	The following species have been recorded, and belong to the families Cyperaceae, Juncaceae & Poaceae: *Bolboschoenus maritimus*, *Cyperus laevigatus*, *Juncus acutus, J. kraussi, Phragmites australis* and *Schoenoeplectus triqueter.*	127
Floodplain	Agriculture and development have removed estuarine habitat from the estuarine functional zone. The remainder of the floodplain mapped in 2014 was a mixture of shrubland and grassy areas.	35 (transformed) 110 (disturbed) 280 (mostly intact)

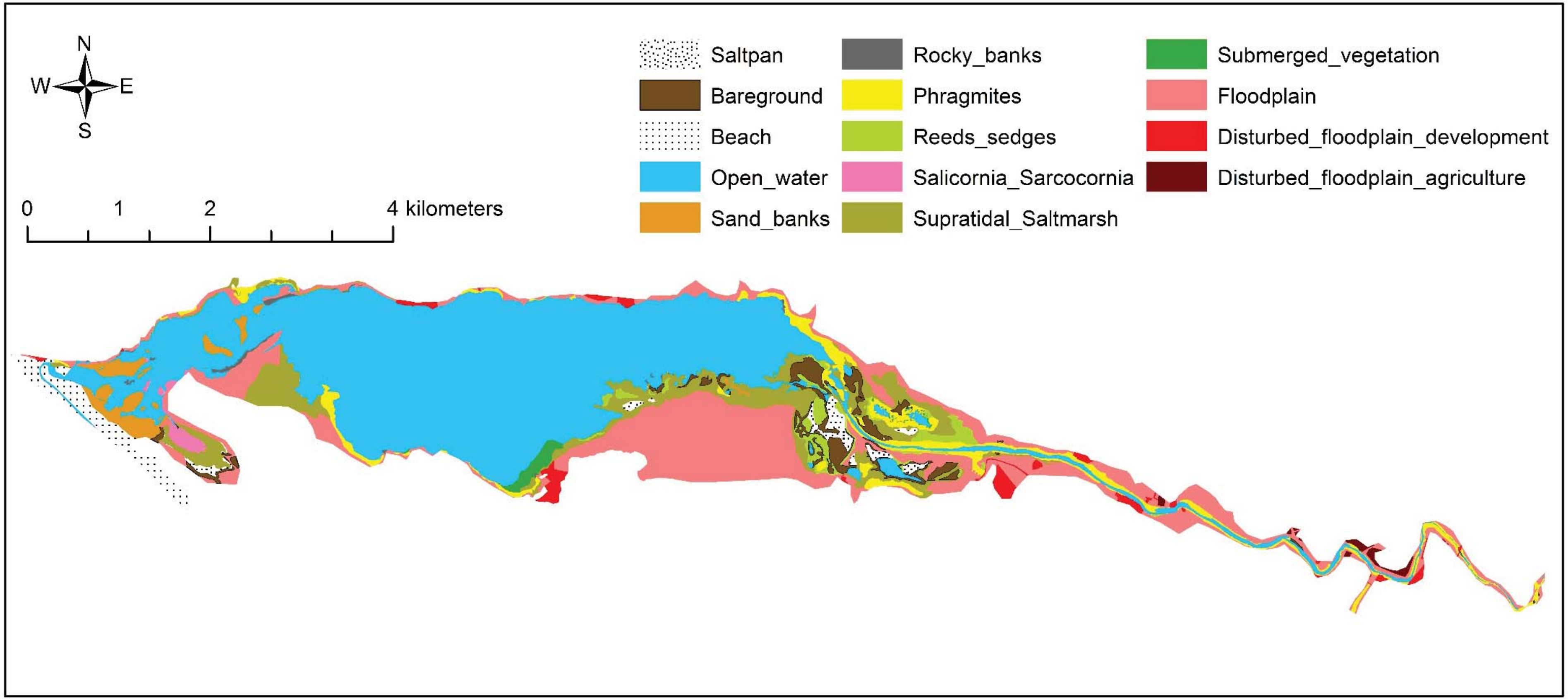

Figure 6.6 Klein: Macrophyte distribution map

Comparison of macrophyte abundance, species richness and community composition show that macrophyte cover (excluding macroalgae) was 1025 ha under the Reference condition but decreased to 826 ha in 2015 (Table 5.5). Species richness has declined due to a reduction in baseflow and an increase in salinity, as well as encroachment by development, disturbance and invasive species. Floodplain agriculture and development has removed 35 ha and disturbed some of the natural floodplain which occupies 390 ha. Invasive plants occupy approximately 10 ha of estuarine habitat. The distribution and abundance of salt marsh habitat have remained similar to Bornman's (2006) vegetation map of the Klein Estuary. Some open water has also developed into saltpans since 2006. This could create more barren bare ground thus reducing the habitat available for salt marsh. Visual comparison of aerial photographs from 1938 and 1980 suggest a similar macrophyte distribution to present, with the steeper north bank being sparsely vegetated and salt marsh dominant in the lower reaches on the south bank. Under natural conditions, the Klein Estuary would have received more river inflow and therefore experienced slightly lower salinity and more open mouth conditions. The water column would have been less turbid which would have favoured submerged macrophyte growth and zonation along the length of the estuary. Nutrient enrichment currently favours the increase of macroalgae that will shade and outcompete submerged macrophytes. Calm sheltered conditions during the closed mouth phase would also favour macroalgae growth, usually filamentous green algae. Although not mapped from aerial photographs invasive species may have displaced indigenous vegetation in the floodplain.

Table 6.5: Klein: Macrophyte habitat area and calculation of the similarity in community composition

MACROPHYTE HABITAT	REFERENCE AREA COVER (ha)	2015 AREA COVER (ha)
Salt marsh	220	169.7
Reeds & sedges	180	127.4
Submerged macrophytes	190	139
Macroalgae	40	92
Invasive plants	0	10
Floodplain	425	280 (disturbed 110 ha not included)

6.4.3 Fish

A total of 51 fish species from 27 families have been recorded from the Klein Estuary (Anchor 2015) (Table 5.6). Including all Category Ia, Ib, IIa & Va species, 23 (45%) of these are entirely dependent on estuaries to complete their lifecycle. Ten of these breeds in estuaries and include the estuarine round-herring *Gilchristella aestuaria*, Bot River klipvis *Clinus spatulatus*, Cape halfbeak *Hyporhamphus capensis*, Cape silverside *Atherina breviceps*, Knysna sand-goby *Psammogobius knysnaensis*, four *Caffrogobius* species, Cape halfbeak *Hyporhamphus capensis* and pipefish *Syngnathus temminckii*. Nine, including dusky kob *Argyrosomus japonicus*, white steenbras *Lithognathus lithognathus*, leervis *Lichia amia*, Cape moony *Monodactylus falciformis*, flathead mullet *Mugil cephalus*, freshwater mullet *Myxus capensis* and Cape stumpnose *Rhabdosargus holubi*, are dependent on estuaries as nursery areas for at least their first year of life. A further three, namely the catadromous African mottled eel *Anguilla bengalensis*, Madagascan mottled eel *A. marmorata* and longfin eel *A. mossambica* require estuaries as transit routes between the marine and freshwater environment. In addition, *Mugil cephalus* and *Myxus capensis* may be regarded as facultative catadromous species (Whitfield 1994). Another 10 (20%) species, e.g. harder *Liza richardsonii*, groovy mullet *Liza dumerilii*, elf *Pomatomus saltatrix* and white stumpnose *Rhabdosargus globiceps* are at least partially dependent on estuaries. In all, 65% of can be regarded as either partially or completely dependent on estuaries for their survival. Eleven of the remaining species are marine species, e.g. piggy *Pomadasys olivaceum* and wildeperd *Diplodus hottentotus*, which occur in, but are not dependent on estuaries; while seven, the indigenous Cape galaxias *Galaxias zebratus* and Cape kurper *Sandelia capensis* and introduced carp *Cyprinus carpio*, largemouth *M. salmoides*, smallmouth *M. dolomieu* and spotted bass *M. punctatus*, Mozambique tilapia *Oreochromis mossambicus* and banded tilapia *T. sparrmanii* are alien euryhaline freshwater species whose penetration into estuaries is determined by salinity tolerance.

In many respects, the composition of the Klein Estuary fish assemblage is identical to that of the Bot Estuary. Species that breed in estuaries and/or estuarine residents make up 20% of the Klein and Bot. Species that are entirely dependent on estuaries comprise 45% of the Klein Estuary fish fauna versus 46% for the Bot, a figure which is slightly lower than the 54% for all south-coast estuaries, but high compared to 26, 25, 22 and 21% for west, southwest, east and KwaZulu-Natal coasts respectively (Bennett 1994, Lamberth and Whitfield 1997, Harrison 1999). Partially estuarine dependent species comprise 20% of the Klein and Bot fish fauna, which is lower than the 29-40% for the west coast but within the 27-18% range for south-west, east and KwaZulu-Natal coast estuaries (Bennett 1994, Lamberth et al. 2008). Non-estuary-dependent marine species comprise a relatively low proportion (20%) of the fish species recorded in the Klein, and most, e.g. gurnard *Chelidonichthys capensis* and smooth houndshark *Mustelus,* can be construed as rare vagrants which seldom enter estuaries. Their occurrence in the temporarily open/closed Klein is largely a function of their chance proximity to the mouth when it was open.

Table 6.6: Klein: A list of all species (51) recorded in the system. The species are arranged according to family (27) and the five major categories of estuarine dependence as suggested by Whitfield 1994. **Anguilla bengalensis* & *A. marmorata* assumed to occur with *A. mossambica* in the catchment

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE CATEGORY
Osteichthyes			
Anabantidae	*Sandelia capensis*	Cape kurper	IV
Anguillidae	*Anguilla bengalensis*	African mottled eel*	Va
	Anguilla marmorata	Madagascar mottled eel*	Va
	Anguilla mossambica	Longfin eel	Va
Ariidae	*Galeichthyes feliceps*	Barbel	IIb
Atherinidae	*Atherina breviceps*	Cape silverside	Ib
Carangidae	*Lichia amia*	Leervis	IIa
Centrarchidae	*Lepomis macrochirus*	Bluegill sunfish	IV
	Micropterus punctatus	Spotted bass	IV
	Micropterus dolomieu	Smallmouth bass	IV
	Micropterus salmoides	Largemouth bass	IV
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV
	Tilapia sparrmanii	Banded tilapia	IV
Clinidae	*Clinus spatulatus*	Bot River klipvis	Ib
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	Ia
Elopidae	*Elops machnata*	Ladyfish	IIa
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV
Gobiidae	*Caffrogobius gilchristi*	Prison goby	Ib
	Caffrogobius natalensis	Baldy	Ib
	Caffrogobius nudiceps	Barehead goby	Ib
	Caffrogobius saldanha	Commafin goby	Ib
	Psammogobius knysnaensis	Knysna sand-goby	Ia/Ib
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
	Pomadasys olivaceum	Piggy	III
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc
	Hyporhamphus capensis	Cape halfbeak	Ib
Lobotidae	*Lobotes surinamensis*	Tripletail	III
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mugilidae	*Liza dumerilii*	Groovy mullet	IIb
	Liza richardsonii	Harder	IIc
	Liza tricuspidens	Striped mullet	IIb
	Mugil cephalus	Springer mullet	IIa/Vb
	Myxus capensis	Freshwater mullet	IIa/Vb
Ophiichthidae	*Ophisurus serpens*	Sand snake-eel	III

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE CATEGORY
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa
	Atractoscion aequidens	Geelbek	III
Soleidae	*Heteromycteris capensis*	Cape sole	IIb
	Solea turbynei	Blackhand sole	IIb
Sparidae	*Diplodus hottentotus*	Wildeperd / zebra	III
	Diplodus capensis	Blacktail / dassie	IIc
	Lithognathus lithognathus	White steenbras	IIa
	Rhabdosargus globiceps	White stumpnose	IIc
	Rhabdosargus holubi	Cape Stumpnose	IIa
	Sarpa salpa	Strepie	III
	Spondyliosoma emarginatum	Steentjie	III
Syngnathidae	*Syngnathus temminckii*	Pipefish	Ib
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III
Osteichthyes			
Triakidae	*Mustelus mustelus*	Smooth houndshark	III
Rhinobatidae	*Acroteriobatus annulatus*	Lesser sandshark /guitarfish	III

Based on their distributional ranges given by Smith and Heemstra (1986), 26 (51%) of the fish recorded in the Klein Estuary are southern African endemics including the Botriver klipvis *Clinus spatulatus* which has an extremely limited range being confined to the Klein and Kleinmond/Bot systems.

Gillnet sampling is usually targeted at the adults and sub-adults of the larger fish species whereas seine-nets are aimed at catching juveniles and the smaller fish species. A total of 232 222 fish representing 31 species from 16 families were caught in 269 seine hauls in the Klein Estuary from 2000 to 2015 (Anchor 2015). A further 3 730 fish representing 18 species from 11 families were caught in 68 (7 X 30 m panels) gillnet sets during the same period. Numerically, the seine catches at 863 fish/haul compare poorly with those in the Bot at 1 918 fish.haul^{-1} over the same time period. Gillnet catches were not significantly different with 55 fish/set versus 58 fish/set in the Klein and Bot respectively. Estuarine resident breeders *Atherina breviceps* (46%) and *G. aestuaria* (28%) dominated seine catches numerically followed by *Liza richardsonii* (10%) and *Psammogobius knysnaensis* (8%) that were also important. Of the remainder, only *C. spatulatus*, *Caffrogobius* and *S. temminckii* contributed more than 1% to the total catch. Gillnet catches of large estuary-dependent fish, e.g. *L. lithognathus* were very low or absent, e.g. *A. japonicus* probably slightly due to more prolonged mouth closure but most likely due to high illegal gillnet effort in the present day. Relatively low gillnet catches of adult Mugillidae in the estuary are also indicative of high gillnet effort.

There has also been a substantial increase in the number of freshwater fish mostly due to the introduction of alien species and to lower salinities arising from prolonged periods of mouth closure. Despite this, the fish assemblage of the Klein is very similar to the Bot and typical of that of temporarily open/closed estuaries, being dominated numerically by estuary-breeders and subject to highly variable recruitment by estuary-dependent marine species. This said, survival of the latter has been severely compromised by illegal netting and, despite some years of good recruitment, their contribution to the fish assemblage remains low. Overall, reduced recruitment, alien fish and illegal netting have reduced abundance to about 60% of reference, a figure that would be lower were it not for the buffering of the numerically dominant estuary breeders.

Resident estuary-breeders, whether they are livebearers (e.g. *C. spatulatus*) or release eggs, (e.g. *G. aestuaria*), reproduce throughout the year with peaks in the spring and summer. Breeding also tends to be concentrated in the dry season to prevent eggs and larvae from being flushed out to sea. Flushing may also be countered by spawning at the head of the estuary and in the freshwater reaches (e.g. *G. aestuaria*) or by producing adhesive eggs (e.g. *A. breviceps*). Estuary-residence and year-round breeding maintain fairly constant biomass and availability to piscivorous predators throughout the year. The peak spawning and recruitment period for obligate estuary-dependent marine species (e.g. *L. lithognathus*) is spring to early summer and, under natural conditions, coincides with higher flow and mouth-opening in the Klein, Bot and other estuaries in the southwestern Cape. Partially estuary-dependent fish (e.g. *L. richardsonii*), peak in early summer but will recruit opportunistically throughout the year through overwash events. If breaching occurs, adults leaving the system may become reproductively active and contribute to another spawning peak in the sea in late summer.

Catadromous (glass) eels enter the Klein (and other systems) mainly in summer, at night on high spring tides, under strong river flow and when the mouth is open. It is not known whether the recruitment of the three eel species is synchronous or varies according to their spawning localities, times and duration of larval stages in the pelagic environment. Upstream migration of elvers is enhanced by high flow and inundated marginal areas. Adult return migration to the sea (8-20 years later) is cued and facilitated by floods and high flow. Physiological and morphological changes in migrating adults silver eels mean that migration is irreversible once it commences, even if conditions deteriorate.

As stated before, the Klein, together with the Bot, account for 25-30% of the available estuarine fish nursery-area from Cape Point to Port Alfred. It is crucial that at least one of these two estuaries is open to the sea during the spring/early summer recruitment window each year. Except for some drought years, the Klein usually opened annually under natural conditions. In the past decade, however, drought, wastewater spills and eutrophication have seen that system and its fish under severe stress from hypoxia and high-water temperatures, with mass mortalities occurring. The Bot, which has opened during this time period, would have provided some level of mitigation by allowing recruitment of juvenile fish and larvae and the export of adult fish to recruit into the marine fisheries. The latter function was probably negated by the high illicit gillnet catches in both the Klein and Bot estuaries, however. Connectivity between the Klein and Bot is highlighted by the fact that *Clinus spatulatus* only occurs in these two systems and nowhere else. This can be at least partly explained by its life-history characteristics but also by the fact that fish recruitment into Walker Bay and its estuaries is limited compared to other bays in South Africa, mostly due to its relative isolation and currents bypassing the bay, deflecting further out to sea. Connectivity between these two estuaries occurs during regional flood events usually coinciding with cutoff-lows when both systems are open and connected via their fluvial plumes (von der Heyden *et al.* 2015).

6.5 Present Health Condition

The density of development around the Klein Estuary is generally low, except for the nodal urban areas of Hermanus and Stanford and some resorts (Whitehead et al., 2007). The Klein estuary is used extensively for recreational purposes and is reported to have high local, regional and even international value (Whitehead et al. 2007). It is a popular venue for sailing, canoeing, kite surfing. Other activities in and around the estuary include hiking, horse riding, birding, swimming, fishing, boating (motor and oars), water-skiing, jetskiing (permit only), and windsurfing. Commercial users within the EFZ include riverboat cruises that operate from Stanford (Whitehead et al. 2007). In the area surrounding the estuary, commercial enterprises include those based on tourism and agriculture. Poaching of marine organisms in the Overstrand area, particularly the use of illegal gill nets to trap fish in the Klein and Bot River estuaries, has received a lot of media attention in recent decades. Some effort has been made to control poaching, but anecdotal evidence suggests that this has met with little success. Other activities that have been highlighted as being of concern on the Klein estuary includes dumping and leaching of sewage from inadequate, badly located or neglected septic tanks, littering; pollution through runoff (fertilisers, pesticides); erection of structures below the 1:50 year flood line and/or the high water mark; clearing of riparian vegetation for development, agricultural livestock grazing and trampling; road, riparian and instream infrastructure, and alien vegetation in the supra-tidal zone. The Klein is in a moderately degraded state. Table 5.7 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 6.7: Klein: Ecological heath condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Significant reduction in base flows.		●				
Hydrodynamics	Artificially breached periodically to prevent flooding of low-lying developments. Mouth location (breaching position) often moved. Sedimentation in the entrance channel is constricting the tide and contributing to premature closures.			●			
Salinity	Salinity ranges from nearly fresh to hypersaline (<40) (when have been open for long periods). Hypersalinity conditions in the upper reaches are on the increase due to reduced freshwater inflow.	●					
General Water Quality	Nutrient enrichment from Stanford Wastewater Treatment Works and agricultural activities in catchments. Low oxygen events have been recorded throughout the estuary.				●		
Physical habitat	Some harding of riparian banks in some areas. Habitat loss due to infilling. Low lying developments in floodplain. Sedimentation caused by artificial breaching at very low levels in the past.			●			
Microalgae	Microalgae blooms have been detected in the system due to enrichment.			●			
Macrophytes	Loss of riparian vegetation due to urban development. Some reed growth due to increased retention and enrichment.			●			
Invertebrates	Some change in community composition and biomass, with largely estuarine species at present in the system. Reduce recruitment opportunities due to increased closed mouth conditions.			●			
Fish	Change in community composition, i.e. loss of freshwater and marine species. Reduce recruitment opportunities. Significant reduction in abundance due to overfishing (gill netting). Pathogens and diseases due to poor water quality and/or microalgae blooms. Alien fish.				●		
Birds	Significant reduction in bird abundance due to human disturbance, fewer prey species and loss of habitat.					●	
ESTUARY HEALTH	**MODERATELY DEGRADED with a downwards trajectory. However, functionality is relatively intact and opportunities for rehabilitation exist.**			⊙			

7. HEUNINGNES

7.1 General Features

The Heuningnes Estuarine Lake (Figure 6.1) system is located south of Bredasdorp and west of Arniston in the Overberg region of the Western Cape in South Africa. The river and lower estuary fall within the Agulhas Plain, an area that contains one of the largest lowland fynbos and Renosterveld habitats within the Cape Floral Region. Heuningnes Lake System is fed by two major tributaries, namely the Nuwejaars and Kars Rivers. The catchment of the Heuningnes has been given as 1 938 km² (Bickerton 1984). The catchment of the Heuningnes is characterised by hilly slopes in the upper reaches of the catchment and a very flat coastal plain in the lower reaches. The Mean Annual Runoff (MAR) was estimated at 42.6 million m^3/a in the 2017 EWR study (Anchor 2017).

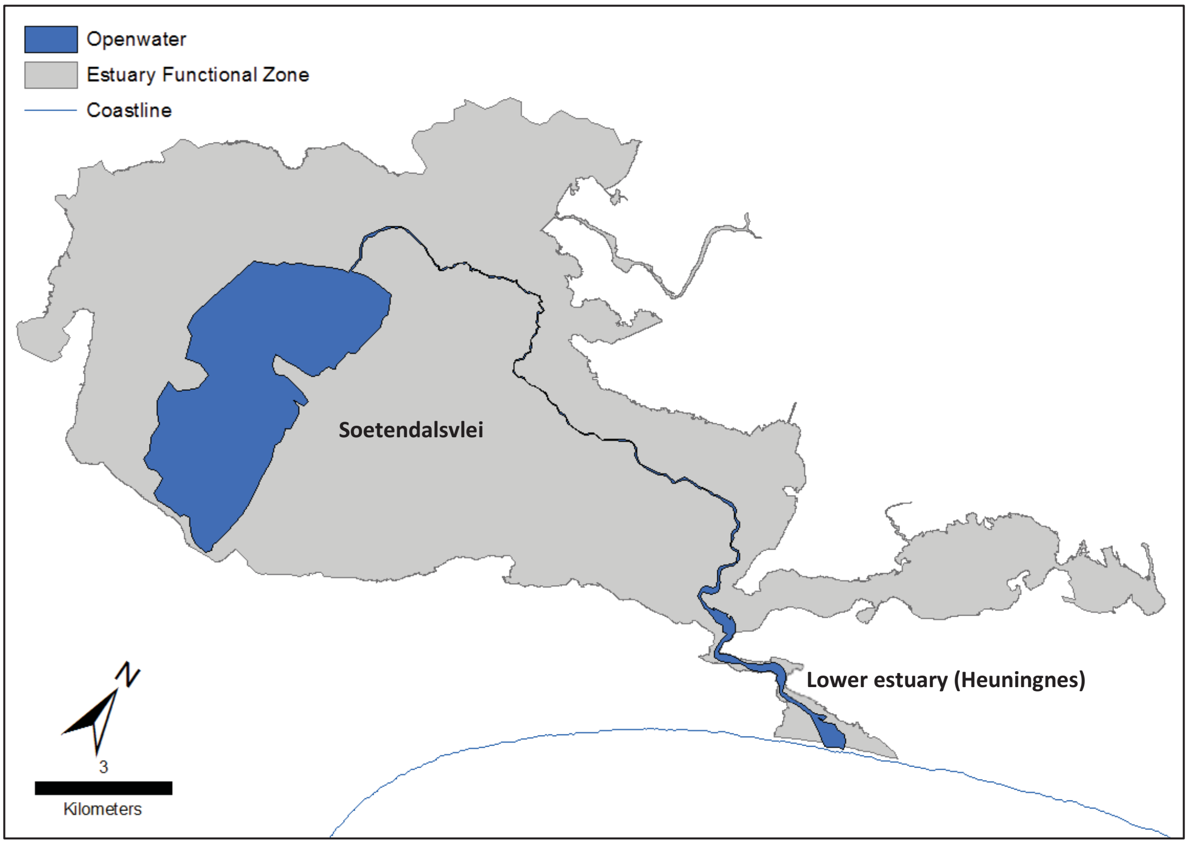

Figure 7.1 Heuningnes: EFZ and openwater area

The lower estuary (called Heuningnes Estuary) has been recorded as being tidal as far up as 12 km upstream of the mouth, although the majority of the tidal influence is within the first 2 km. There are two major natural wetlands in the catchment, namely, Voëlvlei and Soetendalsvlei. Soetendalsvlei is within the EFZ of the lake system, and while not tidal, increases and decreases in water level occur depending on the mouth state of the system. Soetendalsvlei, comprising the lake area within this system, is approximately 8 km along its north/south axis and 3 km wide at the middle.

The Heuningnes has been used by man for centuries (Bickerton 1984). In the recent past, the mouth of the Heuningnes remained open for the most part due to the artificially stabilized sand dunes at the mouth (since 1942). Under more natural conditions this dune system would have been dynamic, and the natural movement of sand would have resulted in more frequent mouth closure and the resultant upstream backflooding. In addition to the influence of dune stabilisation, the mouth of the system has been kept open artificially by manual breaching since 1942, except for a 3-year period between 1973 and 1976 and a more recent closure in the last decade. CapeNature used to keep the mouth open as part of their management strategy but this practice have been discontinued in recent years leading to an increase in mouth closure.

7.2 Zonation and Abiotic States

The Heuningnes Estuarine Lake system can be divided into four zones (Figure 6.2) based on tidal exchange, bathymetry and salinity regime (Anchor 2017):

- Lower tidal estuary section divided into:
  - Zone A: Lower
  - Zone B: Middle
  - Zone C: Upper
- Zone D: Soetendalsvlei.

Figure 7.2 Heuningnes: Zonation

Table 6.1 summarises key features of the various zones (Anchor 2017).

Table 7.1: Heuningnes: Key features of zones

PARAMETER	ZONE A	ZONE B	ZONE C	ZONE D
Area (ha) under open conditions	50	20	50	750
Depth (m) when open	1.5	1.0	2.0	2.0-3.0

Four abiotic states identified for the Heuningnes (Anchor 2017): State 1: Open, Marine, State 2: Open, Gradient, State 3: Open, Fluvial, State 4: Closed. Hydrodynamic characteristics for each state are summarised in Table 6.2.

Table 7.2: Heuningnes: Abiotic states

PARAMETER	STATE 1: OPEN, MARINE	STATE 2: OPEN, GRADIENT	STATE 3: OPEN, FLUVIAL	STATE 4: CLOSED
River inflow (m^3/s)	0-0.2	0.2-5	>5	-
Mouth condition	Open	Open	Open	Closed
Inundation/water levels	None	None	None	Reference: + 5 m MSL Present: +2 m MSL
Tidal range	0.8-0.5 m	0.8-0.5 m	1.0-0.6 m	None
Dominant circulation process	Tidal & Wind	Tidal & Fluvial	Fluvial & Tidal	Wind
Retention	Weeks	Weeks	Days	Months

7.3 Abiotic Response Indicators

Changes in river inflow and artificial manipulation of the mouth have resulted in changes in the mouth condition, water level, salinity distribution, and water quality in the Heuningnes. These effects are described in more detail below.

7.3.1 Mouth dynamics and water levels

While little information is available on the mouth dynamics of the Heuningnes under the Reference condition, simulated river inflow data, the lower estuary bathymetry and present mouth behaviour, all paint a picture of intermitted closures occurring decades apart (Anchor 2017). However, because of the flat topography of the area, inundation would have resulted in a very large open water area that would have taken anything from 2 to 10 years to fill up, given variable inflow, seepage and evaporative losses. When full, this significant body of water would have resulted in extremely high outflow velocities, which in turn would have resulted in a deep basin in the lower reaches and enhanced tidal flows that would have assisted in keeping the mouth open for decades after a breaching. In addition, the mouth position would have shifted depending on the lowest lying point in the frontal dune system, adding additional variability to this complex interaction between river flow, tidal exchange, and sediment processes.

Under its current state, the mouth of the lower system has been artificially manipulated since the early 1940s. This was initially undertaken by the then Department of Forestry and more recently by CapeNature. The rationale behind the practice of keeping the mouth permanently open was to prevent backflooding of riparian properties. The concern was that flooding would result in damage to structures and loss of land under crops due to a combination of prolonged inundation and elevated salinity levels due to the accumulation of salt in the soil.

The mouth has closed on only a few occasions since the 1940s (Anchor 2017). On one occasion, it was closed for a three-year period between 1973 and 1976 but was eventually manually breached when the system started to fill after good rains. There also seems to have been an attempt to breach the system in 1974. The last time the mouth closed was in August 2007, but it was again manually breached on 24 September 2007 after rains threatened to flood the riparian areas. From the 2007 water level record, it is clear that the system started closing earlier in the year as indicated by the low tide levels of February 2007 that shows very constricted levels for about a week (Figure 6.3). The practice of actively stabilizing dunes on either side of the mouth and erecting barriers to trap longshore wind-blown sand was stopped in 2012 pending further studies (Anchor 2017).

At present, like 2007, the mouth would be breached as per the long-standing arrangement with the riparian owners until the Estuary Mouth Management Plan dictates differently. A maximum flood level of 2 m MSL was given as the limit by landowners at a meeting with them on 12 October 2016. They indicated that any rise in water levels above this would flood a portion of their cultivated and grazing lands leading to crop and livestock losses. However, judging by photographic evidence, hard infrastructure is still about a metre above this level. It should also be noted that a high spring tide is >2 m MSL.

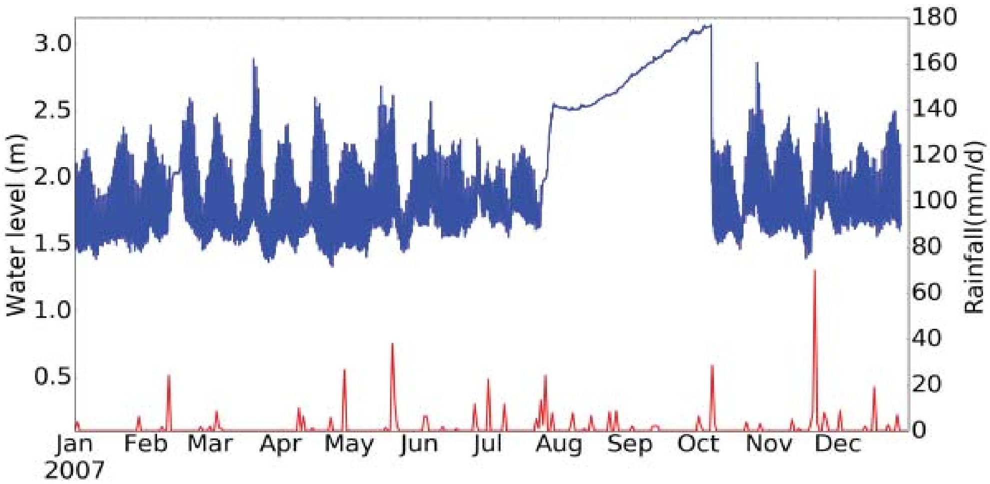

Figure 7.3 Water level recorder showing the closed mouth condition between Aug and Sep 2017

In addition to mouth closure there are a few obstructions to flow in the Heuningnes Estuarine Lake:

- There is a low-lying drift/causeway with several pipe culverts across the channel just downstream of Soetendalsvlei. The drift is overtopped during high water levels and floods. It does, however, restrict the free movement of water and especially the intrusion of saline water into Soetendalsvlei.
- The Bredasdorp/Struisbaai bridge is situated about 12 km from the mouth. Both its pylons and support base and the remnants of the historical drift used before 1943 cause some restriction to flow.
- A suspension footbridge transvers the lower estuary at the De Mond CapeNature Reserve about 1.5 km from the mouth.
- About 1.3 km from the mouth is the rubble remnants of the old causeway that allowed vehicle access to the southern bank. Most of it has been removed, but some rubble and concrete blocks are still visible at very low tides.

Water level data from the DWS station G5T002 for the period 2000 to 2015 (Figure 6.4) show several interesting features (Anchor 2017):

- Water levels in the Heuningnes are sensitive to large scale oceanic events such as sea storms and equinox tides, with very high levels being observed in October 2001, May 2002 and July 2009.
- The breaching level of September 2007 was only about 10 cm higher than some of the higher tides when the mouth was open, i.e. there was no significant increase above the normal flooding levels at this time.
- A smaller closure of a few days can be observed in February/March 2007, before the mouth closure occurs between August and September 2007.
- The April 2005 flood scoured the lower estuary by 20 to 30 cm, with low tide water levels only starting to creep up after the winter of 2005.
- The lowest low tides are observed during neap tides in this system and not spring tides as is the norm in the sea. This is because the mouth acts as a constraint with more water entering the system on a spring high tide than can leave on the spring low tide, resulting in a build-up of water level in the lower estuary. During the neap tides, the entire system drains during each ebb tide, resulting in lower low tides during this period.

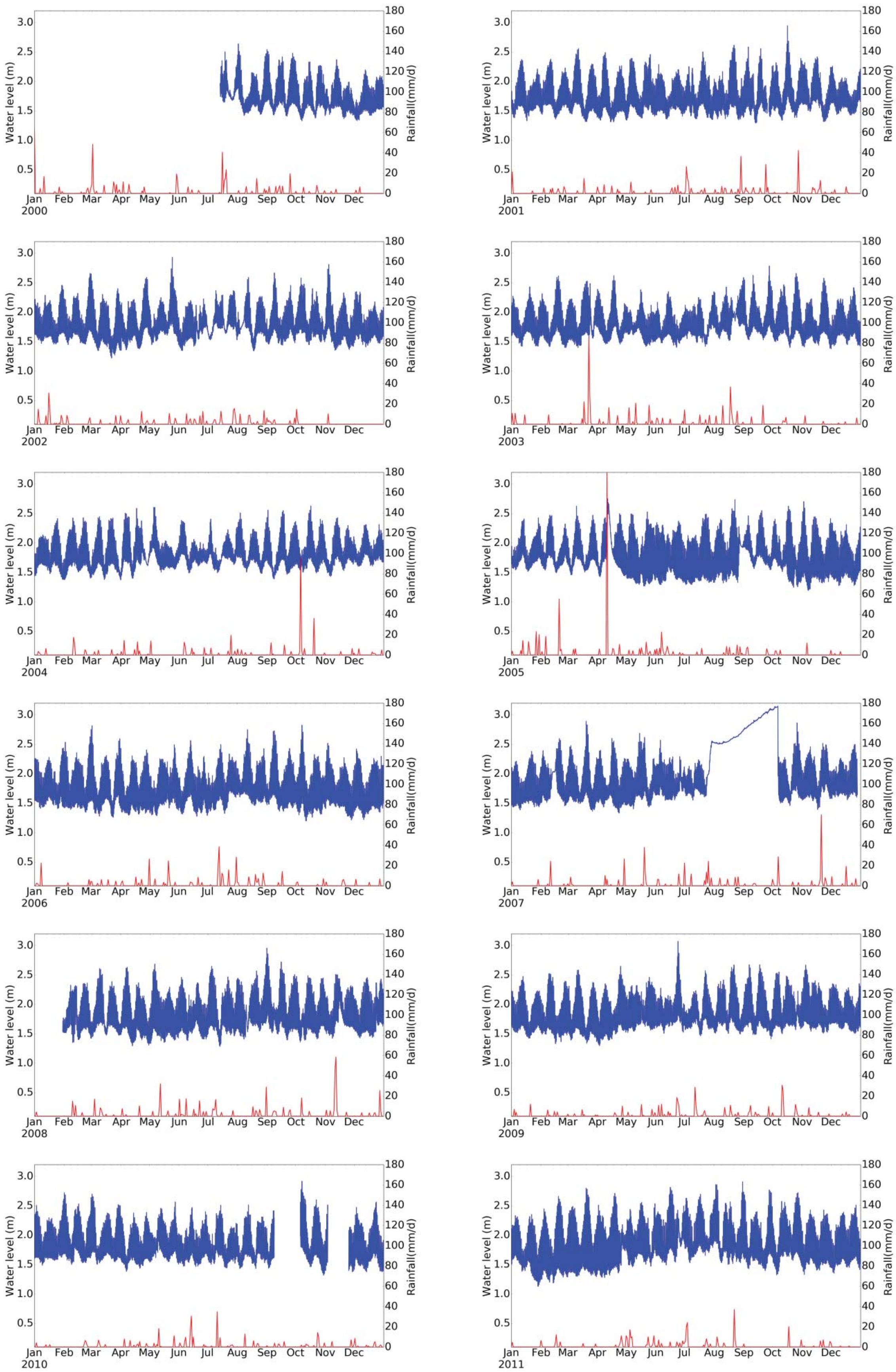

Figure 7.4 Heuningnes: Water level (G5T002) and flow (G5H002) data for period 2000 to 2011

Water level data for the lower estuary shows a clear spring-neap cycle, caused by the dominant semi-diurnal tide (Van der Ende 2015). The system shows a significant decrease in tidal range, from the mouth to upstream. De Mond shows a tidal range of 1.0 to 0.7 m, while 15.5 km upstream the tidal range is only about 0.30 m. At positions 5 km, 7.5 km, 12 km the tidal range is very similar and only about 10 to 20 cm less than at De Mond.

7.3.2 Salinity

Wind mixing plays a key role in this system in the wide exposed areas of the system, which results in a well-mixed water column (Bickerton 1984). Large parts of the upper reaches of the lower estuary and Soetendalsvlei are bordered by 1 m high reeds, which are present year-round. This protects the system from major influences of the wind. However, when wind speed becomes relatively high, the wind influence becomes significant in even the more sheltered areas resulting in a well-mixed system throughout (Anchor 2017).

A limited number of data sets exist that provide insight into the salinity regime of the Heuningnes. During the period of mouth closure (1973 to 1976) when there was minimal run-off from the catchment, hypersaline conditions were reported in the lower estuary with salinities reaching as high as 55 in March 1974. Salinities were slightly reduced to 40 in the winter months of 1973 and 1974, presumably by winter rainfall and run-off. However, note that these salinities were calculated and may well be overstating the extent of hypersalinity. Measurements conducted in September 1997 (Figure 6.5) show the salinity profile of the lower estuary under fluvial dominated conditions, with salinity varying between 35 and 3 in the lower reaches and fresh in the rest of the system (Anchor 2017).

Observation made during December 2008 (Figure 6.6) show the influence of elevated flows in the lower (3-13) and middle (0-3) reaches. The February 2017 (Figure 6.7) observations are representative of extended periods of very low flows, with a salinity of 35 in the lower reaches, between 35 and 33 in the middle reaches and 30 and 24 in the upper reaches to the Bredasdorp-Struisbaai bridge. Under the closed condition of September 2007 (Figure 6.8) salinity varied between 15 and 5 at elevated water levels.

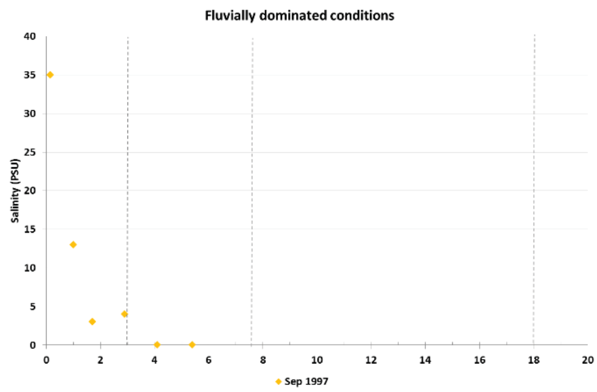

Figure 7.5 **Heuningnes: Salinity regime in the lower estuary under Open Fluvial State (Sep 1997)**

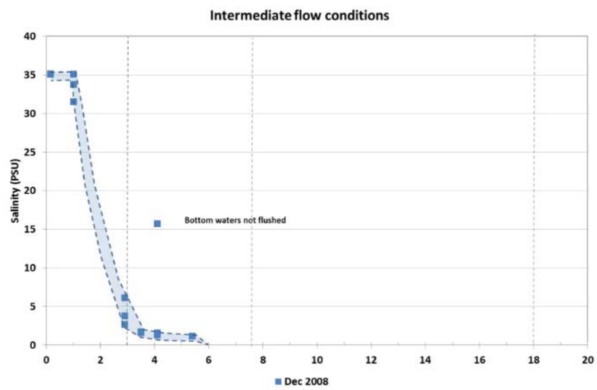

Figure 7.6 **Heuningnes: Salinity regime in the lower estuary under Open Gradient State (Dec 2008)**

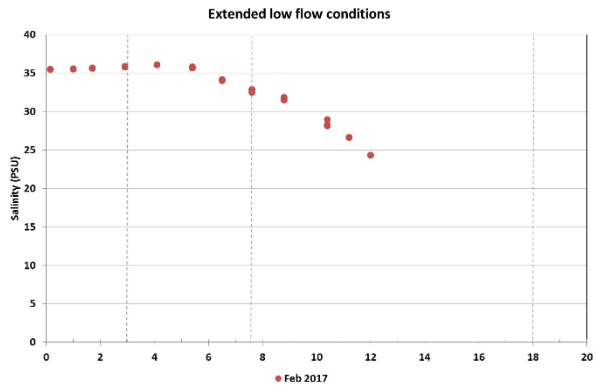

Figure 7.7 Heuningnes: Salinity regime in the lower estuary under Open Marine State (Feb 2017 after extended period of low flows)

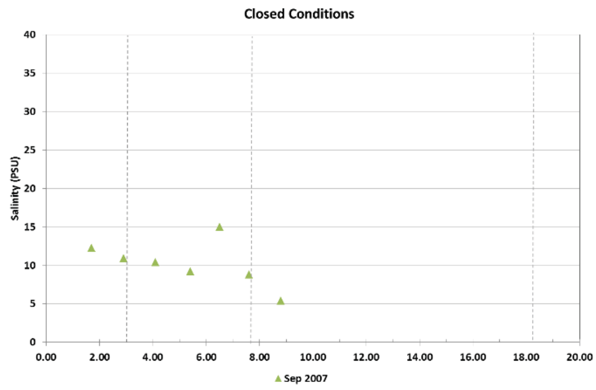

Figure 7.8 Heuningnes: Salinity regime in the lower estuary under Closed State (Sep 2007)

A modelling study showed that the top of the lower estuary is very sensitive to flows ranging between 0.0 to 0.2 m^2/s. For example, during a short simulation, the 5-salinity zone extends from 8 to 12 km upstream as flow decreases in this band (Van der Ende 2015). The results show a clear spring-neap cycle, with a decrease in the absolute and amplitude of salinity is visible when moving upstream. At 15.5 km the salinity variation between spring and neap is almost negligible. Another interesting observation is that the upper reaches show a clear increasing trend, at 15.5 km starting at 1.6 in early December and ending up at 10 in late January. In the lower reaches, salinity oscillated between 30 and 15, while the middle reaches fluctuated been 10 and 25 over the same period.

7.3.3 Temperature

Gordon (2012) showed clear seasonal trends in water temperature in both the lower estuary and the lake (Soetendalsvlei), with typical summer temperature averaging between 18 and 26°C and winter temperature between 12 and 15°C. Recorded pH levels in Soetendalsvlei remained alkaline (between 8 and 9), which is expected considering the geology of the catchment. Overall, pH levels throughout the system were also slightly alkaline, which is not unexpected given the alkaline river inflow and pH levels of seawater being around 8.2 (Gordon 2012; unpublished data, S Lamberth, DAFF; data collected during a field survey for this study in Feb 2017) (Anchor 2017).

7.4 Biological Response Indicators

7.4.1 Microalgae

Information on the microalgae of the Heuningnes, including the wetlands is from Gordon (2012) and Gordon et al. (2011). These studies assessed microalgal biomass and community composition in 2007. Low phytoplankton chlorophyll *a* concentration (<10 µg/ℓ) were measured during the study. However, the large stands of emergent macrophytes (i.e. *Phragmites australis* and *Schoenoplectus scirpoides*) present along the lower estuary may overshadow the increase in nutrient concentrations because of their high nutrient uptake rates. Throughout the study in 2007 the system was well oxygenated. The highest phytoplankton biomass was measured in August (3.5 ± 0.8 µg/ℓ), but there were no differences seasonally. Chlorophytes were dominant during summer and euglenophytes during the autumn/winter period (i.e. closed mouth conditions with high freshwater inflow and reduced tidal exchange). Diatom abundance was greater during summer and maybe of marine origin transported into the system by the strong tidal exchange. Shifts in the phytoplankton community structure in August indicate the importance of freshwater inflow and flushing in maintaining water quality. Five main microalgal groups were identified: diatoms (Bacillariophyceae), dinoflagellates (Dinophyceae), euglenoids (Euglenophyceae), cyanobacteria (Cyanophyceae) and chlorophytes (green microalgae, Chlorophyceae). For all the wetlands, except Soetendalsvlei South, euglenophytes and diatoms co-occurred within the phytoplankton community. In Voëlvlei cyanobacteria were the dominant microalgal group and were replaced by chlorophytes in August 2007. The dominance of chlorophytes was likely due to their small size (high surface area: volume ratio) enabling them to rapidly consume and utilise nutrients within the water column. Chlorophytes also prefer cooler water temperatures and thus favour the high rainfall events associated with winter. Phytoplankton biomass was lowest during winter as the high rainfall and river inflow could dilute chlorophyll *a* concentrations in the wetlands (Gordon, et al. 2011).

Extensive agricultural activities in the catchment have increased inorganic nutrient loading in river inflow, which would increase microalgal biomass. However, the build-up of biomass is possibly also dependent on water residence time. Permanently open mouth conditions have resulted in a more saline tidal system leading to a small change in microalgal species richness and community composition. A change from flagellates, which are motile, to diatoms that favour the turbulent conditions, has occurred (Gordon et al. 2011). Fresher microalgal species and groups would be dominant in Soetendalsvlei but not in the lower estuary. Under natural conditions, when back flooding occurred, the lake would have received some saline water during closed conditions so that when overflow occurred at the end of the rainfall season the salinity in the lake would have been higher than present and the water flowing into the lower estuary would have had a more similar composition and concentration of phytoplankton.

Studies on the surrounding wetland systems indicate that Voëlvlei is eutrophic. The dominance of cyanobacteria (*Anabaena* and *Trichomes* sp.) within Voëlvlei indicates poor water quality that could potentially result in harmful algal blooms (Janse van Vuuren et al., 2007). This is due to increased water residency caused by its unique hydrology, i.e. reverse flow from the Nuwejaars River via its outflow channel during flood periods. High internal nutrient loading from the sediments could also result in the dominance of cyanobacteria during the summer periods when reduced freshwater inflow occurs. Strong winds maintain cells in the photic zone resulting in maximum productivity (Gordon, 2012). The very low phytoplankton biomass recorded at Waskraalsvlei by Gordon (2012) is attributed to the presence of reeds and submerged macrophytes. Expansion of reeds between the north and south sections of Soetendalsvlei has reduced connectivity and open water surface area.

7.4.2 Macrophytes

The dominant macrophyte habitats in the Heuningnes part of the estuarine lakes system are seagrass and salt marsh. Reeds and sedges also occur but are abundant in Soetendalsvlei. Figure 6.9 shows mapped areas for the lower estuary for 2007 to 2014 (excluding Soetendalsvlei). Different areas were mapped and therefore direct comparisons cannot be made particularly because the water level was higher in the 2014 images. Figure 6.10 indicate changes in estuarine vegetation in Soetendalsvlei from 1938 to 2007 (Anchor 2017).

Table 6.3 provides detail on the mapped habitats and areas covered. Large areas of salt marsh (*Limonium*, *Salicornia* and *Sarcocornia* spp.) occur near the mouth and in the middle reaches of the lower estuary, while stands of reeds and sedges (*Phragmites australis* and *Schoenoplectus scirpoides)* line the water channel in the upper reaches. The salt marshes near the mouth are cut off by levees and are only inundated during extreme high tides. Before the artificial management of the mouth, the lower estuary dammed up behind the barrier dune creating a lateral lagoon (Bickerton 1984). Supratidal salt marsh consists of *Sarcocornia pillansii* and *Chrysanthemoides incana*. Fringing reeds in the upper reaches of the lower estuary likely play an important role in nutrient uptake from agricultural inputs. Heydorn and Grindley (1984) reported the submerged macrophyte *Ruppia* 3 km from the mouth of the Heuningnes. It has subsequently been replaced by the seagrass *Zostera capensis*; a clear indication of the increase in saline, tidal conditions. The site visit in February 2017 indicated an expansion of the *Zostera capensis* beds in the lower reaches. They were also heavily epiphytized which indicates calm still water conditions. These seagrass beds will increase in cover when the mouth is restricted, and flow velocities are reduced. However, the next large flood will likely remove these beds.

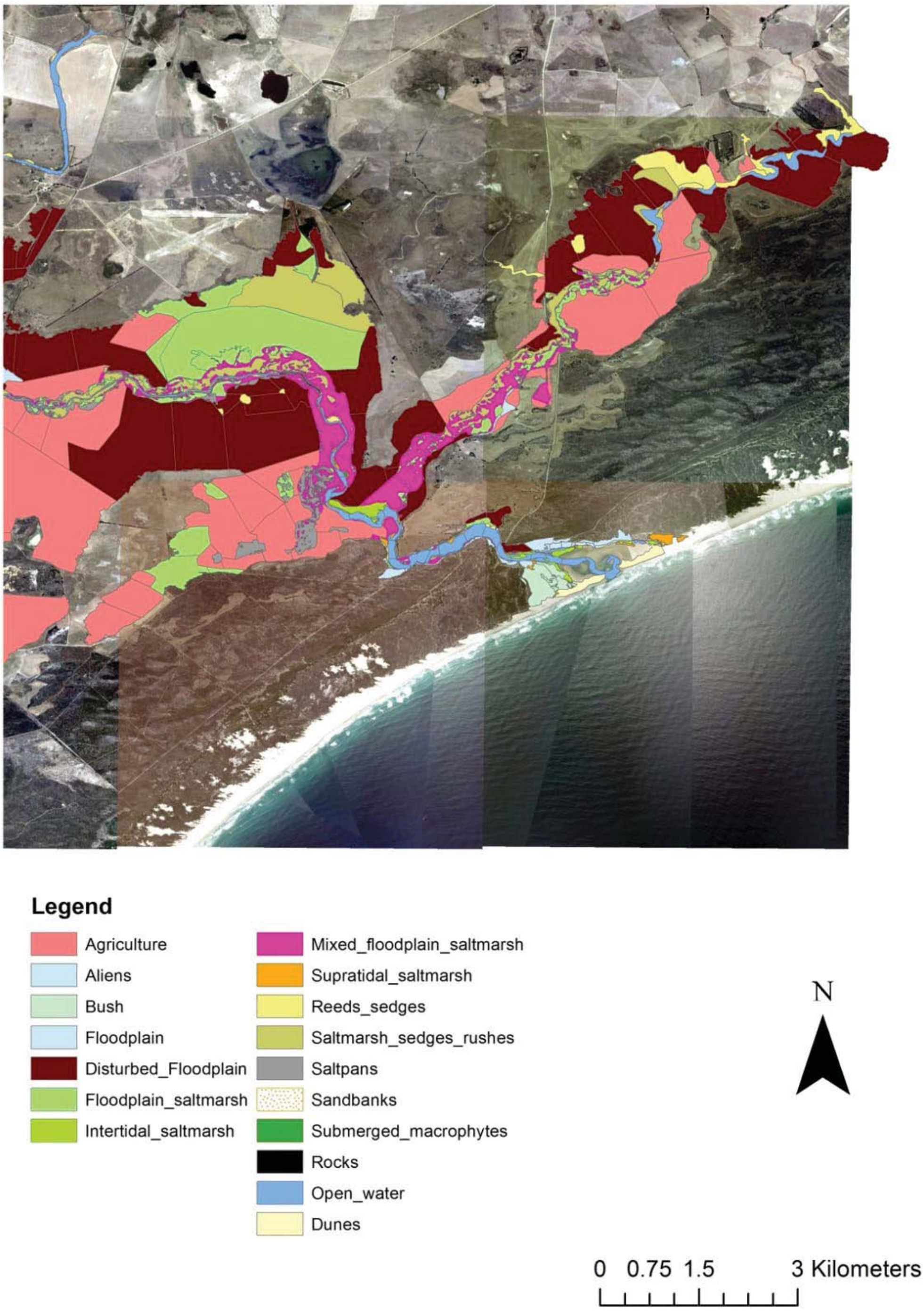

Figure 7.9 Heuningnes: Distribution of the macrophyte habitats excluding Soetendalsvlei

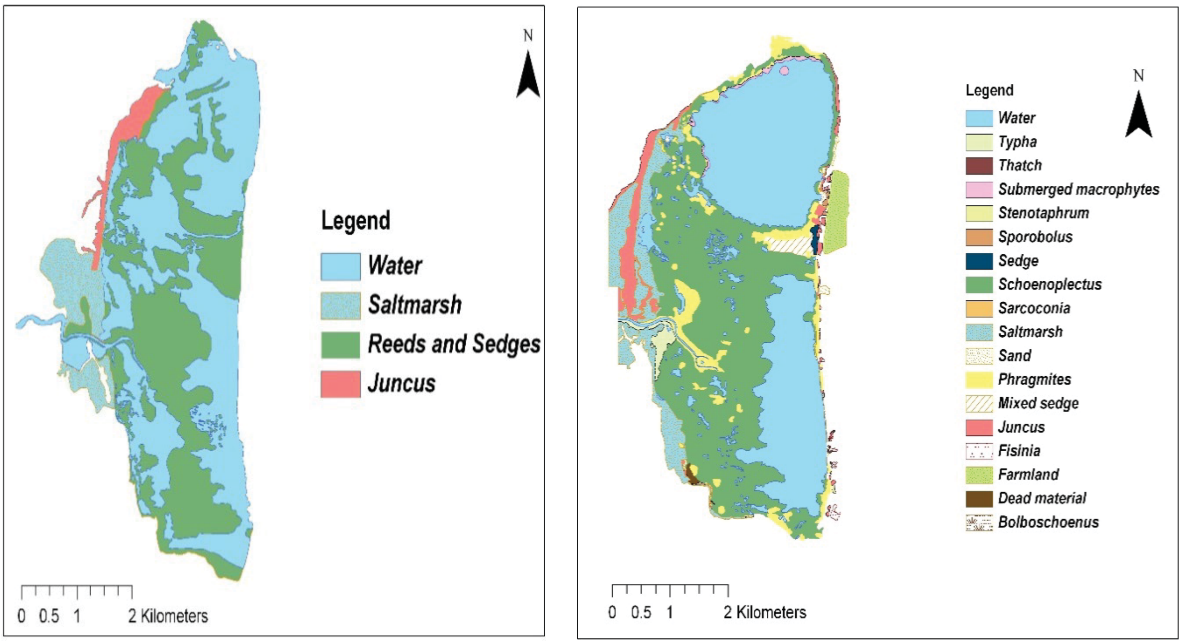

Figure 7.10 Heuningnes: Change vegetation of Soetendalsvlei between 1938 (left) and 2007 (right) (Kotsedi 2007)

Historically the lower estuary was connected to Soetendalsvlei. The latter now consists of a large reed bed of *Phragmites australis* and *Schoenoplectus scirpoides* that separates the vlei into a northern and southern sections. Reed growth is restricted to the western shore due to high winds that blow throughout the year in the region (Gordon 2012). Kotsedi (2007) recorded 45 plant species at Soetendalsvlei mostly from the family Poaceae and Cyperaceae. The submerged macrophyte *Stuckenia pectinata* (pondweed) was present in 2007 (Figure 6.10). Supratidal salt marsh of *Sarcocornia pillansii* and *Bassia diffusia* surrounds the wetland and is inundated under high rainfall events.

Table 7.3: Heuningnes: Estuarine habitat EFZ (entire system)

HABITAT TYPE	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES	AREA (ha)
Open surface water area	Serves as habitat for phytoplankton	907.92
Sand and mudflats	Sand/mud banks provide a possible area for microphytobenthos to inhabit	43.35
Submerged macrophytes	*Zostera capensis* in the lower estuary and *Stuckenia pectinata* in Soetendalsvlei.	10.17
Reeds and sedges	Patches of common rush *Phragmites australis* and *Schoenoplectus scirpoides* fringe the lower estuary and dense beds surround the vlei. Bulrush *Typha capensis* is also present	1154.98
Intertidal salt marsh	*Sarcocornia tegetaria* at lower elevations, followed by *Sarcocornia decumbens*, *Bassia diffusa* and *Suaeda maritima*, with *Limonium scabrum* at the upper elevation	16.18
Supratidal salt marsh	Supratidal salt marsh consists of *Sarcocornia pillansii* and *Chrysanthemoides incana*. Includes the dry elevated saline floodplain habitats	942.4

A summary of the relative changes in macrophytes in the Heuningnes system from 2007 and 2014 is presented in Table 6.4. There has been a significant transformation in the supratidal and floodplain habitat as a result of agricultural development, drainage canals, causeways/weirs and road crossings. Approximately 80% of the total vegetated area in the EFZ consists of agriculture and disturbed floodplain (3214.32 ha of 3999.48 ha). The Estuary Management Plan (EMP) suggested the establishment of a 100 m buffer around the estuary to help minimise the impacts of surrounding agriculture (Anchor 2017). Closed mouth conditions and back flooding due to high water levels may have increased salinity in the supratidal zone leading to bare areas because of salt accumulation. The subtidal habitat is like the reference condition except for the lower reaches where marine sediment has accumulated due to the open mouth and reduced river inflow.

Table 7.4: Heuningnes: Habitat changes between 2007 and 2014 in the lower estuary

HABITAT	2007 (ha)	2014 (ha)	COMMENT
Mobile dunes	71.3	13.85	Different mapping area
Exotic vegetation	6.78	8.38	
Rocky shores	0.44	0	Water level high and rocks not visible
Submerged macrophytes	27.18	0.76	Water level high and submerged not visible
Floodplain salt marsh mosaic	186.02	369.15	Larger lateral area mapped
Reeds and sedges	7.67	83.8	Larger lateral area mapped
Salt marsh sedges, rushes	89.09	219.98	Larger lateral area mapped
Sarcocornia salt marsh	68.37	16.17	Decreased due to higher water level
Intertidal salt marsh	5.53	Included in above	
Supratidal salt marsh	38.59	37.18	Unchanged by water level
Saltpans	46.31	47.16	
Estuarine water	52.98	241.6	Higher water level and larger area mapped
Sandbanks	42.61	33.85	
Agriculture	Not mapped	2114.18	
Bush	Not mapped	27.85	
Floodplain	Not mapped	30.27	
Disturbed floodplain	Not mapped	1100.14	
TOTAL	**642.87**	**4344.32**	

State 1 (marine, tidal, Table 6.2) has increased from reference conditions to the present favouring the growth and spread of salt marsh and the seagrass *Zostera capensis*. However, in Soetendalsvlei there has been a decrease in salinity due to lower water levels and culverts preventing the input of salt. As a result of this and input of nutrients from the surrounding agricultural activities, reeds and sedges have increased in cover reducing the open water surface area. This changed from 837.8 ha in 1938 to 666.3 in 2007 (Anchor 2017). There has been a 10% increase in the vegetated area, which consists mainly of reeds, rushes, and sedges (881 ha in 1938 compared with 1048 ha in 2007 – Kotsedi 2007).

Other impacts include some grazing and trampling in the area surrounding Soetendalsvlei as cattle use the lake for drinking (Gordon 2012). Attempts to access the Heuningnes mouth and beach for recreational fishing resulted in the trampling of salt marsh in the lower estuary near the mouth. Alien invasive plant infestation of *Acacia cyclops* and *Acacia saligna* has taken place in certain portions of the system (HilLand Associates, 2009). However, there has been active removal and according to the De Mond Nature Reserve Complex Protected Area Management Plan 2014-2019 less than 1% of the De Mond and Waenhuiskrans Reserves is invaded. Kikuyu grass *Pennisetum clandestinum* grows around the offices and houses. *Lavatera arborea*, *Leptospermum laevigatum and Ammophila arenaria* occur in the larger reserve area (Hoekstra and Waller, 2014). Palmiet (*Prionium serratum*), a dominant perennial wetland sedge has been reduced over wide areas in the catchment areas due to overgrazing, trampling and bank erosion.

7.4.3 Fish

Bickerton (1984) reports on several fish surveys as well as journal records from the Heuningnes River catchment most in Soetendalsvlei and some in the lower estuary from 1937 to 1984. No quantitative data were available from those times. The first available quantitative information is from a once-off seine and gillnet survey in 1994 (Harrison 1999). Lamberth (In litt) has since established a recreational angler catch-card system in 1995 that is still active. Angler-effort collected is complemented and able to be validated by the CapeNature De Mond gate permit records kept over the same time period. Hutchings & Lamberth (2003) conducted quarterly seine and gillnet surveys in the

Heuningnes and in Soetendalsvlei from 1997-1999 and these have been repeated every four years from then until 2017 (Anchor 2017).

In total, 72 species of fish from 34 families have been recorded from the lake system, including the surf-zone adjacent to the mouth (Anchor 2017) (Table 6.5). Resident fish that breed only in estuaries (Category Ia) comprise four species – estuarine round herring *Gilchristella aestuaria*, Cape halfbeak *Hyporamphus capensis*, kappie blenny *Omobranchus woodii* and the yet to be confirmed but unlikely Knysna seahorse *Hippocampus capensis*. Fish that breed in the marine and estuarine environments (Category Ib), e.g. estuarine pipefish *Syngnathus temminckii* and prison goby *Caffrogobius gilchristi*, were represented by seven species. Obligate estuary-dependent fish that have to spend at least the first year of life in estuaries (IIa), e.g. dusky kob *Argyrosomus japonicus* and white steenbras *Lithognathus lithognatus*, contributed 10 species whereas partially estuary-dependent (IIb), e.g. blackhand sole *Solea turbynei* and marine opportunists that use the best of both worlds (IIc), e.g. harder *Liza richardsonii* provided six and seven species, respectively.

Table 7.5: Heuningnes: List of all fish families and species recorded and classified into five major categories of estuarine-dependence as suggested by Whitfield (1994) (marked with an asterisk *commonly caught in adjacent surf-zone but not recorded in the estuary)

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE CATEGORY	COMMENT
Osteichthyes				
Anabantidae	*Sandelia capensis*	Cape kurper	IV	Endangered
Anguillidae	*Anguilla mossambica*	Longfin eel	Va	CITES II proposed
	Anguilla bengalensis	African mottled eel	Va	CITES II proposed
	Anguilla marmorata	Madagascar mottled eel	Va	CITES II proposed
Ariidae	*Galeichthyes feliceps*	Barbel	IIb	
Atherinidae	*Atherina breviceps*	Cape silverside	Ib	
Blenniidae	*Omobranchus banditus*	Bandit blenny	III	
	Omobranchus woodi	Kappie blenny	Ia	
Carangidae	*Lichia amia*	Leervis	IIa	Optimally exploited
	Seriola lalandii	Yellowtail	III	Optimally exploited
Centrarchidae	*Lepomis macrochirus*	Bluegill sunfish	IV	Alien introduction
	Micropterus dolomieu	Smallmouth bass	IV	Alien introduction
	Micropterus punctulatus	Smallmouth bass	IV	Alien introduction
	Micropterus salmoides	Largemouth bass	IV	Alien introduction
Clinidae	*Clinus superciliosus*	Super klipvis	Ib	
Clupeidae	*Gilchristella aestuaria*	Estuarine round herring	Ia	
	Sardinops sagax	Pilchard	III	
Cyprinidae	*Cyprinus carpio*	Carp	IV	Alien species
	Pseudobarbus burchelli	Burchell's redfin	IV	Critically endangered lineage
Dichistiidae	*Dichistius capensis*	Galjoen*	III	Overexploited
Engraulidae	*Engraulis capensis*	Cape anchovy	III	
Elopidae	*Elops machnata*	Ladyfish / springer	IIa	Optimally exploited
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV	Species complex
Gobiidae	*Caffrogobius gilchristi*	Prison goby	Ib	
	Caffrogobius natalensis	Baldy	Ib	
	Caffrogobius nudiceps	Barehead goby	Ib	
	Psammogobius knysnaensis	Knysna sandgoby	Ib	
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa	Overexploited
	Pomadasys olivaceum	Piggy	III	
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc	
	Hyporamphus capensis	Cape halfbeak	Ia	Vulnerable
Monodactylidae	*Monodactylus argenteus*	Natal moony	IIb	
	Monodactylus falciformis	Cape moony	IIa	
Mugilidae	*Liza dumerili*	Groovy mullet	IIb	
	Liza macrolepis	Largescale mullet	IIa	
	Liza richardsonii	Harder	IIc	Overexploited
	Liza tricuspidens	Striped mullet	IIb	

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE CATEGORY	COMMENT
	Mugil cephalus	Flathead mullet	IIa	
	Myxus capensis	Freshwater mullet	Vb	Vulnerable
	Valamugil buchanani	Bluetail mullet	IIc	
Ophichthidae	*Ophisurus serpens*	Sand snake-eel	III	
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc	Overexploited
Sciaenidae	*Argyrosomus inodorus*	Silver kob*	III	Collapsed
	Argyrosomus japonicus	Dusky kob	IIa	Collapsed
	Umbrina ronchus	Slender baardman*	III	Overexploited
Soleidae	*Heteromycterus capensis*	Cape sole	IIb	
	Solea turbynei	Blackhand sole	IIb	
Sparidae	*Diplodus cervinus*	Wildeperd	III	Overexploited
	Diplodus sargus	Dassie	IIc	Overexploited
	Lithognathus lithognathus	White steenbras	IIa	Collapsed
	Lithognathus mormyrus	Sand steenbras	III	
	Rhabdosargus globiceps	White stumpnose	IIc	Overexploited
	Rhabdosargus holubi	Cape Stumpnose	IIa	Optimally exploited
	Sarpa salpa	Strepie	IIc	Optimally exploited
	Sparodon durbanensis	White musselcracker	III	Overexploited
	Spondyliosoma emarginatum	Steentjie	III	Optimally exploited
Syngnathidae	*Hippocampus capensis*	Knysna seahorse	Ia	Needs confirmation?
	Hippocampus histrix	Thorny seahorse	III	Rare summer vagrant
	Syngnathus temminckii	Pipefish	Ib	Vulnerable
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III	
	Pelagocephalus marki	Rippled blaasop	III	
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III	
Chondrichthyes				
Carcharhinidae	*Carcharhinus leucas*	Zambezi shark	IIa	IUCN near threatened
Dasyatidae	*Dasyatis chrysonota*	Blue stingray	III	
	Gymnura natalensis	Butterfly ray	III	
Myliobatidae	*Myliobatis aquila*	Bullray	III	
	Pteromylaeus bovinus	Duckbill ray	III	
Odontaspidae	*Carcharius taurus*	Ragged-tooth shark	III	IUCN vulnerable
Rhinobatidae	*Acroteriobatus annulatus*	Lesser guitarfish	III	
Sphyrnidae	*Sphyrna zygaena*	Smooth hammerhead*	III	Overexploited
Triakidae	*Mustelus mustelus*	Smooth houndshark	III	Overexploited
	Triakis megalopterus	Spotted gully-shark*	III	Overexploited

Marine vagrants (III), e.g. lesser guitarfish *Acroteriobatus annulatus* reflected the predominantly open estuary mouth with a relatively high 26 species. Freshwater fish (IV) comprised eight species but only three were indigenous, e.g. *Galaxias zebratus*, the rest introduced or translocated, e.g. bass *Micropterus* spp. Three catadromous eels Anguillidae (V) have also been recorded from the Heuningnes catchment and recruited via the estuary. Altogether, including Ia estuarine residents, obligate-dependents and catadromous fish, 17 (24%) of the Heuningnes fish assemblage are completely dependent on estuaries to complete their life-cycle, 20 (28%) are partially estuary-dependent and the remainder split between estuary-independent marine (36%) and freshwater (11%) species. The proportion of estuary-associated fish in the Heuningnes Estuary fish assemblage is relatively low compared to the Breede, Gouritz and other south-coast estuaries but is an artefact of the high contribution of marine vagrants there. Absolute values of estuary-associated fish either match or exceed all adjacent and nearby systems on the south coast.

Of the Heuningnes fish assemblage, 10 (14%), e.g. *Hyporamphus capensis* and 21 (33%), e.g. *L. lithognathus* are South African and southern African endemics respectively. Five (7%), e.g. *Cyprinus carpio* are introduced alien or translocated species. The remaining 34 (47%), e.g. *Lichia amia*, are cosmopolitan. The high degree of endemism is typical of Cape south coast systems.

Seine samples provide the best estimates of small and juvenile fish density and comprise 80 small-mesh seine-net hauls from 1998 to the present day. Numerically*,* *G. aestuaria* (52%) and *L. richardsonii* (25%) dominate the Heuningnes fish assemblage, providing 77% of sampled catches. *Rhabdosargus holubi* (5%), *Caffrogobius spp*. (5%), *Psammogobius knysnaensis* (4%) and 2% each of *Liza dumerili*, *Rhabdosargus globiceps*, *Atherina breviceps* and *Heteromycterus capensis* were also important. The remaining species all contributed <1% to the catch. However, these species, e.g. dusky kob *Argyrosomus japonicus,* spotted grunter *Pomadasys commersonnii* and leervis *Lichia amia* are large exploited species of naturally lower abundance and occurrence and more prevalent in larger mesh gillnet samples and recreational angler catches. *L. richardsonii* occurred in 90% of hauls, *G. aestuaria* and *P. knysnaensis* occurred in over 60% and *R. holubi, S. bleekeri and L. lithoganathus* in >40% of sample hauls. Catches and occurrence of juvenile *L. lithognathus* were relatively high compared to those in the Breede and other estuaries in the region and when considering its overexploited status.

Along-stream distribution of fishes was largely a reflection of salinity preferences and the estuary dependence category to which the fish belonged (Table 6.6). Numerically, 60% of Ia resident breeders, Ib marine & estuarine breeders and IIa obligate estuary-dependent fish (e.g. *G. aestuaria*, *Caffrogobius* spp. and *Myxus capensis* respectively) were in the <10 REI zone, including Soetendalsvlei. High densities (34%) of obligate estuary-dependent fish specifically *P. commersonii* and *L. lithognathus* also occurred in the sandy, clear >30 lower reaches. Densities of IIb partially estuary-dependent fish, e.g. *S. turbynei* and IIc marine opportunists, e.g. *L .richardsonii* were also highest (~60%) in the lower reaches. All (100%) of IV freshwater and V catadromous fish were in the <10 river-estuary interface (REI) zone as surprisingly were most (>50%) category III marine vagrants. Overall, densities of all estuary-dependence categories were lower in the 10-30 salinity zones or middle reaches of the estuary. Ia Resident breeders, e.g. *G. aestuaria* dominated catches (60-85%) in the <10 REI and 10-20 zones, respectively, and shared dominance with category III marine opportunists in the 20-30 reaches (Table 6.7). Marine opportunists (55%) dominated the >30 lower reaches.

Table 7.6: Heuningnes: Distribution of estuary-dependence categories in four salinity ranges

DEPENDENCE CATEGORY		SALINITY			
		>30	20-30	10-20	<10
Ia	Resident breeders	14	11	14	61
Ib	Marine & estuarine breeders	16	19	5	60
IIa	Obligate dependents	34	5	1	60
IIb	Partial dependents	66	6	1	27
IIc	Marine opportunists	58	14	2	27
III	Marine vagrants	19	11	19	52
IV	Freshwater				100
V	Catadromous				100

The persistence of Ia resident breeders and IIa obligate dependents in the upper reaches even when salinity exceeded 20 at the head of the estuary for long periods, suggests a system with a greater freshwater influence historically compared to the often marine-dominated state of the present day. It also suggests that Soetendalsvlei plays a large part in maintaining these REI species in the system even when disconnected during low-flow periods. This said, species richness overall and within each estuary-dependence category was uniform throughout most of the estuary with 21-22 species in the lower >20 and upper <10 reaches. The exception was the 11-20 zone which had only 13 species. This may, however, be an artefact of low dissolved oxygen levels in some years. Marine vagrants increased species richness in all, not just the lower reaches.

Table 7.7: Heuningnes: Numerical contribution (%) of estuary-dependence categories in four salinity ranges

DEPENDENCE CATEGORY		SALINITY >30	20-30	10-20	<10
Ia	Resident breeders	26	45	85	62
Ib	Marine & estuarine breeders	7	18	8	15
IIa	Obligate dependents	7	2	1	7
IIb	Partial dependents	5	1	<1	1
IIc	Marine opportunists	55	34	6	14
III	Marine vagrants	<1	<1	<1	<1
IV	Freshwater	0	0	0	1
V	Catadromous				<1

Seasonally, absolute species richness was highest in spring and summer (23-30 species) and lowest in autumn and winter (12-15 species). Yet, sample or catch species diversity was highest in autumn and lowest in summer with 2.4 species per haul and 0.83 species per haul, respectively. Only 10 species, all category I residents and category II estuary-associated fish, occurred in the estuary in all seasons throughout the year. Absolute species richness was fairly uniform at 21-22 species over the four sampling periods, the exception being 13 species in 2007 during an extended period of mouth closure.

Overall seine catch-per-unit-effort (CPUE) in the Heuningnes has doubled from 354 fish/haul in the period 1997-1999 to 714 fish/haul in 2017. Most of this happened despite declines in catches of several species which were nullified by 2-100-fold increases in CPUE of harder *L. richardsonii*, groovy mullet *L. dumerili*, leervis *L. amia* and Cape stumpnose *R. holubi*. Declines in CPUE occurred with 12 species including spotted grunter *Pomadasys commersonii* and flathead mullet *Mugil cephalus*, whereas the numerically dominant fish in the system *G. aestuaria* remained relatively stable over the whole time period. Similarly, the occurrence of *G. aestuaria*, *L. richardsonii*, *P. commersonii*, *M. falciformis*, *G. feliceps* and *A. japonicus* remained stable, that of *S. turbynei*, *L. lithognathus, L. dumerili and L. amia* increased substantially, whereas *P. knysnaensis* and *Heteromycterus capensis* declined over the same period. During mouth closure in 2007, the occurrence of all except *G. aestuaria*, *L. dumerili* and *A. breviceps* declined, some to zero.

Angler catches became more diverse with an additional 10 species added to catches from 2000 to the present day. Seven of these were sharks and rays, which were caught on few occasions and in low numbers, and mostly reflected an apparent increase in anglers fishing in the surf-zone immediately adjacent to the estuary mouth. In reality, this is an artefact of the off-road vehicle legislation and an increase in anglers now accessing the beach via the De Mond Reserve gate under the added proviso of reporting their catches. With two exceptions, these being the two most targeted species – spotted grunter *P. commersonii* and dusky kob *A. japonicas* – angler catch composition remained unchanged between the 1995-2000 and 2011-2017 periods. *Pomadasys commersonii* catches halved from 44-28%, whereas *A. japonicus* quadrupled from 5-22%. The increase in the proportion *of A. japonicus* is more a function of the drop in *P. commersonii* than a surge in the numbers caught. The decline in *P. commersonii* contrasts with the newly established breeding population, and increase in numbers and catches along the Cape south coast.

Peaks in larval and juvenile recruitment, emigration of adults and movement of fish between estuaries are often associated with high flow or flood events. In the lower estuary, high water levels inundate marginal areas and re-establish connectivity between the lower estuary, Soetendalsvlei and tributaries, allowing juveniles of fish such as moony *M. falciformis* and freshwater mullet *Myxus capensis* to recruit upstream, and for landlocked adults to find their way back to the sea. Size distributions and age-length keys of these fish suggest that many of these fish remain in Soetendalsvlei for 8-10 years and that both recruitment and emigration are linked with 1:10 year flood events. These event-years are often associated with a second late-summer/autumn (as opposed to spring/early summer) spawning peak of *L. richardsonii* in the sea, assumedly due to the emigrants becoming reproductively active once they've left the system.

Recruitment and emigration of catadromous eels *Anguilla* spp. are also strongly linked to flow. Juvenile glass eels recruit into natal estuaries and catchments following olfactory cues which they can detect at dilutions >109 in the sea. Most recruitment takes place over dark-moon spring tides, probably a predator avoidance behaviour. They quickly metamorphose into elvers but can retard their own growth, making it easier to move over obstacles on their way upstream. Depending on the species, adult eels can spend 8-30 years in freshwater before returning to the sea. Return migration is cued by the first winter spates, whereupon adults move downstream gradually transforming into silver eels, their eyes growing bigger and gut atrophying. Once in the sea, they travel at depth to their abyssal spawning grounds which for southern African (and West Indian Ocean) eels seems to be east of Madagascar, where they spawn and die. All the Anguillidae are very susceptible to poor water quality including that which inhibits olfactory location of natal streams.

The Heuningnes spotted grunter *Pomadasys commersonii* population is one of the first to become established in the southern Cape and are the same fish caught in the occasional “grunter runs” in Struisbaai Harbour so spread throughout 10 km of the bay. Data on movements of the Heuningnes *P. commersonii* are limited. Of 45 tagged in the Heuningnes under the ORI Tagging Programme in the 20 years up to 2015, none were recaptured. Dusky kob *A. japonicus* were slightly better, with 34 tagged, four recaptured, two in the Heuningnes and two elsewhere at unknown localities. One *A. japonicus* tagged at Koppie Alleen in the De Hoop MPA was recaptured in the Heuningnes 79 days later, verifying links between the estuary and MPA.

7.5 Present Health Condition

Extensive agricultural activities in the catchment have increased inorganic nutrient loading in river inflow. Extensive areas of low lying land around the estuary have been drained and transformed for crops and grazing. Recreational fishing (shore angling) is popular on the lower estuary and is having a moderate impact on stocks of exploited species in the system. However, illegal fishing (net and line) is having a significant impact on linefish species such as kob, grunter, leervis and white steenbras in the system. Bait collecting is not permitted on the estuary. The invasive bivalve, *Mytilus galloprovincialis* and polychaete *Ficopomatus enigmaticus* are present in the system. Alien fish species that have been introduced to the Heuningnes catchment include carp *Cyprinus carpio*, and small mouth bass *Micropterus dolomieu*. These fish compete with and predate on indigenous fish species that use the system and are affecting populations of the indigenous species. There is a limited disturbance of water birds on the system by recreational anglers.

The Heuningnes is important from a biodiversity perspective and a conservation priority (Turpie and Clark 2007, Van Niekerk et al. 2019). The lower estuary is managed by CapeNature as a provincial nature reserve (De Mond Nature Reserve). While the Agulhas National Park, proclaimed in 1998, also manages a section of Soetendalsvlei. The Heuningnes lower reaches is a proclaimed a Ramsar site.

The Heuningnes Estuarine Lake system is in a moderately to heavily degraded state. Table 6.8 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 7.8: Heuningnes: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Significant reduction in flows.			●			
Hydrodynamics	Historically artificially kept open. Current when the mouth closes it is artificially breached at low water levels to prevent flooding of surrounding farmland. Sedimentation in the entrance channel is constricting the tide. Closed mouth conditions do not occur anymore for significant periods. Reduce connectivity with Soetendalsvlei as a result of lower water levels.				●		
Salinity	Salinity on the increase in the estuary reduces the brackish gradient. Hypersalinity conditions in the upper reaches of the estuary are on the increase due to reduced freshwater inflow. Lower water levels prevent the mixing of saline water into Soetendalsvlei.				●		
General Water Quality	Nutrient enrichment from agricultural activities in catchments.			●			
Physical habitat	Sedimentation caused by artificially keeping the mouth open and now breaching at very low levels. Habitat loss due to infilling (e.g. old causeway) and agriculture in floodplain. Low lying developments in the floodplain.			●			
Microalgae	Microalgae blooms have been detected in the system due to enrichment.			●			
Macrophytes	Significant loss of riparian vegetation due to agriculture. Some reed growth in Soetendalsvlei due to increased retention and enrichment.				●		
Invertebrates	Some change in community composition and biomass, with an increase in marine species and a loss of freshwater species.				●		
Fish	Change in community composition, i.e. loss of freshwater and brackish species. Reduction in abundance due to overfishing.				●		
Birds	Some reduction in bird abundance due to human disturbance, reduction of prey species and loss of habitat.			●			
ESTUARY HEALTH	**MODERATELY TO HEAVILY DEGRADED with a downwards trajectory. However, functionality is relatively intact and opportunities for rehabilitation exist.**			◉			

8. TOUW/WILDERNESS

8.1 General Features

The Touw/Wilderness system (Figure 7.1) comprises a series of three coastal lakes (Eilandvlei, Langvlei and Rondevlei) interconnected by shallow channels and a temporarily open/closed estuarine section (Touw Estuary). Although the Touw shows strong longitudinal gradients in physico-chemical characteristics, the Wilderness Lakes are more uniform. Variability in the Touw is seasonal whereas that in the lakes is more inter-annual (DWS 2014).

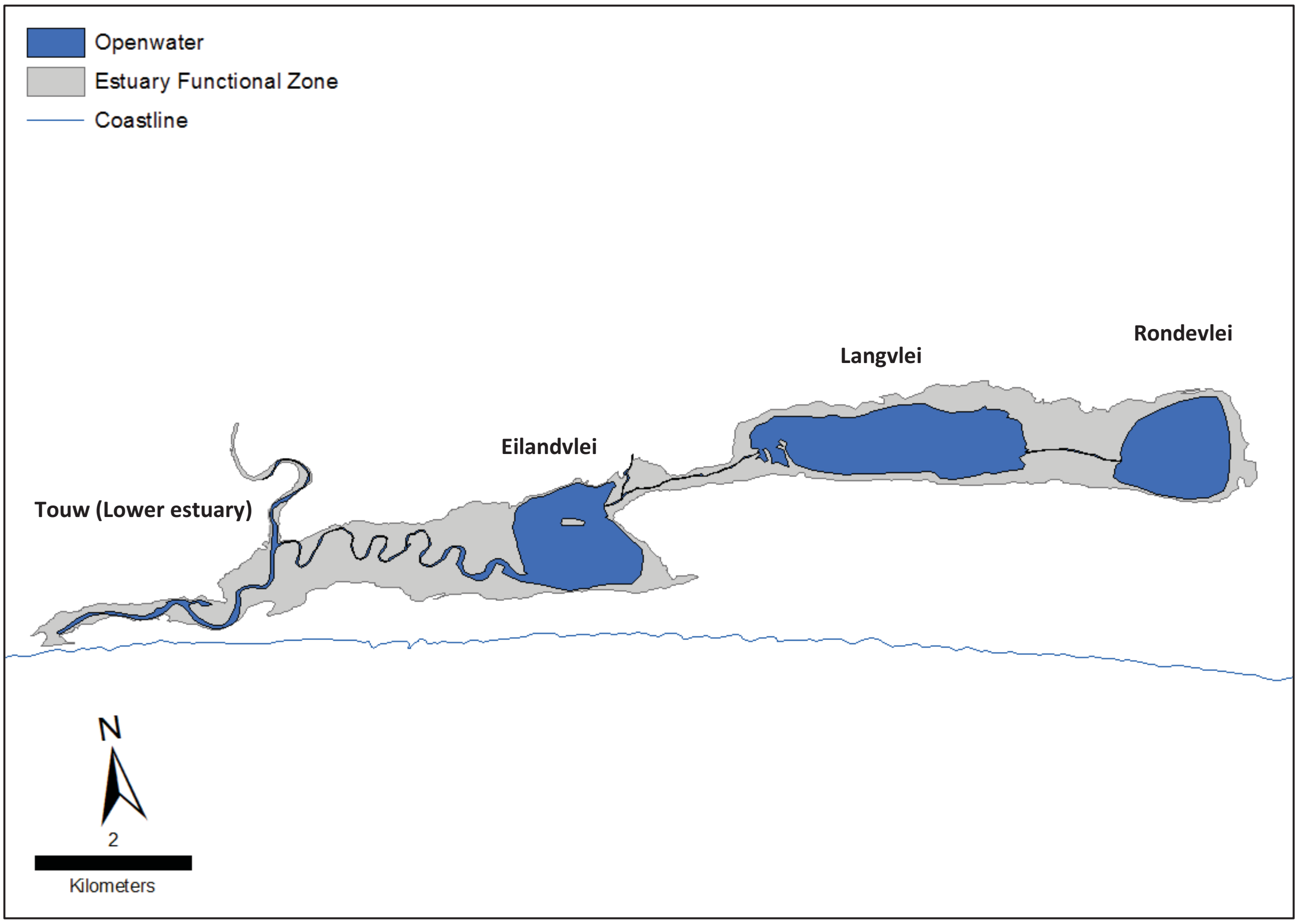

Figure 8.1 Touw/Wilderness: EFZ and openwater area

Under naturally occurring high lake levels there would have been a free connection between all the parts of the system when the mouth is closed (Fijen 1995a). At present artificial breaching has reduced the lake levels by more than 1.5 m, resulting in loss of connectivity and dredging of link channels between the lakes to maintain connectivity. However, under drought conditions, Rondevlei can still be completely separated from Langvlei (Olds et al. 2016, Whitfield et al. 2017).

The present MAR into the Touw/Wilderness Estuarine Lake system is 25.15 million m^3. This is a decrease of 15% compared to the natural MAR of 29.66 million m^3 (DWS 2014). The net seepage and evaporation losses from the Wilderness System are estimated at 6.2 million m^3/a (Fijen 1995). This is equivalent to a monthly volume of 0.52 million m^3. An evaluation of the simulated flow data indicates that the combined inflow to the system exceeded this monthly volume for only 55% of the time under present conditions, while it exceeded this value for about 69% of the time under natural condition.

Flow in the Touw River is the primary abiotic driver of the Touw section and the three lakes as it strongly influences mouth condition of the system. The Touw River feeds directly into the Touw section and provides about 60% of the total runoff to the Touw/Wilderness system under the Present State. Under Reference Condition it contributed 58% but the relative percentage increased under the Present State as a result of flow reduction from the Duiwe River. The present MAR of the Touw River is estimated at 15.34 million m^3. This 11% lower than the natural MAR (17.2 million m^3). Floods volumes were about 5% higher than at present, depending on the size class.

8.2 Zonation and Abiotic States

The 2014 EWR study on the Touw/Wilderness System (DWS 2014) subdivided the system into **two units**, namely the **Touw (lower estuary)** and the **Wilderness estuarine lakes** (Figure 7.2), with key features summarised in Table 7.1.

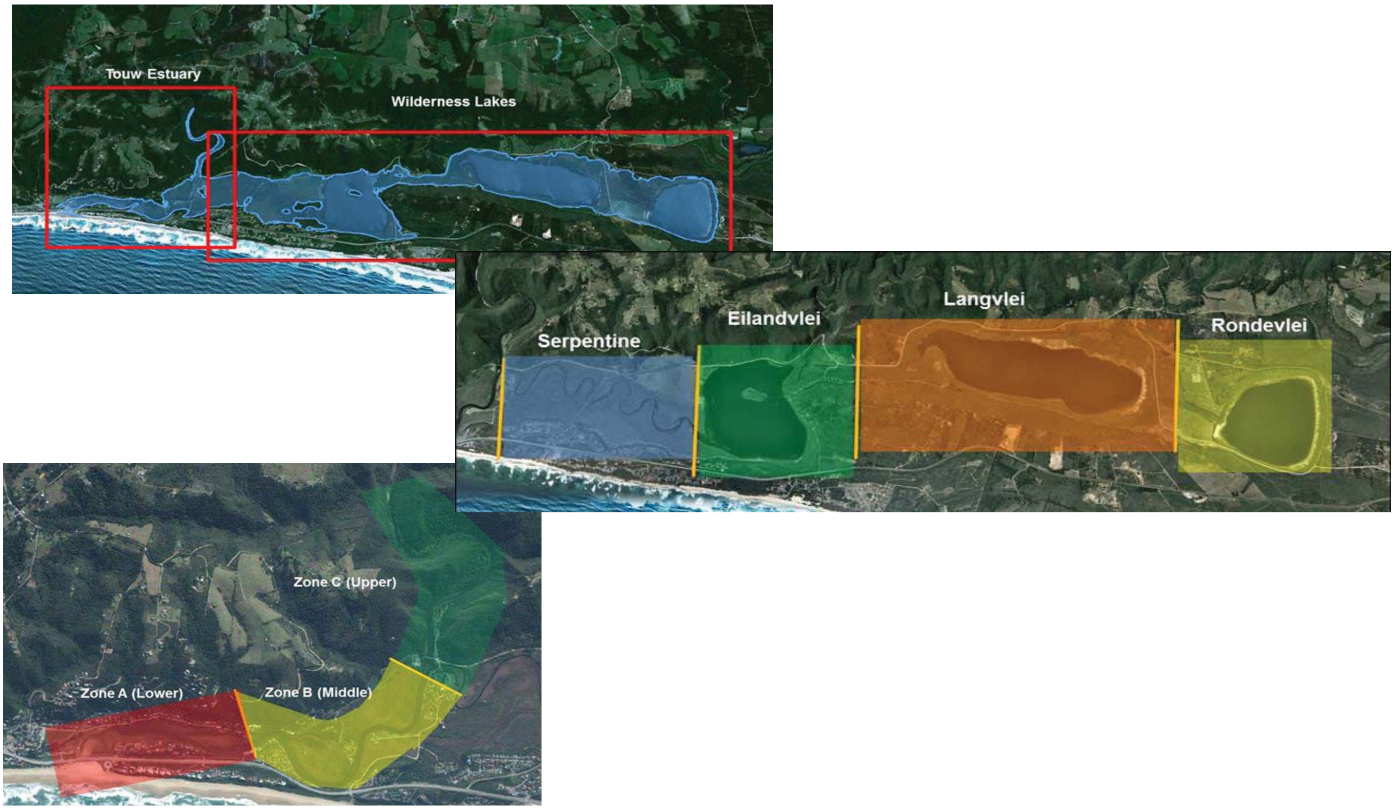

Figure 8.2 Touw/Wilderness: Zonation

The motivation for this is that these two sub-systems function at markedly different spatial and temporal scales. In the case of the Touw, the system shows strong longitudinal gradients in physico-chemical while these characteristics are more uniform in the lakes. Also, temporal variability of the hydrodynamics and water quality in the Touw show stronger intra-annual (seasonal) variability, while the lakes show stronger inter-annual (across years) temporal variability.

Table 8.1: Touw/Wilderness: Characteristics of different zones

FEATURE (TOUW)	ZONE A (lower)	ZONE B (middle)	ZONE C (upper)
Area (ha)	18.8	10.75	7.1
Depth (m)	1.0	1.5-2.0	1.0

FEATURE (LAKES)	ZONE Serpentine	ZONE Eilandvlei	ZONE Langvlei	ZONE Rondevlei
Area (ha)	20	137	203	106
Depth (m)	1.5	Max=6.5 Ave=3.0	Max=4.0 Ave=2.0	Max=6.0 Ave=3.0

A number of characteristic 'abiotic states' was identified for the Touw/Wilderness System, associated with specific flow ranges, and taking into account the variability in characteristics such as tidal exchange, salinity distribution, estuary mouth manipulations (breaching and closures) and water quality (Tables 7.2 and 7.3) (DWS 2014). Characterisation of abiotic states for the Wilderness Lakes was primarily based on the water levels in the lakes. Water levels in the lakes, in turn, are primarily influenced by the state of mouth in the Touw, or high flow events. For example, when the Touw mouth is closed there are no outflows from the Wilderness system and water levels become high. When the estuary mouth is open, water drains from the Wilderness system resulting in low lakes levels. During periods of high flows, the lakes fill for short periods resulting in very high-water levels.

Table 8.2: Touw/Wilderness: Abiotic states in Touw (lower estuary)

STATE	FLOW RANGE (m^3/s)	DESCRIPTION
State 1	<0.3 (Reference); <0.5 (Present)	Closed State
State 2	0.1-1	Open with full salinity gradient
State 3	>20	Open, freshwater dominated

Table 8.3: Touw/Wilderness: Abiotic states in Lakes

STATE	WATER LEVEL IN LAKES	CORRESPONDING FLOW IN TOUW RIVER (m^3/s)	DECRIPTION
State 1	High	<0.3 (Reference)/ <0.5 (Present)	Touw mouth closed
State 2	Low	0.1-1	Touw mouth open or recently open
State 3	Very high	>20	High fluvial flow into the system

The transition between the different states will not be instantaneous but will take place gradually. Under the Reference Conditions the Touw (Figure 7.3). Estuary mouth used to be open for about 40% of the time, at present it is open for about 25% of the time. Under the Reference Conditions maximum water levels before a breaching were about 3.0 to 3.5 m MSL, while under the Present State the mouth is breached between 2.1 and 2.4 m MSL.

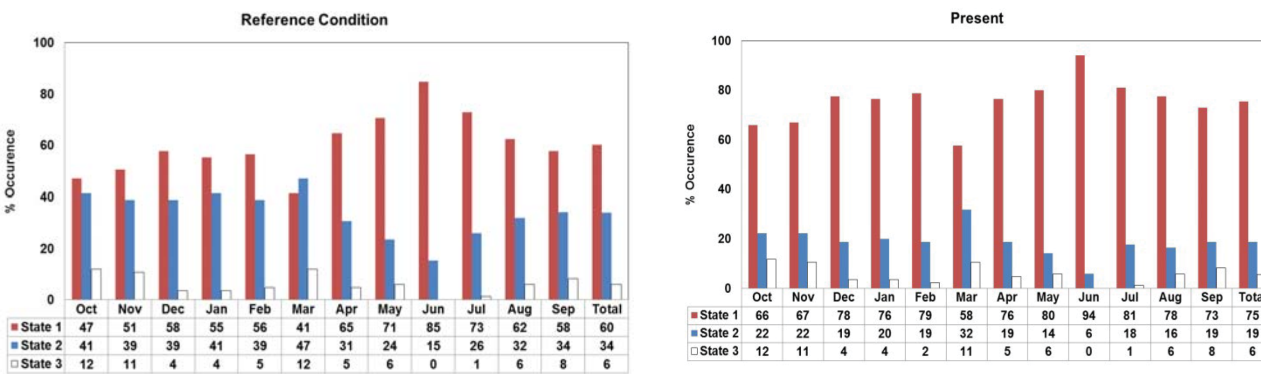

Figure 8.3 Touw/Wilderness: Occurrence of abiotic states in Touw (lower estuary) Reference and Present states

8.3 Abiotic Response Indicators

8.3.1 Mouth dynamics and water levels

Under present conditions in the Touw, frequent interventions in mouth dynamics and berm morphology result in lower flushing of sediment from the lower part of this section of the estuary and probably more ingress of marine sediment into this area. Catchment activities have caused a slight increase in the riverine fine sediment load to the estuary, with slightly reduced coarser load (sand and gravel). The small reduction in large floods would result in slightly less flushing of sediments from all parts of the Touw, and enable marine sediment to ingress slightly further into the system on average. An additional effect would be slightly longer retention of riverine sediment deposits, enabling more consolidation and more plant growth, all contributing to slightly less dynamic estuarine geomorphology (DWS 2014).

There are road and rail bridges crossing the Touw in all three zones. Although the bridge spans are relatively wide, bridge pier and especially their abutments on the banks have constricting effects and have fixed the Touw channel and banks in the direct vicinity (up- & down-stream). The banks of the middle and especially the lower part of the Touw have been heavily impacted by development (houses, banks stabilization structures/revetments, slipways & jetties, etc.).

In the Reference Condition the middle reaches of the Touw were more directly connected to the coastal dynamics. Occasionally breaching to the sea at the big bend in the middle reaches was possible during extreme flood events. There would also have been significant input of aeolian sediment into the Touw at this location, especially during spring and autumn seasons. With the construction of the highway, such breaching is no longer possible, and no aeolian sediment transport can reach the middle reaches of the Touw from the adjacent beach. The road construction also involved some infilling of the seaward side of the channel at this location, narrowing the channel slightly from the southern (road) side.

Very little information or data regarding Reference versus Present state of the morphology and sediment dynamics of the Wilderness Lakes exist. The catchments of the lakes' tributaries (i.e. Duiwe and Langspruit) are less pristine than that of the Touw catchment. Agriculture and forestry occur in patches. Exotic vegetation occurs in some areas. There are significant resort settlements around the lakes. Hotels, camping, picnicking, boat launching are concentrated around- and west of Eilandvlei. There is therefore an expected increased sediment inputs into the lakes from catchments and surrounding areas.

The lakes act as a natural sediment sink (trap) for sediments from the catchments and surrounding areas. Only a small amount of fines could be exported through the lakes to the Touw during high flows. A "sluice" gate was constructed on the Serpentine channel. The channel between Eilandvlei and Langvlei is severely overgrown; the consequent localised siltation of the channel has created an effective block to lake interflow when levels fall below +1.2 m MSL.

Artificial breaching of estuaries has been undertaken along the South Coast since the early nineteenth century. Flooding of agricultural land along Langvlei and Eilandvlei motivated farmers to combine their labour forces to excavate a trench by hand through the sandbar blocking the mouth. Apparently, the original mouth was located in the vicinity of Leentjiesklip (western corner of Wilderness beach). The estuary mouth was fixed in its current position by the construction of the railway bridge in 1928 (Fijen 1995a). In the 1950s the mouth was opened for the first time by mechanical means. As developed increased in the area, breachings were conducted at lower and lower levels. The Lakes Area Development Board took over the management of the system in 1975 and insisted on higher breaching levels. SANParks took over in 1983 and currently allows the sandberm height near the mouth to grow to 2.4 m MSL, after which it is skimmed to 2.1 m MSL. Naturally, the berm height would have been between 3.0 and 3.5 m MS (Fijen 1995a). At present the estuary mouth is also closed artificially once the inlet channel becomes constricted to prevent sedimentation in the lower reaches.

The estuary mouth is closed most often during the winter period that is associated with high wave conditions (Figure 7.4). The duration of an open mouth state is also shorter, with a duration of 3 weeks versus the average of about 8 to 10 weeks historically observed for the system.

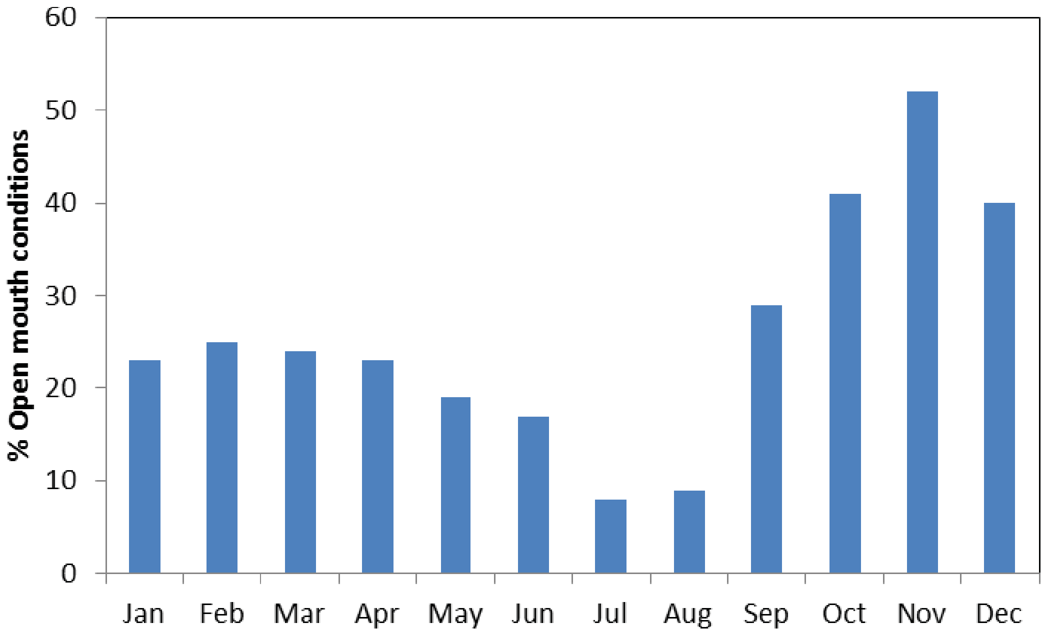

Figure 8.4 Touw/Wilderness: Distribution of open mouth states

A water balance of the Wilderness Lakes during the closed mouth periods indicates that net annual seepage and evaporation losses equate to about 6.2 x 10^6 m^3/year or 17 000 m^3/day. This is equivalent to a decrease in water level of about 6.6 cm/month (Fijen 1995a).

The average water level in the Touw Estuary during open mouth conditions is about 0.8 m MSL, which is higher than the average high tide in the sea because of significant sediment in the lower reaches of the estuary. The minimum water level in Eilandvlei is about 1.0 m MSL and cannot decrease below that as a result of the depth of the Serpertine channel. The minimum water levels in Langvlei and Rondevlei are also 1.0 m MSL, which again correspond to the bottom-levels in the interconnecting channels and the road crossing culverts bisecting the channels.

Water level variation in the Touw is significant and driven by floods from The Touw River (maximum) and the scoring after a breaching (minimum). Small floods, not sufficient to break through the mouth, cause a rapid rise in water level after which levels decline as water flows from the Touw into the Eilandvlei and the rest of the lake system. Water levels in Eilandvlei under the closed mouth state are like those measured in the Touw, but minimum water levels are higher during the open tidal phase and maximum water levels are lower during floods (restricted by limited connectivity and lower inflows from Duiwe River). Water level fluctuations are about 1.6 m (between 1.0 to 2.6 m MSL). The water levels in Langvlei and Rondevlei are virtually identical and fluctuate by about 0.9 m (from about 1.0 to 1.9 m MSL) (Figure 7.5).

Rondevlei has no influent rivers, while Langvlei has only a small tributary flowing into it. The water levels in these two lakes are determined by direct rainfall, groundwater inflow, inflow from Eilandvlei and evaporation. The water levels of Rondevlei and Langvlei are of a cyclic nature in that high evaporation rates from November to March can cause a decrease in lake levels while inflow from Eilandvlei can cause levels to increase between April to October. Water levels in Langvlei and Rondevlei respond very sluggishly to floods from the Touw and Duiwe Rivers as a result of the narrow link channels. The water levels are much lower and maximum water levels occur 3 to 7 days later than in the Touw. Outflow from Langvlei and Rondevlei occurs for a period of 2 months after a breaching.

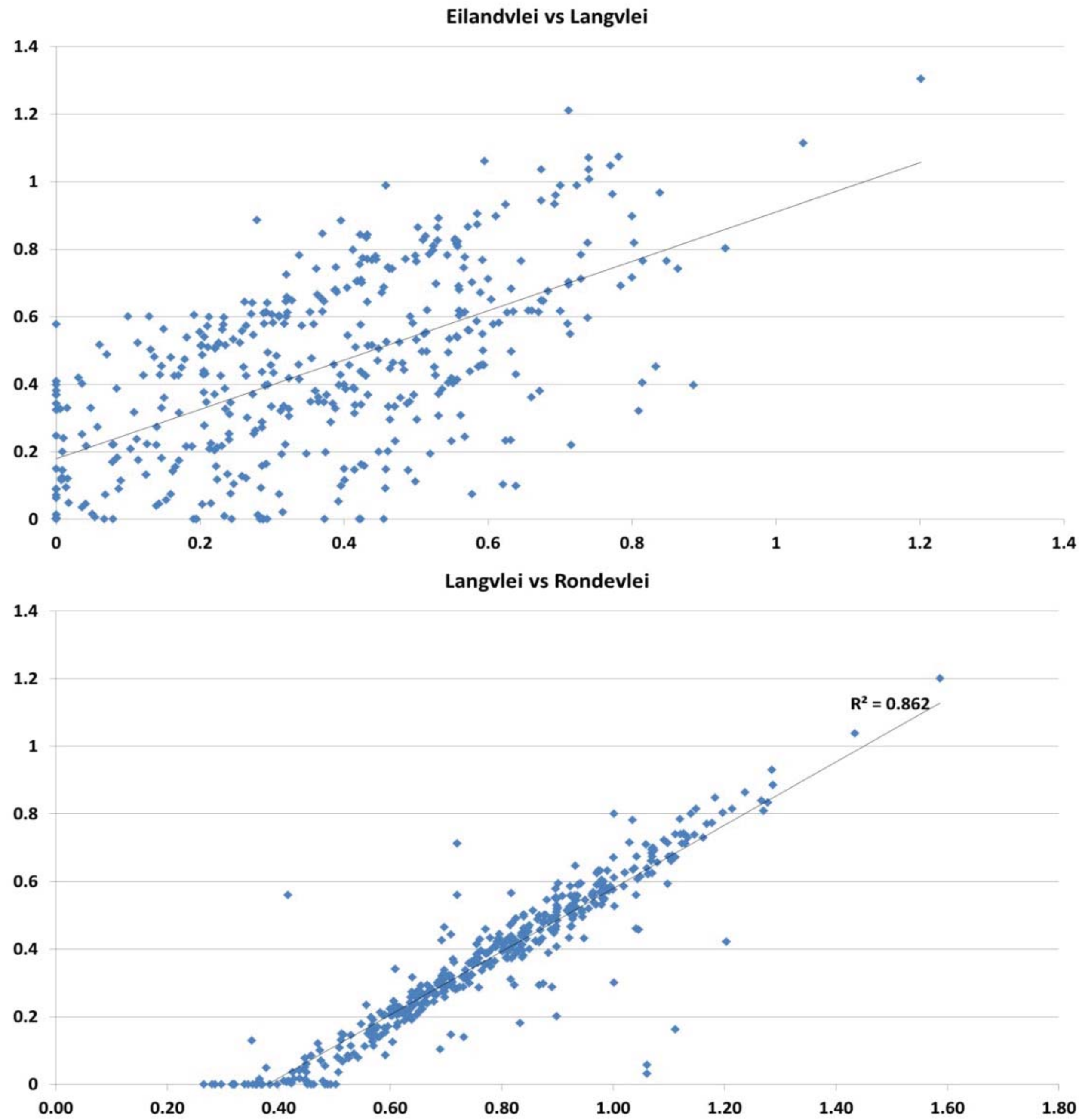

Figure 8.5 Touw/Wilderness: Correlation of median monthly water levels for Eilandvlei, Langvlei and Rondevlei

At present the sand berm at the mouth is artificially kept at a height of between 2.1 and 2.4 m MSL. When a flood occurs, water rapidly rises to the level of the berm and the system is either artificially breached or over tops (Figure 7.6). Under the current restricted water levels, limited spillover occurs from the Touw into Eilandvlei and from there into Langvlei and Rondevlei. A flood in the Touw results in a rapid rise in water levels in the Touw as a result of its relative small surface area and the restricted flow to Eilandvlei through the Serpentine channel. On the opening of the mouth, the water level in the Touw rapidly declines within 5 to 10 hours. The maximum water level in Eilandvlei can be very similar to that of the lower part of the Touw (Zone A) depending on whether the Duiwe River is also in flood. Maximum levels in Eilandvlei are achieved within 30 hours after maximum levels in the Touw. After breaching levels in Eilandvlei also decline rapidly, this can be somewhat retarded because of the constriction of the Serpentine channel.

Flooding under the Reference Condition at low initial water levels (e.g. 1.4 m MSL), would have resulted in the water level in the Touw (and in Eilandvlei if the Duiwe floods) increasing quickly and spilling over into Langvlei and Rondevlei (Figure 7.7). There would then be a slower buildup of water levels in the Langvlei and Rondevlei, but as the water levels rose in the Touw and lakes the connectivity would increase, with through flow becoming more efficient with increasing water levels. The maximum water level would stay below the berm height, with no rapid break through to sea. Under this model water level in the Touw will dissipate after small floods as the water gets distributed over the entire lake system. The effect of a flood is that the total water level increases with final lake levels dependent on the size of the flood. For example, a 1:5 year flood with a volume of 5.5 x 10 m^3 will increase the initial water levels from 1.4 m to 2.1 m MSL. It will also lead to an overall reduction in salinity levels. The same effect could also be achieved if there was a steady inflow from the rivers without actually having a flood.

During high initial levels (e.g. 2.1 m MSL) there would be a quick rise in water level in the Touw and in Eilandvlei into Langvlei and Rondevlei (with less friction in link channels under higher water levels) (Figure 7.8). Water levels will build up to a level higher than the berm height (3.0-3.5 m MSL) and the mouth would break open to the sea. The outflow to the sea would now consist of both the Touw volume and the volume of water stored in the lakes. There would be a large outflow from the combined system, with flow from Langvlei and Rondevlei decreasing as water level decreased and interconnectivity in the channels declined. The combined outflow would take place over a long period. The result would be larger outflow volumes, higher outflow velocities, increased sediment scour in lower reaches, increase tidal flows thereafter and longer open mouth periods. It should also be noted that the higher berm level in itself would reduce ingress of marine sediment during the closed period through overwash. This leads to a deepening of the mouth area which would assist in maintaining longer open mouth conditions and increased salinity penetration.

It is therefore envisaged that under natural conditions, the estuary mouth would have been open less often, as initial, high runoff and flood volumes need to fill up the lake system. However, when the mouth breached naturally, it would have stayed open for longer periods compared to the present. During low flow periods (i.e. droughts) the mouth would have stayed closed for long periods.

At present when the mouth breached artificially the Touw stays open for about 8 to 10 weeks on average. Fijen (1995a) estimated that under natural conditions the mouth would have remained open for about 40% of the time, roughly 20 weeks per year.

8.3.2 Salinity

Patterns of change in relation to freshwater and saltwater inflows differed between the Touw and the lakes. Open mouth conditions are associated with high runoff, with such events occurring either during the open states (2 and 3) or triggering breaching in response to rises in water level in the Touw. This enabled the inflow of sea water that causes higher salinity within the Touw. However, extended closed-mouth conditions, which were often associated with low-rainfall periods, did not always result in reduced salinity levels. Periods of both sustained high salinity (Mar 2001-Sep 2002) and of declining salinity (Dec 2008-Jul 2010) coincided with closed conditions (Russel 2013). A significant decline in salinity has occurred in both Langvlei and Rondevlei, despite shorter-term increases during the low rainfall period of 2008-2010 (Russel 2013). Eilandvlei showed a five-year oscillation between higher and lower salinity states, but no significant trend was evident. Russel (2013) explained that the dominant trend in the Touw was an increase in salinity when the system was open for a protracted (> 3 month) period, and a decline in salinity when the system was closed. The opposite trend was predominant in the lakes, with a decline in salinity following the increased freshwater inflow, which frequently precipitated breaching of the mouth and increasing salinity during periods when the estuary mouth was closed.

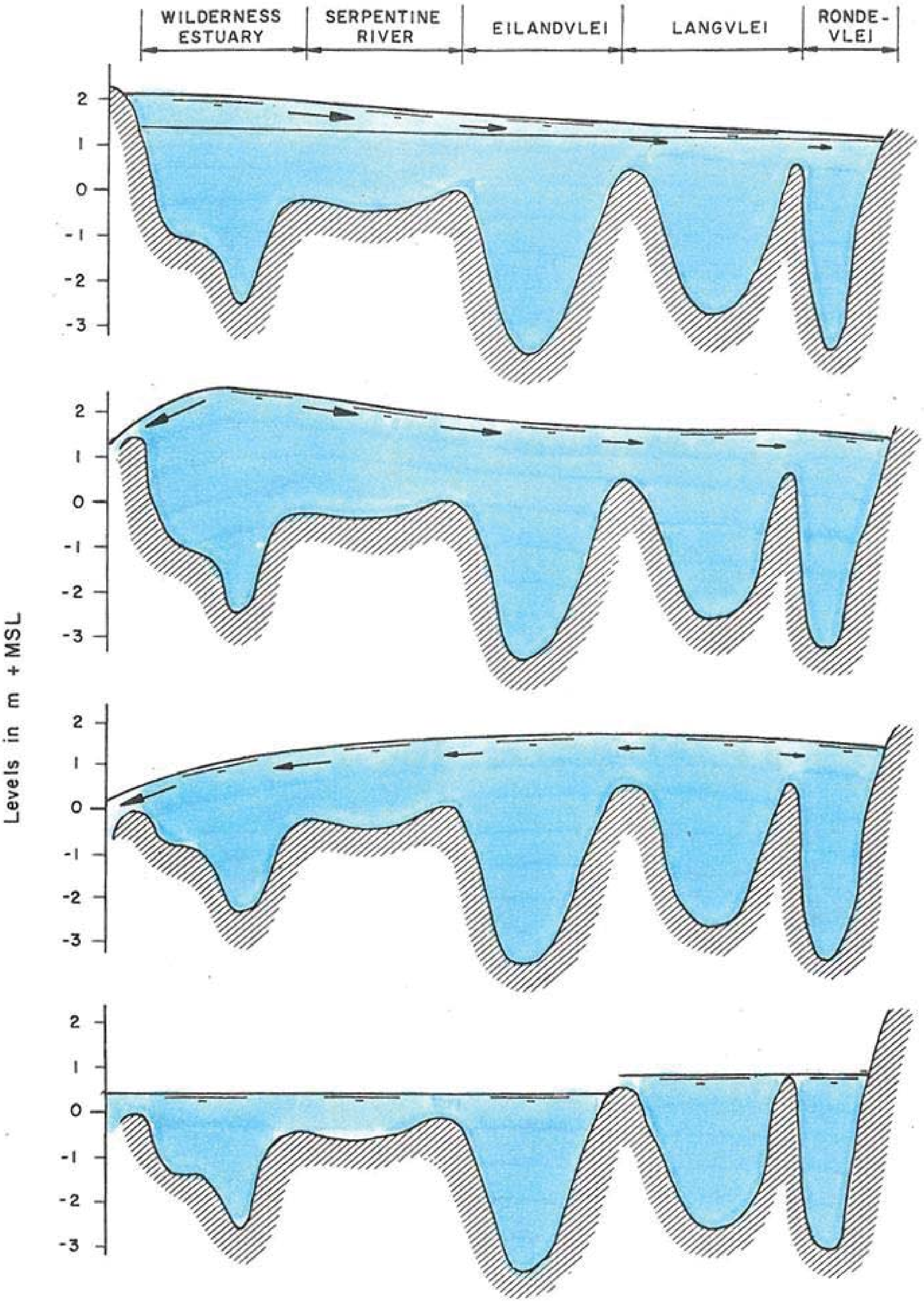

Figure 8.6 Touw/Wilderness: Present State, flood volumes cause breaching (Fijen 1995a)

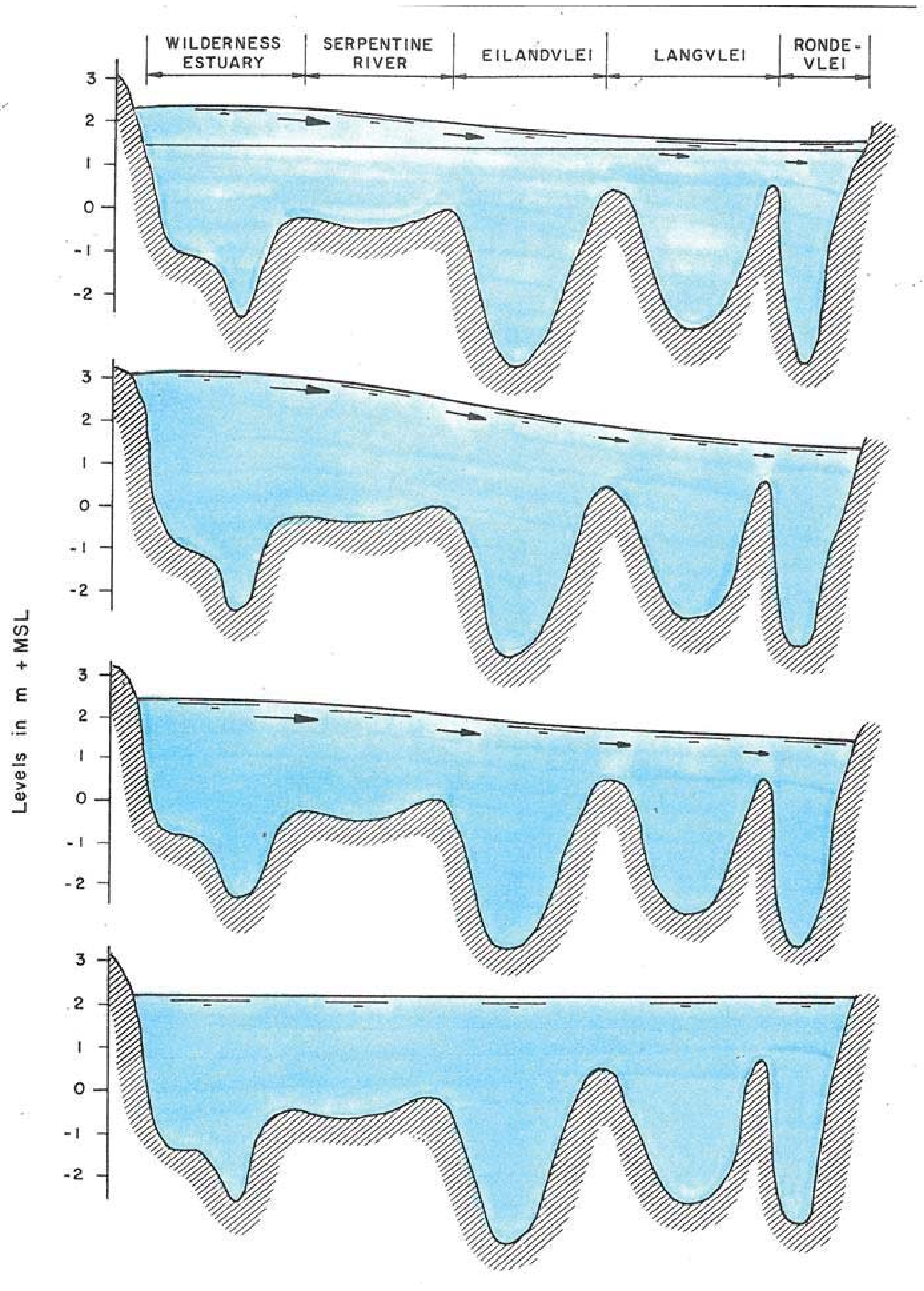

Figure 8.7 Touw/Wilderness: Reference flood volumes stored in lakes (Fijen 1995a)

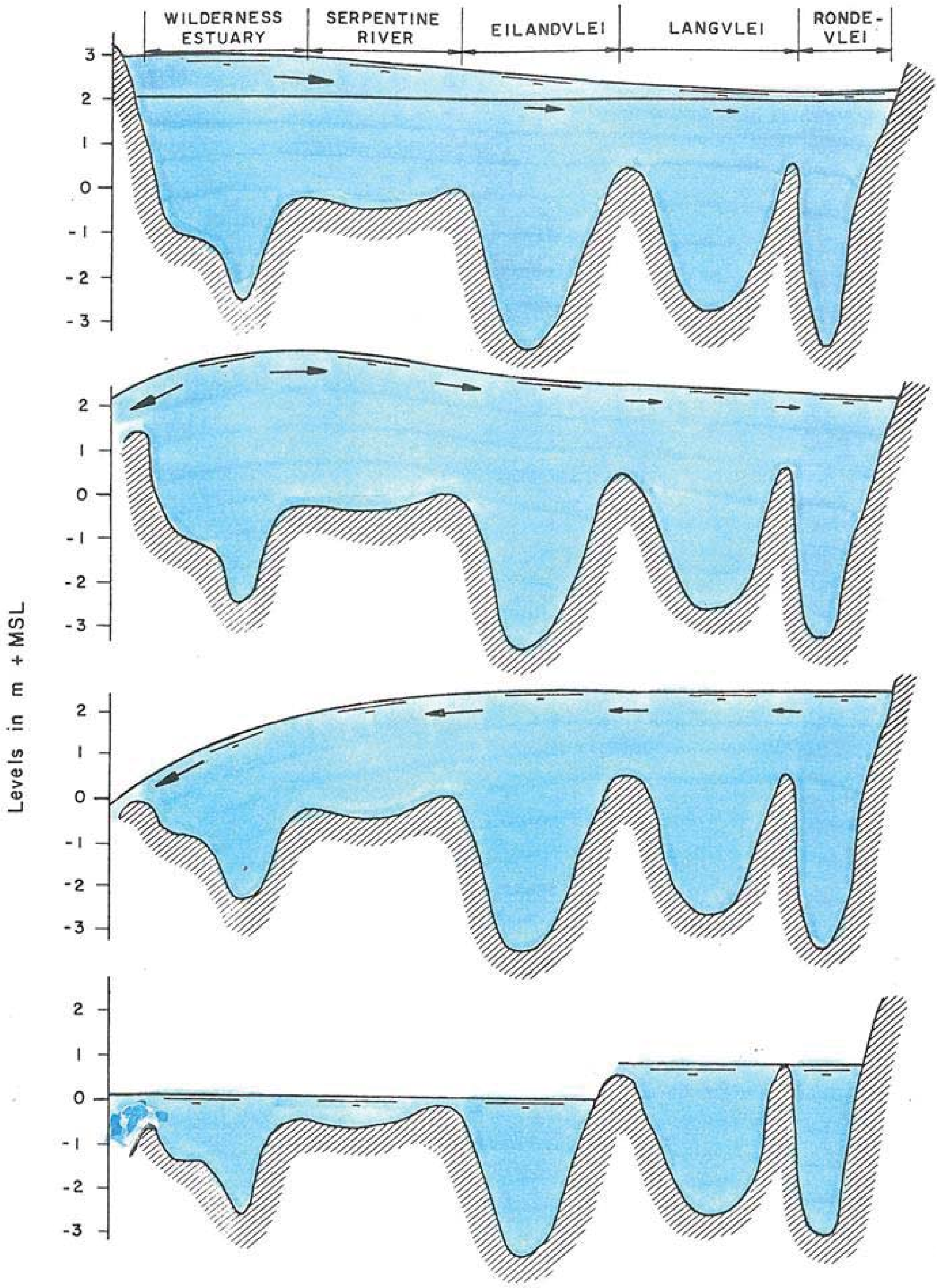

Figure 8.8 Touw/Wilderness: Reference large outflow through the estuary mouth (Fijen 1995a)

Electrical connectivity (EC) for the period 1978 to 2013 shows a similar decline in salt content with increased freshwater inflow, while EC values tended to rise during periods of low flow because of evaporation during the closed state (State 1). While the effect of the long-term wet-dry cycle can be observed between years, very few seasonal patterns can be seen from the data set.

8.3.3 Temperature

Temperature data collected in the Touw during once-off surveys in 2013 are presented in Figure 7.9 (CSIR unpublished data in DWS 2014). During January, April, and July 2013 the mouth of the estuary was closed, but the system was open during December 2013. Results show a strong seasonal signal with the highest temperature during summer and lowest during winter. Long-term temperature data sets (1991-2010) collected in the Touw (Russell 2013) also revealed strong seasonal variability with the highest water temperatures occurring in December and January (summer) and the lowest in July (mid-winter) with average summer temperature generally above 20°C and winter temperature below 20˚C

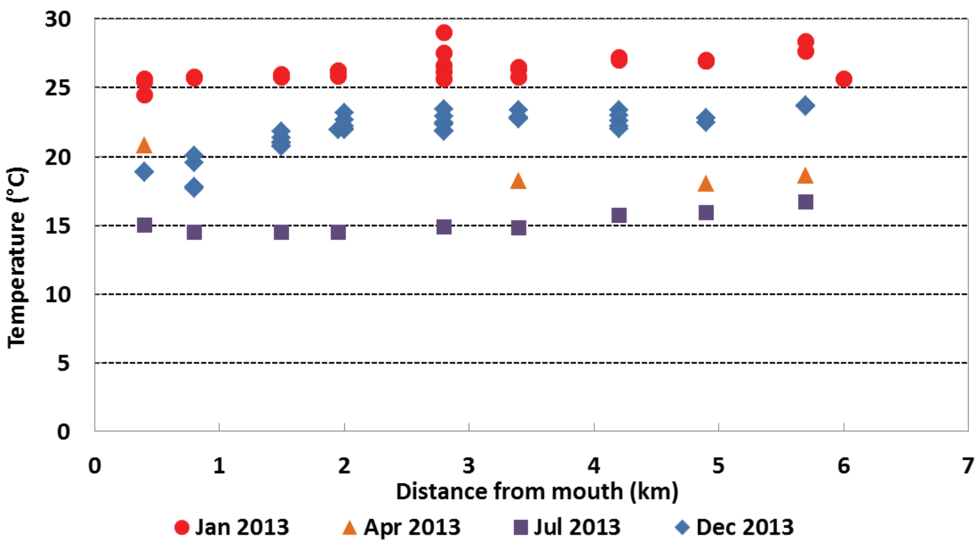

Figure 8.9 Touw/Wilderness: Temperatures in Touw during Jan 2013, Apr 2013, Jul 2013 and Dec 2013

Water temperature in the system, therefore, is primarily influenced by atmospheric conditions. However, seawater temperature may affect conditions in the lower part of the Touw (Zone A) during tidal intrusion of new seawater when the mouth is open. For example, during upwelling in summer cold water (well below ambient temperature) can be introduced to the Touw when the mouth is open. Russell (2013) recorded exceptionally low temperature in the Touw at times (8.2°C) which was attributed to upwelling during open, tidal states. The lower temperatures recorded near the mouth (up to 2 km from the mouth) during the open phase in December 2013 (Figure 7.9) are likely attributable to such influence from upwelling.

Long-term temperature data (1991-2010) collected in the three Wilderness lakes (Russell, 2013) revealed strong seasonal variability with the highest temperatures occurring in December and January (summer) and the lowest in July (mid-winter). The temperature ranges in Eilandvlei, Langvlei and Rondevlei were 11.0-26.2°C, 11.5-27.4°C and 12.3-26.5°C, respectively. The strong seasonal signal was also observed during four surveys conducted during 2013 as illustrated in Figure 7.10 (DWS 2014).

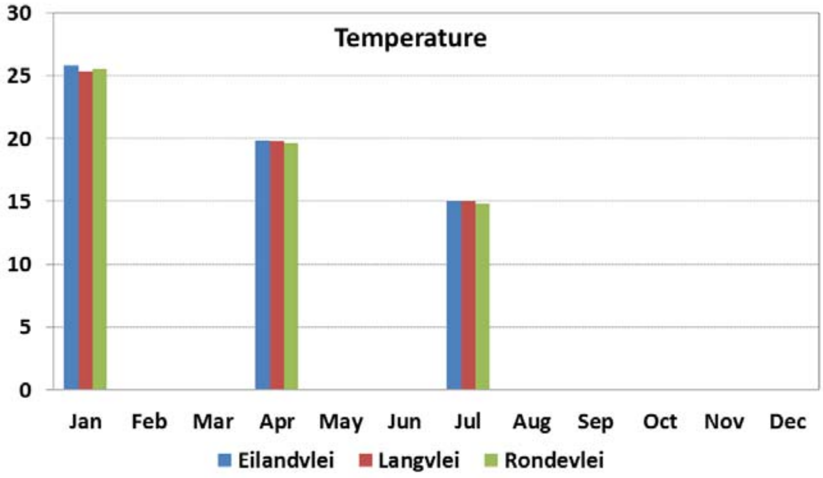

Figure 8.10 Touw/Wilderness: Average temperature measured in Wilderness Lakes during Jan 2013, Apr 2013 and Jul 2013

8.4 Biological Response Indicators

8.4.1 Microalgae

Harrison (unpublished data) sampled three sites in the Touw on 19 June 1994 (winter) when the mouth was closed. The sites ranged from 0.2 m to 1.6 m deep and the water was clear to the bottom throughout in a well-mixed water column (DWS 2014). Nutrient concentrations were generally low and phytoplankton chlorophyll *a* was below detectable limits at all sites. Van Ginkel and Hohls (2001) reported that in 1998 the phytoplankton was dominated by dinoflagellates (*Peridinium* sp.) during spring and summer. During winter the xanthophytes were dominant (filamentous yellow-green *Tribonema* sp.). Other groups that were present included the chlorophytes (*Ankistrodesmus* sp.), cryptophytes (*Cryptomonas* sp.) and euglenophytes (*Euglena* sp.). Some cyanobacteria (blue-greens; *Anabaena* sp.) were recorded during the study but their numbers were low and considered to be negligible. Van Ginkel and Hohls (2001) concluded that the Touw had the potential to develop occasional eutrophic conditions, however, the low chlorophyll *a* in the water column may have been the result of salinity and the low nutrient conditions in the system.

Four sites were sampled in the Touw in December 2013 measuring microalgal variables (Table 7.4). These data included phytoplankton and microphytobenthos (MPB) biomass, phytoplankton group composition, and dominant (>10% of relative abundance) benthic diatoms. Phytoplankton chlorophyll a ranged from 1.98 ± 0.30 µg/ℓ to 7.59 ± 3.52 µg/ℓ, subtidal microphytobenthos chlorophyll *a* from 10.81 ± 6.05 mg/m^2 to 225.44 ± 20.66 mg/m^2, and intertidal microphytobenthos chlorophyll *a* from 4.90 ± 1.55 mg/m^2 to 144.25 ± 2.92 mg/m^2. Benthic chlorophyll *a* exceeding 100 mg/m^2 is extremely high and indicative of a eutrophic environment (suggesting influence from WWTW and/or septic tanks) (DWS 2014; Lemley et al., 2015).

Table 8.4: Touw/Wilderness: Phytoplankton and microphytobenthos biomass (using chlorophyll *a* as index) in Touw in Dec 2013

SITE (km from mouth)	PHYTOPLANKTON CHLOROPHYLL *a* (µg/ℓ)	INTERTIDAL CHLOROPHYLL *a* (mg/m^2)	SUBTIDAL CHLOROPHYLL *a* (mg/m^2)
1 (0.5 km)	1.98 ± 0.30	4.90 ± 1.55	10.81 ± 6.05
2 (1.9 km)	4.97 ± 0.81	121.40 ± 11.64	196.45 ± 38.44
3 (3.4 km)	7.59 ± 3.52	144.25 ± 2.92	225.44 ± 20.66
4 (5.1 km)	0.68 ± 0.15	8.27 ± 0.12	-

Phytoplankton group composition was dominated (up to 90%) by flagellates (likely cryptophytes and chlorodendrophytes) throughout the Touw, ranging from a low vertical average of 239 to 470 cells/mℓ. Diatoms ranged from 3 to 25 cells/mℓ and dinoflagellates from 4 to 28 cells.ml^{-1}. There were no other phytoplankton groups present in the Touw. There were few benthic diatoms in the sandy sediment near to the mouth of the Touw (0.5 km), which was dominated by *Amphora* sp. in the intertidal (81% relative abundance) and subtidal (58%) sampling sites. Site 2 (1.9 km) was much muddier, typically dominated by epipelic diatoms, and was dominated by *Stauroneis dubitabilis* (59%) and *Fallacia pygmaea* (13%) in the intertidal zone, and by *Cocconeis placentula* (25%) intertidally. Both *F. pygmaea* and *C. placentula* are tolerant of eutrophic conditions. The sediment at Site 3 (3.4 km) was coarse with rocks and pebbles and had high benthic microalgal biomass. The intertidal zone was dominated by *C. engelbrechtii* (19%), *Entomoneis paludosa* var. *paludosa* (17%) and *Opephora horstiana* (15%). The subtidal zone was dominated by C. *placentula* var. *euglypta* (36%) and *F. pygmaea* (15%). Site 4 (5.1 km) was located near to the upper part of the Touw (Zone C) and the sediment was coarse with rocks and pebbles. The water was extremely shallow, and it was only possible to collect intertidal samples that were dominated by *Diploneis elliptica* (29%), *Tabellaria flocculosa* (29%) and *Eunotia rhomboidea* (20%). All three dominant species typically occur in oligotrophic and circumneutral/slightly acidic waters. The Shannon diversity and evenness scores for the Touw were 1.86 and 0.66 respectively; lower than the nearby Keurbooms (2.08 and 0.81) and Klein Brak (1.95 and 0.73) estuaries. Based on these results the water in the Touw River was oligotrophic but was impacted by nutrient loading in the middle reaches of the Touw (Zone B) (based on the benthic microalgal results only).

Based on the results of Harrison (unpublished data), Van Ginkel and Hohls (2001), and December 2013 survey results, phytoplankton chlorophyll *a* was generally low, i.e. below detectable limits to <10 µg/ℓ for 80% of the time. Phytoplankton cell density was low too and dominated by small flagellates (90%) when the estuary mouth was open with few diatoms and dinoflagellates. The Touw is prone to dense stands of filamentous algae when the mouth is closed, and conditions are stable. These results suggest the Touw is oligo- to mesotrophic but benthic microalgal results contradict these findings. Average benthic chlorophyll *a* exceeded 100 mg/ℓ in the middle and middle-upper reaches of the Touw (Zone B), which is considered to be extremely high (Lemley et al., 2015). Many of the dominant diatoms have a high tolerance for polluted or eutrophic conditions. Water column nutrients were low at the time of sampling, so it is most likely that local diffuse seepage of nutrients or the mineralisation of nutrients from the sediment support such high benthic microalgal biomass. Factors such as tidal flushing, coarse-grained sediment and low-nutrient river flow limited benthic microalgal biomass at sites near the mouth and the head of the Touw (Zone C). Fortunately, the Touw is relatively shallow and the water column well-oxygenated. This prevents the release of nutrients from the sediment into the water column, preventing the development of phytoplankton blooms.

8.4.2 Macrophytes

Reeds and sedges are dominant in the Wilderness system (the common reed *Phragmites australis* and the sedge *Schoenoplectus scirpoideus*), with smaller areas of salt marsh and submerged macrophytes (DWS 2014) (Table 7.5). Other recorded sedge species are *Bolboschoenus maritimus* and *Typha capensis* (bulrush). *Juncus kraussii* (sharp rush) occurs on more saline soils than the reeds and sedges. The succulent salt marsh plant *Sarcocornia* spp. is also present as well as *Cotula coronopifolia*. Submerged macrophytes were represented by *Stuckenia pectinata* within the more brackish regions as well as *Ruppia cirrhosa* and *Zostera capensis*. *Charophyta* (*Chara globularis* and *Lamprothamnium papulosum*) and filamentous algae such as Enteromorpha (*Ulva* spp.) are also abundant. These primary producers are essential for food production; they provide habitat diversity and play an important role in bank stabilisation and recycling of nutrients. Similarly to Swartvlei Lake the centre of biological productivity for the lakes lie in the littoral zone to a depth of 2 m (Howard-Williams 1980). Weisser and Howard-Williams (1982) provide a comprehensive description of vegetation distribution for the Wilderness Lakes in 1978 and Russell (2003) provides maps, a comprehensive description for 1997 and an assessment of changes over time.

Table 8.5: Touw/Wilderness: Estimates of macrophyte habitat (ha)

HABITAT TYPE	DEFINING FEATURES, TYPICAL/DOMINANT SPECIES	ALL	TOUW
Open surface water area	Serves as a possible habitat for phytoplankton.		21.1
Sand & mud flats	Intertidal zone provides a possible area for microphytobenthos to inhabit.		
Macroalgae	Charophyta, *Cladophora* spp., *Enteromorpha* spp.		
Submerged macrophytes	*Zostera capensis*, *Ruppia cirrhosa*, *Stuckenia pectinata*	4	-
Salt marsh	*Juncus kraussii* (sharp rush) occurs on more saline soils than the reeds and sedges. The succulent salt marsh plant *Sarcocornia* spp. is also present as well as *Cotula coronopifolia*.	42.3	0
Reeds and sedges	Common reed *Phragmites australis* is abundant as well as the sedge *Schoenoplectus scirpoideus*. Other recorded species are *Bolboschoenus maritimus* and *Typha capensis* (bulrush).	227.9	19.7
Floodplain (grassland & fields)	This area has possibly expanded because of lower water levels and drying of some wetland areas as well as the removal of wetland vegetation to make way for development. In the Serpentine channel area *Juncus* stands have been replaced by kikuyu and buffalo grass.	107.2	12.9

Mapping of the distribution of plants in the 1970s (Weisser & Howard-Williams 1982) and 1990s (Russell 2003) indicated localised increases in *P. australis, T. capensis,* scrub or trees, and grass or fields, and decreases in *Juncus kraussii, Schoenoplectus scirpoideus* and low scrub or fynbos in the Touw River system. Probable causes of change in the distribution of wetland plants include the natural tendency of plants to colonise new areas, as well as anthropogenic manipulation of physical, chemical, and biological processes, including the cessation of disturbance by large herbivores, water-level stabilisation, changes in soil salinity and the accumulation of plant litter within wetland areas (Russell 2003).

The submerged macrophytes in the lake also respond to salinity. Howard-Williams (1980) showed that lowered water levels coincided with increased salinity and in 1975 *Stuckenia pectinata* disappeared from Rondevlei when salinity increased to 22. As observed for the Swartvlei system the horizontal zonation of the submerged macrophytes was maintained by salinity with *Zostera capensis* at the saline end (35), *Stuckenia pectinata* at the fresh (<10) end and *Ruppia cirrhosa* in between.

There has been an increase in common reed *Phragmites australis* that is believed to be the result of the artificial breaching of the estuary mouth and lower stable water levels. Within the Touw *Phragmites australis* forms dense continuous bands along the river and *Schoenoplectus scirpoideus* and *Juncus kraussii* occur in certain areas. Submerged macrophytes were represented by *Stuckenia pectinata* within the more brackish regions and *Ruppia cirrhosa* towards the lower section of the river (Weisser and Howard-Williams 1982). The Serpentine connects the Touw River and Wilderness Lagoon with Eilandvlei and the rest of the Wilderness Lakes. Lower salinity within this section of the system limits the distribution of more saline species such as *Zostera capensis* and *Ruppia cirrhosa*, at the same time promoting the establishment of species such as *Stuckenia pectinata* and *Typha latifolia* subsp. *capensis*. Charophyta and filamentous algae are also abundant.

Assessments of standing biomass of the submerged macrophytes were conducted from 1992 to 2005 at Eilandvlei, Rondevlei and Langvlei (Russell et al. 2009). Fluctuations in biomass were thought to be the result of fungal diseases, changes in water nutrients, shading by *Enteromorpha* and dinoflagellate blooms, reductions in water transparency and reduced calcium: magnesium ratios in the water column (Russell et al. 2005).

Howard-Williams (1980) showed that higher organic content occurs in the sediment below the emergent macrophytes as opposed to that below the submerged macrophytes due to the greater accumulation of detritus. This occurs as the emergent species have higher productivity but slower decomposition rates. Productivities of the various macrophytes in the system were in the order of *Typha latifolia* > *Phragmites australis* > *Scirpus littoralis* > *Stuckenia pectinata* > *Chara globularis* > *Ruppia cirrhosa*.

The Wilderness Lakes area has been disturbed by man's activities for many years. The declaration of the National Park in 1983 and listing as a Ramsar site in 1991 reduced some of the pressures such as encroaching development and livestock grazing. Dredging of the channels between the different lake sections would have changed water level and salinity causing changes in wetland vegetation. Dredged spoil was deposited adjacent to canals, forming vegetated levees and interfering with water movement (Russell 2003). Historical aerial photographs indicate the changes over time caused by development. Macrophyte habitat associated with the banks of the middle and especially the lower Touw has been disturbed by houses, bank stabilization, slipways and jetties. Hotels, camping, picnic sites, boat launching concentrated around and west of Eilandvlei would have resulted in the removal of some estuarine vegetation. The data in Tables 7.6 and 7.7 give some indication of overall changes over time, namely a decrease in open water area and salt marsh habitat due to reed encroachment. There has been an increase in reeds and sedges, floodplain and developed areas (DWS 2014).

Table 8.6: Touw/Wilderness: Vegetation units and their area (ha) for 1975 / 1978 (modified from Weisser and Howard-Williams) and for 1997 (modified from Russell 2003)

VEGETATION	1978	1997	1978 TOTAL	1997 TOTAL	TREND
Open Water in Wetland	2.21	0.33	2.21	0.33	⇩
Submerged macrophytes					
Stuckenia pectinata &/or *Ruppia cirrhosa*	42.7		46.59	-	
Ruppia cirrhosa	3.89				
Salt marsh					
Cotula coronopifolia	1.52	0.96			
Juncus kraussii	111.66	40.4			
Sarcocornia spp	0	1.13	113.18	42.49	⇩
Reeds and sedges					
Phragmites australis	102.14	176.71			
Scirpus littoralis Schoenoplectus scirpoideus)	33.6	27.08			
Scirpus maritimus (Bolbochoenus maritimus)	0.38	3.10			
Sedge marsh	1.13				
Cladium mariscus	4.24	3.25			
Cyperus textilis	0	3.39			
Ficinia nodosa	0	0.74			
Schoenoplectus triquester	0	0.38			
Typha latifolia subsp. capensis	8.82	13.2	150.3	227.85	⇧
Floodplain					
Grassland & Fields	66.46	107.18	66.46	107.18	⇧
Other					
Riparian vegetation	30.71				
Development					
Human Use areas	10.76	34.5	15.38	34.5	⇧
Roads	4.62				
Total			394.12	412.35	

Mapping of the distribution of plants in the 1970s (Weisser & Howard-Williams 1982) and 1990s (Russell 2003) indicated localised increases in *P. australis*, *T. capensis*, scrub or trees, and grass or fields, and decreases in *Juncus kraussii*, *Schoenoplectus scirpoideus* and low scrub or fynbos in the Touw River system. Probable causes of change in the distribution of wetland plants include the natural tendency of plants to colonise new areas, as well as anthropogenic manipulation of physical, chemical and biological processes, including the cessation of disturbance by large herbivores, water-level stabilisation, changes in soil salinity and the accumulation of plant litter within wetland areas (Russell 2003).

The changes recorded by Russell (2003) from vegetation mapping of the Wilderness Lakes between 1975 and 1997 were *Phragmites australis* (53.9 ha; +53%), grass or fields (23.1 ha; +35%) and scrub or trees (12.2 ha; +45%). Over the same period the area of human habitation more than doubled (10.8 to 23.3 ha). Substantial declines occurred in the distribution of *Juncus kraussii* (76.2 ha; -243%), *Schoenoplectus scirpoideus* (10.1 ha; -38%) and low scrub or fynbos (7.8 ha; -66%).

Table 8.7: Touw/Wilderness: Vegetation units and their area (ha) in the Touw for 1975/1978 (Modified from Weisser and Howard-Williams) and for 1997 (modified from Russell 2003)

VEGETATION	1978	1997	TREND
Salt marsh *Juncus kraussii*	1.06	-	⇩
Reeds and sedges (total)	9.3	19.7	⇧
Phragmites australis	7.51	19.38	
Scirpus littoralis (Schoenoplectus scirpoideus)	1.55	-	
Scirpus maritimus (Bolbochoenus maritimus)	0.11	0.04	
Cyperus textilis	-	0.27	
Typha latifolia subsp. Capensis	0.13	-	
Floodplain Grassland & Fields	4.71	12.9	⇧
Human Use areas	6.56	23.62	
Total	21.63	56.22	

Stabilization of the water level has resulted in the proliferation of the robust common reed, *P. australis*. The feared loss of biodiversity due to the encroachment of *P. australis* since the 1970s has led to several management interventions being suggested such as cutting, burning, and increasing water and salinity levels (Russell and Kraaij 2008). Cutting alone has been ineffective in the eradication of *P. australis* as it results in higher density. Cutting combined with flooding was more effective as the regeneration of shoots are less likely the longer the flooding period and the higher the water level. For best results, cutting and flooding should coincide with periods of high salinity.

The submerged macrophytes in the lake also respond to salinity. Howard-Williams (1980) showed that lowered water levels coincided with increased salinity and in 1975 *Stuckenia pectinata* disappeared from Rondevlei when salinity increased to 22. As observed for the Swartvlei system the horizontal zonation of the submerged macrophytes was maintained by salinity with *Zostera capensis* at the saline end (35), *Stuckenia pectinata* at the fresh (<10) end and *Ruppia cirrhosa* in between.

There may have been some drying of high lying areas due to breaching at low water levels to prevent the flooding of low-lying residential areas. Decreases in soil salinity would account for the loss of saline macrophytes such as *Juncus kraussii* at the expense of freshwater reeds, sedges and rushes. Disturbance from changes in surrounding land use will have led to increases in nutrients. This would increase the growth of the littoral vegetation, leading to macroalgal blooms and smothering of submerged macrophytes. In the Swartvlei Lake Howard-Williams and Allanson (1981a, 1981b) found that the major nutrient pathway was from the sediments to the water via the macrophytes. *Stuckenia pectinata* took up sediment nutrients, upon decomposition, there was an almost complete breakdown of macrophyte tissue with little sedimenting-out as particulate matter. Nutrient flows in the littoral zone depended not only on the macrophytes but on the complex of bacteria, macrophyte epiphyte algae and fauna. The dense submerged macrophyte beds with their associated epiphytic algae were useful nutrient filters. Any disturbance to these macrophytes would change the nutrient dynamics of the system.

Biomass of submerged macrophytes would also be influenced by waterbird grazing. Red-knobbed Coot feeds almost exclusively on *Stuckenia pectinata* and *Chara* spp. (Russell et al. 2009). Between 1992 and 2005 decreases in submerged macrophyte biomass in Eilandvlei (decreases) and increases in Rondevlei were associated with changes in ducks. There was a dieback of submerged macrophytes in Wilderness Lakes between 1979 and 1981 which was attributed to phytoplankton blooms, development of periphyton on the plants and uprooting of plants by wave action during strong winds (Weisser and Howard-Williams 1982).

8.4.3 Fish

The earliest assessment of the fish community within the Touw and the three lakes was completed between 1982 and 1984 (Hall et al. 1987) over a two-year period and recorded a total of 32 species from 18 families. Since then work by Russell (1996) has looked at changes in fish abundance relative to various environmental factors (recording 14 species from 8 families) whilst Olds (2012) investigated the spatial and temporal abundance and distribution of native and alien fish within the system. The two previous studies utilised beach seine nets and gill nets for their sampling whilst Olds (2012) incorporated both Fyke nets and scoop nets in addition to seine and gill nets, recording 26 species from 18 families. During a once-off sampling of the Touw using beach seine and gill nets (James and Harrison, 2008) 18 species from 11 families were sampled whilst seine net sampling in 2014 (DWS 2014) resulted in 18 species from ten families being recorded.

Overall the Touw/Wilderness Lakes system ichthyofauna comprises fishes in all but one (pure marine – category III) of Whitfield's (1998) estuarine categories, the majority falling within the marine migratory component with small proportions of native estuarine species, catadromous and alien freshwater species (Tables 7.8 and 7.9). Estuarine resident species that spawn only within estuaries (Ia) are represented by one species whilst resident species spawning both in estuaries and nearshore marine environments (Ib) are represented by seven species. Obligate estuary dependent species (IIa) comprise nine species with four partially estuary dependent fish species (IIb and IIc). Catadromous species comprise the longfin eel (*Anguilla mossambica*) and the facultative catadromous freshwater mullet (*Myxus capensis*). Of the four freshwater species found within the system, none are endemic, and all are classified as alien invasive. In describing the fish community throughout the system Olds (2012) showed that the proportion of species in each estuarine category was independent of sampling area but the relative biomass of species in each estuarine group showed significant spatial variation throughout the system.

Native estuarine species contributed between 15% and 21% in each of the lakes and the Touw (highest in the Touw and Rondevlei) and euryhaline marine species contributed between 29% (Langvlei) and 66% (Eilandvlei). Rondevlei had the highest biomass (20%) of catadromous species and Touw the lowest biomass (2.2%) whilst alien species dominated within Langvlei (52%). Overall, there is a high degree of estuarine dependency with 85% of the fish assemblage comprising fish species that are either partially or completely dependent on estuaries (DWS 2014).

During both Hall's (1987) and Olds (2012) surveys the Touw and Eilandvlei held the highest number of species indicating that these areas form the major nursery areas of the system. There were slight variations between studies but overall Mugilidae (5 species), Sparidae (2 to 5 species) and Gobidae (2 to 4 species) were the most important families represented (Tables 7.10 and 7.11). Numerically, *Atherina breviceps* (60%) and *Gilchristella aestuaria* (38.6%) dominated the fish assemblage in the Touw during the 2012 seine net surveys (Olds 2012).

Table 8.8: Touw/Wilderness: Fish species sampled in 30 m seine net in Touw, Eilandvlei, Langvlei and Rondevlei expressed as percent relative number of fish (%N), frequency of occurrence (%FO), percentage mass of fish (%M) and the index of relative importance (%IRI) (n is shown in parenthesis)

SPECIES	EA	TOUW				EILANDVLEI				LANGVLEI				RONDEVLEI			
		%N (51439 fish)	%FO (36 hauls)	%M (158098g)	IRI	%N (58184 fish)	%FO (24 hauls)	%M (179472g)	IRI	%N (18751 fish)	%FO (18 hauls)	%M (79798g)	IRI	%N (21681 fish)	%FO (13 hauls)	%M (80706g)	IRI
Atherina breviceps	Ib	60.1	72.2	14.5	50.70	54.0	83.3	17.4	47.12	15.3	38.9	10.8	9.60	26.5	53.8	14.7	15.75
Gilchristella aestuaria	Ib	38.6	63.9	16.0	32.80	41.5	79.2	16.6	36.48	73.2	66.7	16.1	56.27	39.3	84.6	16.9	33.80
Caffrogobius gilchristi	Ib	0.002	2.8	0.01	0.0002	0	0	0	0	0	0	0	0	0	0	0	0
Psammogobius knysnaensis	Ib	0.4	63.9	0.2	0.33	0.2	50.0	0.2	0.14	0.01	5.6	0.001	0.0004	0.03	30.8	0.01	0.007
Redigobius dewaali	Ib	0.01	8.3	0.001	0.001	0.002	4.2	0.0004	0.0001	0	0	0	0	0	0	0	0
Hyporhamphus capensis	Ia	0.004	2.8	0.0001	0.0001	0.7	66.7	3.3	2.14	11.2	77.8	15.6	19.72	34.0	76.9	44.2	42.74
Syngnathus acus	Ib	0.1	30.6	0.02	0.03	0.02	25.0	0.01	0.01	0	0	0	0	0.02	15.4	0.01	0.004
Lichia amia	IIb	0.01	11.1	2.2	0.23	0.01	8.3	7.9	0.52	0	0	0	0	0	0	0	0
Monodactylus falciformis	IIa	0.03	22.2	0.6	0.12	0	0	0	0	0	0	0	0	0	0	0	0
Mugil cephalus	IIa	0	0	0	0	0.002	4.2	0.3	0.01	0	0	0	0	0	0	0	0
Liza richardsonii	IIc	0.04	11.1	7.7	0.80	0.03	12.5	6.1	0.61	0.1	22.2	11.2	2.35	0.1	30.8	9.78	2.154
juvenile Mugilidae	IIa	0.2	5.6	0.1	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Lithognathus lithognathus	IIa	0.1	27.8	15.3	4.00	0.1	62.5	13.9	6.91	0	0	0	0	0	0	0	0
Rhabdosargus holubi	IV	0.2	30.6	22.3	6.50	0.1	20.8	9.2	1.53	0	0	0	0	0	0	0	0
Oreochromis mossambicus	IV	0.2	22.2	20.9	4.40	3.4	25.0	13.9	3.42	0.1	38.9	22.5	8.31	0.1	53.8	14.4	5.543
Cyprinus carpio	IV	0.004	2.8	0.0003	0.0001	0.01	12.5	11.1	1.10	0.03	16.7	20.6	3.25	0	0	0	0
Gambusia affinis	IV	0.2	27.8	0.01	0.06	0	0	0	0	0	0	0	0	0	0	0	0
Myxus capensis	Vb	0.002	2.8	0.2	0.005	0	0	0	0	0.02	16.7	3.1	0.49	0	0	0	0

Table 8.9: Touw/Wilderness: Fish species sampled in gill nets in Touw, Eilandvlei, Langvlei and Rondevlei expressed as percent relative number of fish (%N), frequency of occurrence (%FO), percentage mass of fish (%M) and the index of relative importance (%IRI) (IRI=FO(N%+M%) (n is indicated in parentheses)

SPECIES	EA	TOUW (n= 134)				EILANDVLEI (n= 414)				LANGVLEI (n= 580)				RONDEVLEI (n= 355)			
		%N (134 fish)	%FO (16 nets)	%M (68.0 kg)	%IRI	%N (414 fish)	%FO (24 nets)	%M (278.3 kg)	%IRI	%N (580 fish)	%FO (24 nets)	%M (237.3 kg)	%IRI	%N (355 fish)	%FO (24 nets)	%M (317.3 kg)	%IRI
Galeichthys feliceps	IIb	39.6	18.8	4.4	14.53	0	0	0	0	0	0	0	0	0	0	0	0
Lichia amia	IIb	4.5	18.8	9.8	4.72	1.7	16.7	9.4	1.33	0	0	0	0	0.3	4.2	3.4	0.13
Elops machnata	IIa	0	0	0	0	0.2	4.2	0.5	0.02	0	0	0	0	0	0	0	0
Pomadasys commersonnii	IIa	14.9	56.3	26	40.59	15.9	75.0	22.1	20.4	0	0	0	0	0.3	4.2	1.4	0.06
Monodactylus falciformis	IIa	9.0	18.8	1.1	3.34	3.4	33.3	0.7	0.97	47.9	87.5	9.8	42.6	26.5	75.0	5.9	20.40
Mugil cephalus	IIa	0.7	6.3	1.7	0.27	3.1	25.0	6.3	1.70	0.5	12.5	2.2	0.29	2.3	25.0	5.3	1.58
Liza dumerili	IIb	1.5	12.5	0.7	0.47	20.8	75.0	8.9	16.00	0.2	4.2	0.1	0.01	0	0	0	0
Liza richardsonii	IIc	17.2	37.5	15.8	21.84	39.9	91.7	35.8	49.70	9.8	70.8	16.2	15.50	23.7	79.2	21.1	29.90
Liza tricuspidens	IIb	0	0	0	0	0.5	8.3	0.8	0.08	0	0	0	0	0.8	8.3	0.7	0.11
Argyrosomus japonicus	IIa	0	0	0	0	0.2	4.2	0.2	0.01	0	0	0	0	0	0	0	0
Lithognathus lithognathus	IIa	3.0	12.5	3.3	1.40	5.8	50.0	8.7	5.19	0	0	0	0	1.7	16.7	8.9	1.49
Rhabdosargus holubi	IV	0	0	0	0	1.7	20.8	1.3	0.44	0.3	4.2	0.3	0.02	5.1	25.0	0.1	1.08
Oreochromis mossambicus	IV	4.5	12.5	29.9	7.59	0.2	4.2	0.03	0.01	36.2	50.0	53.5	37.8	8.2	45.8	23.3	12.10
Cyprinus carpio	IV	0.7	6.3	0.2	0.10	0	0	0	0	0	0	0	0	0	0	0	0
Myxus capensis	Vb	4.5	25	7.2	5.217	6.5	50.0	5.0	4.14	5.0	45.8	4.8	3.78	31.0	70.8	24.6	33.20

However these surveys were conducted after a prolonged drought period (closed mouth) with limited recruitment potential of euryhaline marine species (highlighted by a lack of juveniles sampled throughout the system). Dominant species caught within the gillnet surveys included *Galeichthys feliceps* (39%), *Liza richardsonii* (17%), *Pomadasys commersonnii* (15%), *Monodactylus falciformis* (9%), *Oreochromis mossambicus*, *Myxus capensis*, *Lichia amia* (all 4.5%) and *Lithognathus lithognathus* (3%). The most important species by mass in the gill nets were *O. mossambicus* (30%), *P. commersonnii* (26%), *L. richardsonii* (16%) and *L. amia* (9.8%) (Olds, 2012). In comparison to Hall *et al*. (1987), *L. richardsonii* dominated numerically followed by *Rhabdosargus holubi* (15%), *G. aestuaria* (8%) and *Mugil cephalus* (7%). In terms of biomass although *L. richardsonii* dominated (22%) this was followed by *Argyrosomus japonicas* (18%), *L. lithognathus* (14%), *Liza dumerilii* and *L. amia* (both 12%). The low representation of both *A. japonicus* and *L. lithognathus* in later studies is more than likely a reflection of their national decline rather than local recruitment changes. The dominant species in terms of numbers during the once-off survey by James and Harrison (2008) were *L. richardsonii* (36.8%), *R. holubi* (18%), juvenile mugillids (13%), *L. dumerili* (8.4%), *Psammogobius knysnaensis* (7.3%) and *Caffrogobius gilchristi* (4%). The most important species by mass were *L. richardsonii* (60.6%), *L. dumerili* (15.5%), *O. mossambicus* (7.2%) and *L. lithognathus* (4.4%) (DWS 2014).

Table 8.10: Touw/Wilderness: Summary table showing overall distribution of fish species sampled from the system, Western Cape, South Africa between autumn 2010 and summer 2011

EA = Estuarine Association category (after Whitfield 1998), Locality: TE= Touw; SC= Serpentine channel; EV= Eilandvlei; C= channel; LV= Langvlei, RLC= Rondevlei-Langvlei channel and RV= Rondevlei. Sampling gear type: F= Fyke, 10 m= 10 m seine net, 30 m= 30 m seine net, G= gill net and A= angling. Black shading indicates confirmed distribution and grey indicates probable distribution due to a catch higher up the system.

FAMILY	SPECIES	EA	LOCALITY							GEAR TYPE
			TE	SC	EV	C	LV	RLC	RV	
Anguilidae	*Anguilla mossambica*	Va	■	▒	■					F
Ariidae	*Galeichthys feliceps*	IIb	■							G,F
Atherinidae	*Atherina breviceps*	Ib	■	▒	■	▒	■	■	■	10m, 30m
Carangidae	*Lichia amia*	IIa	■	■	■	▒	▒	▒	■	G, 30m
Cichlidae	*Oreochromis mossambicus**	IV	■	■	■	■	■	■	■	F, 10m, 30m, G
Clupidae	*Gilchristella aestuaria*	Ib	■	▒	■	▒	■	■	■	10m, 30m
Cyprinidae	*Cyprinus carpio**	IV	■	■	■	▒	■	▒	■	F, 30m
Elopidae	*Elops machnata*	IIa	▒	▒	■					G
Gobiidae	*Caffrogobius gilchristi*	Ib	■	■	■					F, 30m
	Glossogobius callidus	Ib	■	■						F
	Psammogobius knysnaensis	Ib	■	■	■	▒	■	■	■	F, 30m,10m
	Redigobius dewaali	Ib	■	▒	■					10m, 30m
Haemulidae	*Pomadasys commersonnii*	IIa	■	■	■	■	▒	▒	■	G
Hemiramphidae	*Hyporhamphus capensis*	Ia	■	▒	■	▒	■	■	■	10m, 30m
Monodactylidae	*Monodactylus falciformis*	IIa	■	■	■	▒	■	▒	■	F, 30m, G
Mugilidae	*Mugil cephalus*	IIa	■	▒	■	▒	■	▒	■	G
	Myxus capensis	Vb	■	■	■	■	■	▒	■	G, 30m
	Liza dumerili	IIb	■	▒	■	▒	■			G
	Liza richardsonii	IIc	■	■	■	■	■	▒	■	F, G, 30m
	Liza tricuspidens	IIb	▒	▒	■	▒	▒	▒	■	G
	juvenile Mugilidae	II	■	■						30m
Poeciliidae	*Gambusia affinis**	IV	■	■	■	■	■	■	■	30m, 10m, S
Sciaenidae	*Argyrosomus japonicus*	IIa	▒	▒	■					G
Soleidae	*Solea bleekeri*	IIa	■	■	■					F
Sparidae	*Lithognathus lithognathus*	IIa	■	▒	■	▒	▒	▒	■	30m, G
	Rhabdosargus holubi	IIa	■	▒	■	▒	■	▒	■	F, 30m, G
Syngnathidae	*Syngnathus acus*	Ib	■	■	■	■	■	■	■	30m, 10m, G

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Olds (2012) determined the establishment success of the alien invasive species concluding that Mozambique tilapia (*Oreochromis mossambicus*) and mosquito fish (*Gambusia affinis*) are established (widespread, abundant and breeding), the common carp (*Cyprinus carpio*) are in an establishing phase (widespread and breeding but low abundance) and the largemouth bass (*Micropterus salmoides*) are causal in that their distribution is limited, abundance is low, and no breeding occurs in the Lakes system.

Table 8.11: Touw/Wilderness: List of all species and families recorded species are classified into five major categories of estuarine dependence as suggested by Whitfield (1994)

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE
OSTEICHTHYES			
Anabantidae	*Sandelia capensis*	Cape kurper	IV
Anguillidae	*Anguilla mossambica*	Longfin eel	Va
	Anguilla bengalensis	African mottled eel	Va
	Anguilla marmorata	Madagascar mottled eel	Va
Ariidae	*Galeichthyes feliceps*	Barbel	IIb
Atherinidae	*Atherina breviceps*	Cape silverside	Ib
Carangidae	*Lichia amia*	Leervis	IIa
	Trachurus capensis	Maasbanker	III
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	IV
	Micropterus salmoides	Largemouth bass	IV
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV
Clinidae	*Clinus superciliosus*	Super klipvis	Ib
Clupeidae	*Gilchristella aestuaria*	Estuarine round herring	Ia
Cyprinidae	*Cyprinus carpio*	Carp	IV
	Pseudobarbus afer	Eastern Cape redfin	IV
Elopidae	*Elops machnata*	King springer, ladyfish	IIa
Gobiidae	*Caffrogobius gilchristii*	Prison goby	Ib
	Glossogobius callidus	River goby	Ib
	Psammogobius knysnaensis	Knysna sandgoby	Ib
	Redigobius dewaali	Checked goby	Ia
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
Hemiramphidae	*Hyporhamphus capensis*	Cape halfbeak	Ia
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mugilidae	*Liza dumerili*	Groovy mullet	IIb
	Liza richardsonii	Harder	IIc
	Liza tricuspidens	Striped mullet	IIb
	Mugil cephalus	Flathead mullet	IIa
	Myxus capensis	Freshwater mullet	Vb
Poeciliidae	*Gambusia affinis*	Mosquito fish	IV
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa
Soleidae	*Heteromycterus capensis*	Cape sole	IIb
	Solea bleekeri	Blackhand sole	IIb
Sparidae	*Lithognathus lithognathus*	White steenbras	IIa
	Rhabdosargus holubi	Cape Stumpnose	IIa
	Rhabdosargus sarba	Tropical stumpnose	IIa
	Sarpa salpa	Strepie	III
Syngnathidae	*Syngnathus temminckii*	Longsnout pipefish	Ib
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III

In comparing the fish community between 1985 and 2012, Olds (2012) has shown an increase in the number of alien invasive freshwater species but relatively little change in the composition and relative abundance of species within other estuarine categories. At the time of the study, there was no evidence that the alien invasive species had a negative impact on the native fish abundance. However, the fish assemblages within each of the lakes differed.

8.5 Present Health Condition

The Wilderness Lakes area has been disturbed by man's activities for many years. The declaration of the National Park in 1983 and listing as a Ramsar site in 1991 reduced some of the pressures such as encroaching development and livestock grazing. Dredging of the channels between the different lake sections has changed water level and salinities causing changes in wetland vegetation. Dredged spoil was deposited adjacent to canals, forming vegetated levees further interfering with water movement (Russell 2003). Historical aerial photographs indicate the changes over time caused by development. Macrophyte habitat associated with the banks of the middle and especially the lower Touw has been disturbed by houses, bank stabilization, slipways and jetties. Hotels, camping, picnic sites, boat launching concentrated around and west of Eilandvlei would have resulted in the removal of some estuarine vegetation.

Major threats included alien invasive species, agriculture in the catchment, low lying development pressures, water resource management and climate change. Large changes in the emergent vegetation have been documented in response to water level fluctuations, herbivory and changes in soil salinity (Russell 2003; Weisser et al. 1992). Between 1979 and 1982 submerged vegetation died back significantly in response to the high water level management policy at the time, planktonic algal blooms, epiphytic growth on submerged plants and uprooting of plants from wave action induced by strong winds. Natural breaching levels in the past were +3.5 m MSL but due to development in the low lying areas, artificial breaching is at a much lower level (2.1 to 2.4 m MSL). The Touw/Wilderness Estuarine Lake system is presently in a category C ecological status while the lakes sections is in a B/C (DWS 2014). The system is highly important as it is an important nursery for collapsed and endangered fish species like dusky cob and elf. It is also an important refuge area along a stretch of coast known for extreme upwelling conditions that can cause fish kills (DWS 2014).

The system is a highly important estuary from a biodiversity perspective (Importance rating score = 72) and a conservation priority (Turpie and Clark 2007; Van Niekerk et al. 2019). The system falls within the Garden Route National Park and a Ramsar site.

Overall, the Touw/Wilderness Estuarine Lake system is in a Near Natural to Moderately Degraded state. Table 7.12 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 8.12: Touw/Wilderness: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Some reduction in flows.		●				
Hydrodynamics	Artificially breached at low water levels to prevent flooding of surrounding urban developments. Sedimentation in the entrance channel is constricting the tide. Reduce connectivity with lakes because of lower water levels.			●			
Salinity	Salinity on the decrease because of reduced connectivity with marine environment. Lower water levels prevent the mixing of saline water into lakes.		●				
General Water Quality	Nutrient enrichment from stormwater (Touw) and agricultural activities in catchments.		●				
Physical habitat	Sedimentation caused by artificially breaching at very low levels. Habitat loss due to infilling, road infrastructure and urban development in floodplain.		●				
Microalgae	Microalgae blooms (particularly benthic) have been detected in the system due to enrichment.			●			
Macrophytes	Loss of riparian vegetation due to urban development. Some reed growth in lakes due to increased retention, lower water levels and enrichment.		●				
Invertebrates	Some change in community composition and biomass, with a decrease in marine species.		●				
Fish	Change in community composition, i.e. loss of marine species. Reduction in abundance due to overfishing. Pathogens and diseases due to poor water quality and/or microalgae blooms. High densities of alien fish in lakes.			●			
Birds	Significant reduction in bird abundance due to human disturbance, reduction of prey species and loss of habitat.				●		
ESTUARY HEALTH	**NEAR NATURAL TO MODERATELY DEGRADED with a downwards trajectory. However, functionality is intact and opportunities for rehabilitation exist.**		⊙				

9. SWARTVLEI

9.1 General Features

The Swartvlei Estuarine Lake (Figure 8.1) system is situated on the Cape south coast and is fed by three rivers that arise in the Outeniqua mountains (Kok and Whitfield 1986). There are two connected but distinct parts of the system; the humic-stained upper reaches (Swartvlei) and the shallow sinuous lower estuary. The MAR to the systems was 83.4 million m^3 under natural conditions, compared with 56.6 million m^3 under the present state (DWA 2009).

Swartvlei has a mean depth of 5.5 m and a maximum depth of 16.7 m (Howard-Williams and Allanson 1981). The lake is 8.8 km^2 with a maximum depth of 16.7 m and a mean depth of 5.5 m. There is a wide littoral shelf, covered in sand, which slopes to a depth of 2 m, followed by a basin of 12 m deep of which the bottom is filled with mud (Whitfield et al. 1983). The lower estuary forms a 7.2 km long shallow channel that links the Swartvlei to the sea, has a maximum depth of 4 m and a water surface area of 2 km^2. The lower estuary is a 7 km long channel extending from the rail bridge to the mouth and is shallow (maximum depth 4 m) with a narrow central channel bordered by intertidal sand flats of varying widths.

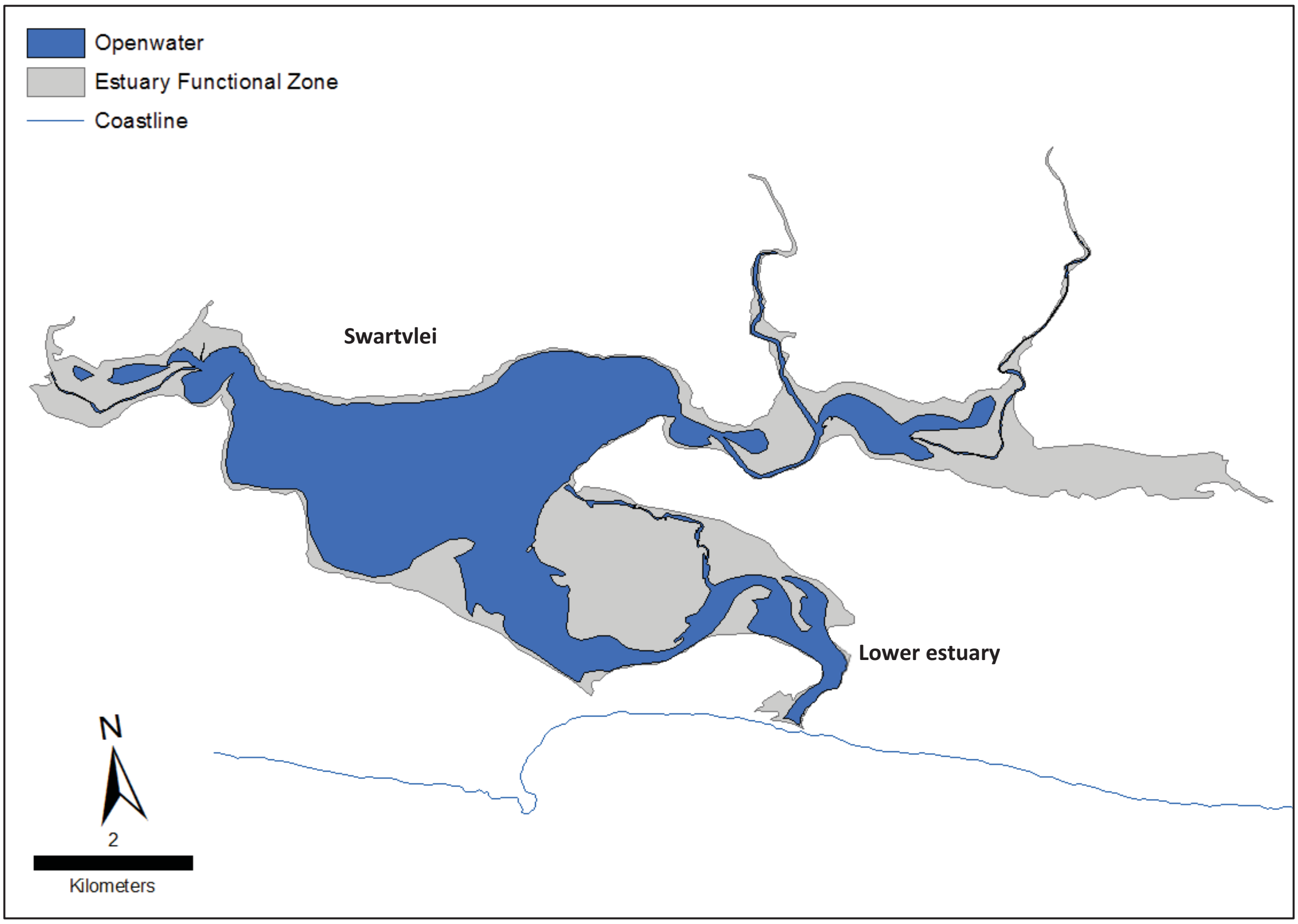

Figure 9.1 Swartvlei: EFZ and openwater area

The estuary mouth frequently closes during the winter owing to the heavy south-westerly wave conditions which are predominantly responsible for longshore sand transport along the Cape south coast (Whitfleld et al. 1983). Salinity in the lower estuary decreases from the mouth to the rail bridge and from spring to neap tides (Liptrot 1978). Swartvlei Lake is subject to fluctuations in salinity owing to seawater inflow.

9.2 Zonation and Abiotic States

Zonation of the Swartvlei system is illustrated in Figure 8.2, depicting the main basin and the lower estuary (DWA 2009).

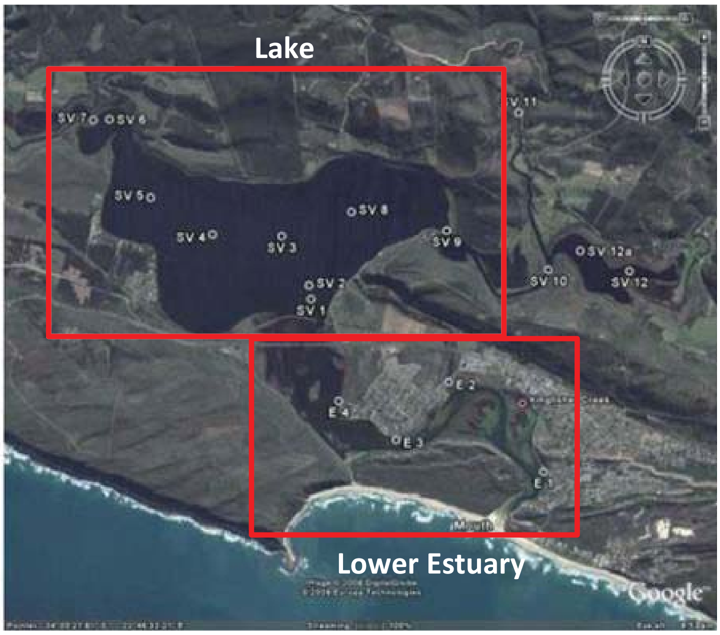

Figure 9.2 Swartvlei: Zonation

Because the Swartvlei system is not driven by seasonal river inflow patterns, but rather interannual patterns, the relationship between "river inflow" and abiotic states can best be described in terms of water levels. Four distinct abiotic states occur in the system (DWA 2009) (Table 8.1).

Table 9.1: Swartvlei: Abiotic states

STATE	DESCRIPTION	AVERAGE WATER LEVEL (m MSL)
1	System is open. Lake exists in stratified (merimitic) state	0-1.5
2	Closed; Lower estuary becomes fresher. Lake moves from stratified (merimitic) state to mixed water body if closure >1 year (~10)	0-2 (Present) 0-3.5 (Reference)
3	Closed; Lower estuary becomes more saline. Lake exists as a mixed water body (salinity~10)	0-3
4	Closed; Lower estuary becomes more saline. Lake exists as a mixed, more saline water body (salinity ~15 and above)	<3

9.3 Abiotic Response Indicators

9.3.1 Mouth dynamics and water levels

The mouth of Swartvlei is sensitive to high wave conditions (coupled with a reduction in runoff) and it shows a tendency to close during the winter when high waves tend to occur more frequently. Unfortunately, a long-term record (84 years) does not exist of the wave conditions along the South Coast. A water balance model was developed to incorporate this aspect by artificially closing the estuary mouth in May. This allows for a comparison between scenarios for the period the systems stay closed due to changes in river inflow to the estuary (DWA 2009).

Swartvlei is sensitive to the neap-spring-neap tidal cycle as more closures occur on or after a neap tide in comparison to a spring tide. As the water balance model is based on monthly time steps this issue is not addressed as part of this study. At present, the estuary mouth is artificially breached at about 2.0 m MSL. In the recent past, the system was even breached between 1.5 and 1.8 m MSL. The Swartvlei System natural breached at levels up to 3.5 m MSL (Fijen 1995).

There is a relationship between the height of the berm and periods between breachings, i.e. the longer the system was closed the higher the berm. This feature is not addressed as part of the water balance model. Mouth closure occurred between 0.5 m MSL and 1.0 m MSL. For the water balance model, mouth closure was taken to occur at a water level of ~0.8 m MSL. Based on a surface area of about 14 200,000 m^2 the Swartvlei requires about 14.2 million m^3 of water to breach at the present breaching level of ~2 m MSL. At the natural breaching level of ~ 3.5 m MSL it would have required about 38.34 million m^3 to breach (Fijen 1995b). Seepage is estimated to be ~ 0.4-0.8 m^3/s, depending on the water level in the lower estuary behind the berm. It was assumed that losses due to seepage were cancelled out by groundwater inflow from the surrounding areas (Fijen 1995b). Overwash events also occur depending on the height of the berm.

In general, the higher the water level in an estuary before a breaching event, the more efficient the scouring of sediment in the estuarine channels and mouth area during a breaching, resulting in longer periods of open mouth conditions after the breaching. This relationship is especially important in the case of the estuarine lakes as a small increase in breaching level results in significantly more outflow at breaching, i.e. a significant increase in scouring potential. Based on the Swartvlei water level data (DWA) and mouth observation data (SANparks) a relationship was established between the water level before breaching and the period the mouth stayed open after a breaching event. According to this relationship, the Swartvlei mouth will close on average within about 2 months at a breaching level of ~1.5 m MSL and remain open for up to 3 years at a breaching level of ~3.5 m MSL. This sensitivity to breaching water levels was incorporated in the water balance model in the form of an assumption that the Swartvlei estuary would not close within 12 months of a natural breaching due to the effective scouring of sediment from the mouth area. This is a somewhat conservative estimate as the system may well have been able to maintain open mouth conditions in excess of two years under low flow conditions. At present, baseflows play an important role in maintaining open mouth conditions in the absence of effective scouring (DWA 2009).

9.3.2 Salinity

The lake area is normally meromictic because of strong vertical stratification (DWA 2009) (Figure 8.3). This is the result of the saline bottom layer (monimolimnion) formed because of the intrusion of saline water from the lower estuary overlaid by a fresher surface layer (mixolimnion) that is sustained by freshwater inflow from the rivers (Allanson and Howard-Williams 1984). Saline intrusion from the lower estuary occurs during the open phase, particularly during spring high tides. Wind stresses required to break down this strong stratification is considerable and as a result the system typically remains in the meromictic state when the mouth of the estuary is open. The depth of the halocline is typically at about 5 m. This stratification in the lake has a marked effect on the fate of flood waters in the system.

Flood water entering the system is typically of lower density (i.e. fresh and possibly colder than the resident water in the lake) and as a result, it flows over the top layer of the lake up to a depth of about 0.5 m. If there are no strong winds during these events very little mixing will occur in the lake, the freshwater layer will extend across the lake and enter the lower estuary at the N2 bridge. Consequently, floods can have relatively little influence on the salinity of the lake (Whitfield et al. 1983). During low inflow periods, when the mouth of the estuary closes, considerable mixing by wind is likely to occur in the lake, gradually breaking down the bottom layer (monimolimnion). The longer the mouth remains closed, the more likely it is that stratification will break down. Low flow periods (possible coinciding with the closed phases) are considered important to prevent incremental increases in salinity in the lake (Whitfield et al. 1983). Marked reductions in base flow could therefore result in the lake becoming more saline (e.g. evaporation exceeds freshwater inflow).

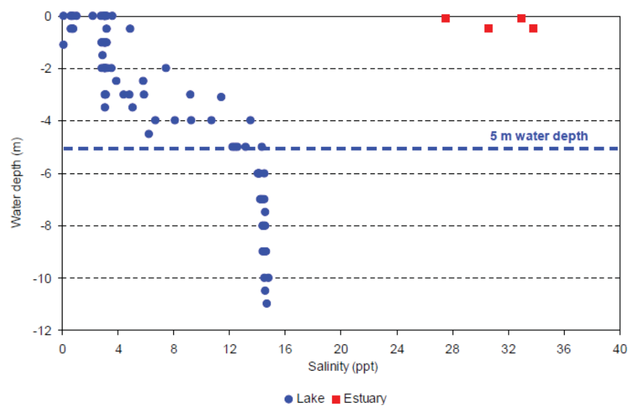

Figure 9.3 Swartvlei: Salinity in the lake and lower estuary (Feb 2008)

Salinity in the lower estuary varies, depending on the state of the mouth. During the open state, salinity decreases from the mouth towards the N2 bridge reflecting tidal influence. During the open marine dominated state, substantial volumes of seawater move into the lower estuary, resulting in high salinities (above 20). During floods, low salinities occur in the lower estuary. After the estuary closes, salinity gradually decreases as waters in the lower estuary become diluted by low inflows from the rivers and from the lake (Fijen 1995b).

9.3.3 Temperature

Water temperature in the lower estuary and lake follow a seasonal trend with winter temperatures typically ranging between 10-14°C and summer temperatures between 25-29°C (Whitfield et al. 1983). When monimolimnion is present, the temperature in this bottom layer will be lower compared with the mixolimnion, particularly during summer (DWA 2009) (Figure 8.4). When the system is open during summer tidal intrusion can introduce cooler temperatures to the lower estuary (Fijen 1995b). Upwelling, known to occur along this part of the coast specifically during summer, can occasionally reduce the temperature in the lower estuary (~10°C) for periods of a few days.

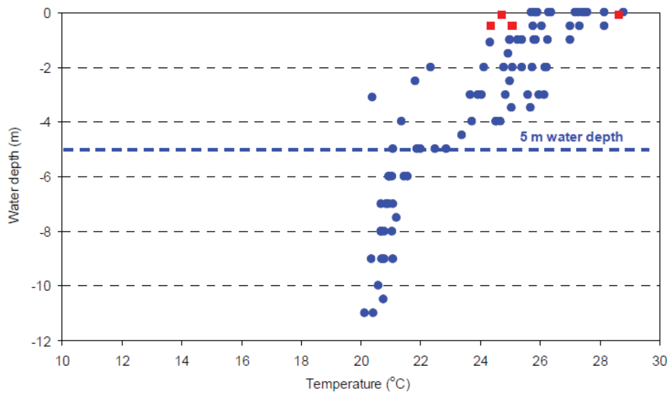

Figure 9.4 Swartvlei: Temperature in lake and estuary (Feb 2008)

9.4 Biological Response Indicators

9.4.1 Microalgae

Phytoplankton: One week after an August 2006 flood, chlorophyll *a* was low (<1.0 µg/ℓ) throughout the lower estuary and lake. After 20 days, distinct maxima were measured at the sites in tributaries entering the lake: 7.8 ± 4.3 µg/ℓ (9.7 km from mouth) and 4.6 ± 2.5 µg/ℓ (10.8 km from the mouth) respectively. These maxima persisted to the following sampling session (+ 52 days) and increased in concentration; 21.5 ± 10.1 µg/ℓ and 10.4 ± 2.7 µg/ℓ respectively. Vertically averaged salinity measured at the interfaces ranged from 2.4 to 5.7, which are consistent with previous studies of river-estuary interfaces (the sector where maximum water column chlorophyll *a* occurs and where integrated vertical salinity values are generally less than 10 (Snow et al. 2000). There was a poor relationship between phytoplankton chlorophyll *a* and nutrient concentrations throughout the study period. Based on these results, phytoplankton biomass is elevated in the Swartvlei Lake, at the point of entry of the two main tributaries, and the river input can sustain phytoplankton biomass exceeding 20 µg/ℓ (representative of an algal bloom). In fact, chlorophyll *a* exceeded 50 µg/ℓ in surface waters of the small tributaries 52 days after the flood. No samples were analysed for community structure but the presence of a salinity gradient, both vertical and longitudinal in the lower estuary, suggests that a dinoflagellate bloom could have contributed to the chl-*a* peak. It is expected that as river flow decreases and becomes negligible, there would be a shift from an estuary dominated by dinoflagellates and some diatoms to one dominated by cryptophytes and cyanophytes (associated with anoxic conditions at depth) (DWA 2009).

Benthic microalgae: No data are available for benthic microalgae. It is expected that the low nutrient concentrations in the system as well as the coarse sediments in the system would only support a low median chl-*a* content, i.e. < 50 mg m^{-2} (excl. epiphytic microalgae). The benthic microalgal community is likely to be made up of episammic taxa on exposed sand and epiphytic species on the large stands of *Phragmites australis* in the upper reaches of the lake (in the tributaries), *Zostera capensis* and *Ruppia cirrosa* beds in the lower estuary and *Stuckenia pectinata* within the lake itself (DWA 2009).

9.4.2 Macrophytes

Howard-Williams and Allanson (1979) identified five dominant aquatic macrophytes in Swartvlei; *Stuckenia pectinate*, *Chara globularis var kraussii*, *Lamprothamnium papulosum*, *P. australis* and *Scirpus littoralis*. Recorded vegetation cover was captured by Whitfield et al. (1983). In the 70s the littoral (vegetated) zone covered one-third of the lake area. Chara beds covered 65% of the littoral zone and occurred in the shallows (<1 m depth). *P. pectinatus* covered 26% and extended into deeper areas (2-2.6 m). The macroalga *Ulva instestinalis* was reported to form dense mats in the lower estuary. The submerged macrophytes produce high biomass of up to 2500 g m^{-2} of dry matter per year (Howard-Williams, 1978 and 1981). According to Howard-Williams and Allanson (1979) the centre of biological productivity for the lake lies on the edges of the lake to a depth of 2 m below MSL. This littoral zone contributes almost 10 times more organic matter to the lake than the pelagic zone. Associated with the littoral plants is a large invertebrate population of bivalves, isopods, amphipods and crabs, which attract many of the 33 fish species found in the lake (Whitfield et al. 1983). Whitfield (1988) showed the importance of the detrital pathway as most of the fish biomass was supported directly or indirectly by detritus. Utilisation of *P. pectinatus* in Swartvlei is on the foliage, seeds and flowers. The resident population of coot (*Fulica cristata*) feeds exclusively on aquatic macrophytes of the littoral zone (Howard-Williams and Allanson 1979). Whitfield (1988) showed that plant consumption by herbivorous fishes in the lower estuary centred around filamentous algae and diatoms growing on *Z. capensis* rather than seagrass leaf material.

In the lower estuary, dense macrophyte beds occur of both *Zostera capensis* and *Ruppia cirrhosa*. These support a large epiphytic algal community. The green alga, *Enteromorpha*, initially attaches as an epiphyte, but soon exceeds the mass of the supporting leaves and then forms dense algal mats over the *Zostera* in winter. The bottom of the channel is usually bare of macrophytes (Whitfield et al. 1983). The marginal salt marshes of the lower estuary occupy about 65 ha and are flooded during high spring tide and when the mouth is closed (Whitfield et al., 1983). Species present were *Sarcocornia natalensis*, *Salicornia meyeriana*, *Paspalum vaginatum*, *Sporobolus virginicus* and *Juncus kraussii*. The lower estuary and associated wetlands are considered as an area of high conservation value and were identified for special protection to reduce any potential habitat loss and to minimize tourist and development impacts (DWA 2009).

Changes over time: Howard-Williams and Allanson (1979) compared the distribution of plants for 1936, 1958 and 1974 photographs. Construction of the road and railway bridge in the 1950s resulted in sediment deposition, colonisation and spread of the sedge, *Scirpus littoralis*. Cartographic evidence on estuary changes was looked for and significant changes that could be discerned from historical and recent maps, as well as from sets of aerial photographs, were a progressive drying out of the low-lying area between the upper portion of the lower estuary and the Perdespruit channel. These drying out processes can be associated with the increasing practise of premature, artificial mouth breachings, aimed at the prevention of inundation of these wetlands. On a smaller scale, increased erosion in the feeding rivers has formed sand spits where these rivers enter the lake (Whitfield, et al., 1983).

Macrophyte encroachment occurred historically during dry periods when water clarity improved, and regression occurred during rainy periods due to the humic laden freshwater input. In 1979 the littoral zone was dominated by *P. pectinatus*, *C. globularis* and *Lamprothamnium papulosum*. This community was replaced by filamentous algal mats during 1980. This was related to a flood in September 1979 which decreased water transparency. In 1981 these disappeared, and the littoral was transformed into a sandy habitat.

Whitfield (1986) showed that these changes caused a highly significant decline in the numbers of fishes in the littoral zone. Mullet stocks increased which was attributed to the increase in benthic microalgal production. Unpublished SANParks data (Russell pers. comm.) have shown that the biomass and population size of submerged macrophytes in the Swartvlei system has remained stable in recent years despite changes in turbidity. However, the large floods in 2006 and 2007 both resulted in a 50% decrease in biomass.

Table 9.2: Swartvlei: Area covered by macrophyte habitats (Whitfield et al. 1983)

HABITAT	AREA (ha)	% AREA	% MACROPHYTE
Zostera capensis	22.89	1.8	4.4
Ruppia cirrhosa	69.69	5.4	13.4
Stuckenia pectinate	78.21	6.1	15.0
Z. capensis, R. cirrhosa	35.47	2.8	6.8
Ruppia cirrhosa + Charophyta	13.13	1.0	2.5
Scirpus littoralis, Phragmites australis	114.03	8.9	21.8
Juncus kraussii & Scirpus nodosus	53.03	4.1	10.2
Tidal salt marsh	135.57	10.5	26.0
Sand	133.36	10.4	-
Water	630.91	49.0	-

Recently the submerged aquatic *Ceratophyllum demersum* has been found in Swartvlei which could indicate a decrease in salinity of the lake. However, the recent floods, scouring and open mouth conditions have caused an increase in lake salinity. Salinity on 23 Jul 2008 was measured at 15 and there was die-back of the submerged macrophyte, *S. pectinata* (Allanson pers. comm.). Encroaching development and reclamation has resulted in a loss of approximately 10% of macrophyte habitat in the lower estuary and 5% in the lake. This loss is insignificant in relation to the large changes that have taken place in the surrounding areas and catchment. Development increases nutrient input and change in land-use causes silt run-off which could cause significant changes in the Swartvlei system (DWA 2009).

9.4.3 Fish

At least 33 fish species are known to occur in Swartvlei and 58 species in the lower estuary (DWA 2009). Many of these taxa are either totally or partially dependent on the estuarine environment and a high proportion of the species found within the system are endemic to southern Africa. The rare and endangered Knysna seahorse (*Hippocampus capensis*), which is confined to three estuaries in the southern Cape, is found within aquatic macrophyte beds of the lower estuary. The large number of juvenile marine fish that occur in the littoral zone of both the lake and lower estuary reflects the importance of this large system to many coastal species.

Table 9.3: Swartvlei: A list of all species recorded in the system. The species are arranged according to family (27) and the five major categories of estuarine dependence as suggested by Whitfield 1994.

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE CATEGORY
Osteichthyes			
Anabantidae	*Sandelia capensis*	Cape kurper	IV
Anguillidae	*Anguilla bengalensis*	African mottled eel*	Va
	Anguilla marmorata	Madagascar mottled eel*	Va
	Anguilla mossambica	Longfin eel	Va
Ariidae	*Galeichthyes feliceps*	Barbel	IIb
Atherinidae	*Atherina breviceps*	Cape silverside	Ib
Carangidae	*Lichia amia*	Leervis	IIa
Centrarchidae	*Lepomis macrochirus*	Bluegill sunfish	IV
	Micropterus punctatus	Spotted bass	IV
	Micropterus dolomieu	Smallmouth bass	IV
	Micropterus salmoides	Largemouth bass	IV
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV
	Tilapia sparrmanii	Banded tilapia	IV
Clinidae	*Clinus spatulatus*	Bot River klipvis	Ib
Clupeidae	*Gilchristella aestuaria*	Estuarine roundherring	Ia
Elopidae	*Elops machnata*	Ladyfish	IIa
Galaxiidae	*Galaxias zebratus*	Cape galaxias	IV
Gobiidae	*Caffrogobius gilchristi*	Prison goby	Ib
	Caffrogobius natalensis	Baldy	Ib
	Caffrogobius nudiceps	Barehead goby	Ib
	Caffrogobius saldanha	Commafin goby	Ib
	Psammogobius knysnaensis	Knysna sand-goby	Ia/Ib
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
	Pomadasys olivaceum	Piggy	III
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc
	Hyporhamphus capensis	Cape halfbeak	Ib
Lobotidae	*Lobotes surinamensis*	Tripletail	III
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mugilidae	*Liza dumerilii*	Groovy mullet	IIb
	Liza richardsonii	Harder	IIc
	Liza tricuspidens	Striped mullet	IIb
	Mugil cephalus	Springer mullet	IIa/Vb
	Myxus capensis	Freshwater mullet	IIa/Vb
Ophiichthidae	*Ophisurus serpens*	Sand snake-eel	III
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc
Sciaenidae	*Argyrosomus japonicus*	Dusky kob	IIa
	Atractoscion aequidens	Geelbek	III
Soleidae	*Heteromycteris capensis*	Cape sole	IIb
	Solea turbynei	Blackhand sole	IIb
Sparidae	*Diplodus hottentotus*	Wildeperd / zebra	III
	Diplodus capensis	Blacktail / dassie	IIc
	Lithognathus lithognathus	White steenbras	IIa
	Rhabdosargus globiceps	White stumpnose	IIc
	Rhabdosargus holubi	Cape Stumpnose	IIa
	Sarpa salpa	Strepie	III

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE CATEGORY
	Spondyliosoma emarginatum	Steentjie	III
Syngnathidae	*Syngnathus temminckii*	Pipefish	Ib
Tetraodontidae	*Amblyrhynchotes honckenii*	Blaasop	III
Triglidae	*Chelidonichthys capensis*	Cape gurnard	III
Osteichthyes			
Triakidae	*Mustelus*	Smooth houndshark	III
Rhinobatidae	*Acroteriobatus annulatus*	Lesser sandshark /guitarfish	III

9.5 Present Health Condition

The Railway bridge near where the N2 crosses the Swartvlei system acts as an obstruction to flood flows, reducing scouring of the lower estuary. It also limits tidal flows, but these would not increase significantly if the bridge was removed, because of the shallowness of the system. The support structures of the Railway bridge also constrain the penetration of saline water from the lower estuary into the lake potentially reducing the lake salinities. Diffuse stormwater runoff introduces nutrients and possibly increased levels of toxic substances. The introduction of agricultural chemicals in the catchments may also have resulted in some accumulation of these chemicals, specifically in the lake. Resort developments along the banks use septic tanks, which could be a source of nutrient enrichment during the peak holiday periods or when high lake levels flood these tanks. The Swartvlei is artificially breached at much lower levels than under natural, with breaching levels being reduced from about 3.5 m MSL to 2 m MSL at present. In the 70s and 80s the system was breached at levels between 1.5 and 1.8 m MSL. The lower breaching levels is causing sedimentation in the lower estuary and reducing the period the mouth can stay open. There has been extensive clearing of estuarine and riparian vegetation within the EFZ of the system for development and agriculture. The system is subjected to significant fishing pressures.

The Swartvlei Estuarine Lake system is a highly important estuarine system from a biodiversity perspective and a conservation priority (DWS 2009, Van Niekerk et al. 2019). The system falls within the Garden Route National Park and a Ramsar site. The system is in a Near Natural to Moderately Degraded state. Table 8.3 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 9.4: Swartvlei: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Some reduction in flows.		●				
Hydrodynamics	Artificially breached at low water levels to prevent flooding of surrounding urban developments. Sedimentation in the entrance channel is constricting the tide. Railway and road bridge reducing connectivity. Reduce connectivity with main lake as a result of lower water levels.			●			
Salinity	Salinity is on the decrease as a result of reduced connectivity with the marine environment. Lower water levels also prevent the mixing of saline water into lake.			●			
General Water Quality	Some nutrient enrichment from stormwater (lower estuary) and agricultural activities in catchments.		●				
Physical habitat	Sedimentation caused by artificially breaching at very low levels. Habitat loss due to infilling, road infrastructure and urban development in floodplain.		●				
Microalgae	Microalgae biomass increasing possibly due to enrichment.		●				

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Macrophytes	Loss of riparian vegetation due to urban development. Some reed growth in lakes due to increased retention, lower water levels and enrichment.			●			
Invertebrates	Some change in community composition and biomass, with a decrease in marine species.		●				
Fish	Change in community composition and biomass, i.e. loss of marine species. Reduction in abundance due to overfishing.			●			
Birds	Some reduction in bird abundance due to human disturbance, reduction of prey species and loss of habitat.			●			
ESTUARY HEALTH	**NATURAL TO NEAR NATURAL with a downwards trajectory. However, functionality is intact and opportunities for rehabilitation exist.**		⊙				

10. uMHLATHUZE

10.1General Features

Pre-development, uMhlathuze Estuarine Lake was a large system covering some 3 100 ha comprising two main parts; a broad shallow lake '"Umhlatuzi Lake') and a narrow channel to the sea (Millard and Harrison 1954) (Figure 12.1). The present-day classification of South African estuaries would have categorised the system in this pre-development state as an estuarine lake (Weerts and Macka, 2019). The naturally narrow and shallow mouth constrained the tidal range in the lower estuarine channel to 0.5 m and 0.2 m across the lake. Salinities were marine (>30) in the channel and typically polyhaline (18-30) in the lake (Millard and Harrison, 1954). The low tidal range restricted mangrove distribution to the system's lower reaches and the eastern shore of the lake. Swamp vegetation (*Phragmites* reeds and *Juncus* rushes) covered most of the lake's banks and played an important role in trapping river sediments and preventing siltation and shallowing of the system. Eelgrass beds (*Zostera capensis*) covered extensive areas in the upper and middle channel where sediments were muddy sand and water was more saline and less turbid than in the lake. Sediments were sandy at the mouth and muddy in the lake. The system's ecology was driven by its hydrology, the estuarine salinity gradient, the nature of the sediments and the *Zostera* beds, which provided habitat for an abundance and diversity of small fish and crustaceans and a productive detrital food base for the greater system. uMhlathuze was recognised as one of the most productive, diverse and least impacted estuaries in KwaZulu-Natal when still functioned as an estuarine lake system (Millard and Harrison 1954).

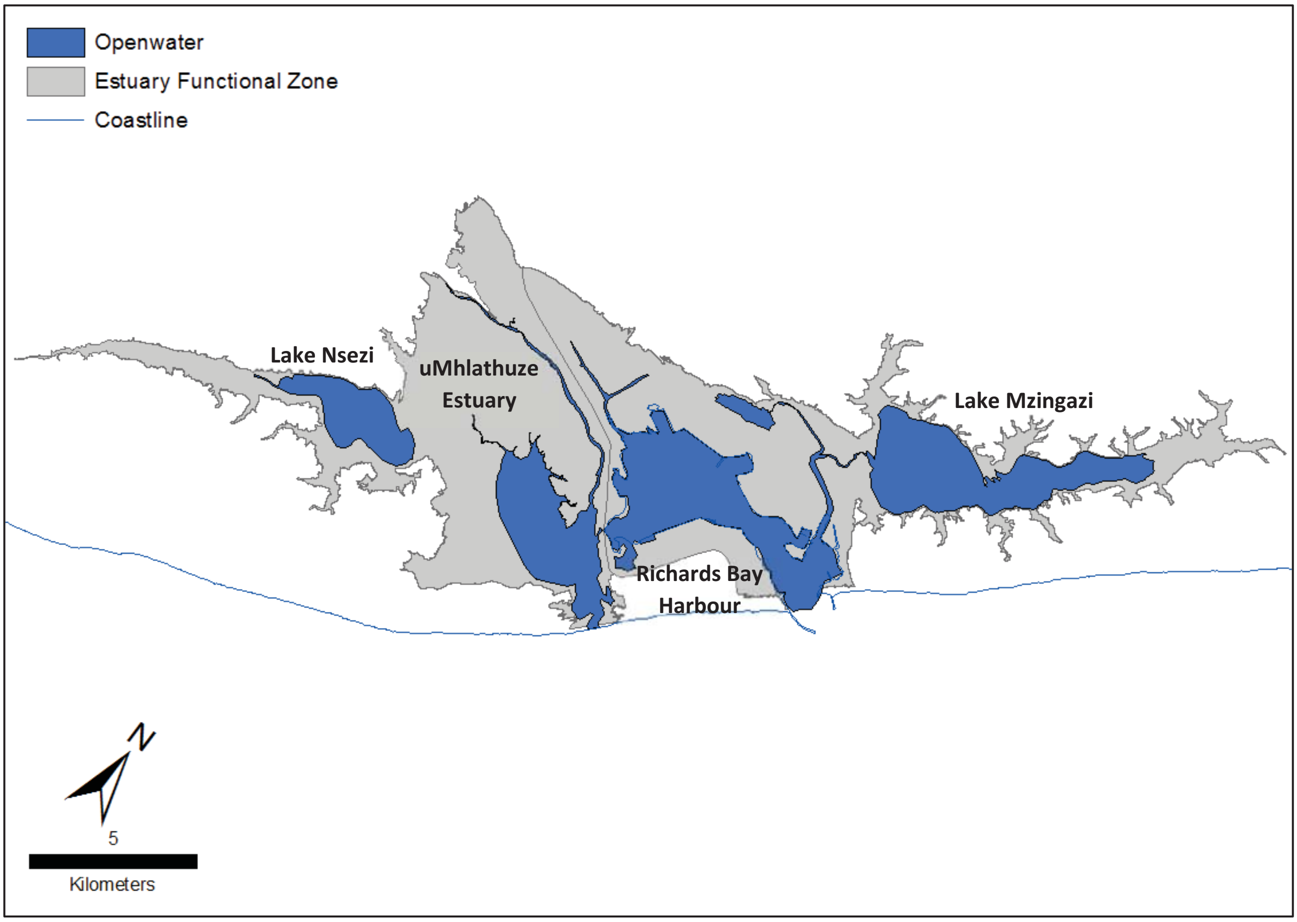

Figure 10.1 uMhlathuze: EFZ and openwater area

This changed in 1972 when construction of a deepwater port commenced, entailing the division of the previously undisturbed system into two sections (Figure 12.2) by the construction of a 4 km long dividing berm (Weerts and Cyrus 2002). The bay to the north-east was given over to development and has grown into South Africa's largest port, the Port of Richards Bay ('Richards Bay Estuary') The remaining area (approximately 1 200 ha) to the south-west of the berm was designated as a nature sanctuary (now 'uMhlathuze Estuary') following the re-routing and canalisation of the lower uMhlathuze River and cutting of a new estuary mouth (Begg 1978). These changes had immediate and far-reaching impacts. *Zostera* beds were destroyed, and fish and crustacean species associated with eelgrass were lost. The widening and deepening of the pre-existing mouth to act as a port entrance channel, and the cutting of a new mouth to serve the sanctuary area, resulted in a significant increase in tidal range in both new basins with consequent tidal exposure of previously shallow subtidal areas. Large areas of shallow subtidal habitat were lost with a concomitant increase in the intertidal area. Changes in residence time caused by increased tidal flushing reduced plankton productivity. Nevertheless, connectivity to the sea allowed continued recruitment of marine spawned biota to both the new port and the sanctuary (CSIR/NIWR 1976) and an essentially estuarine character and function was retained in both the Richards Bay Estuary (an estuarine bay) and uMhlathuze Estuary (a predominantly open system).

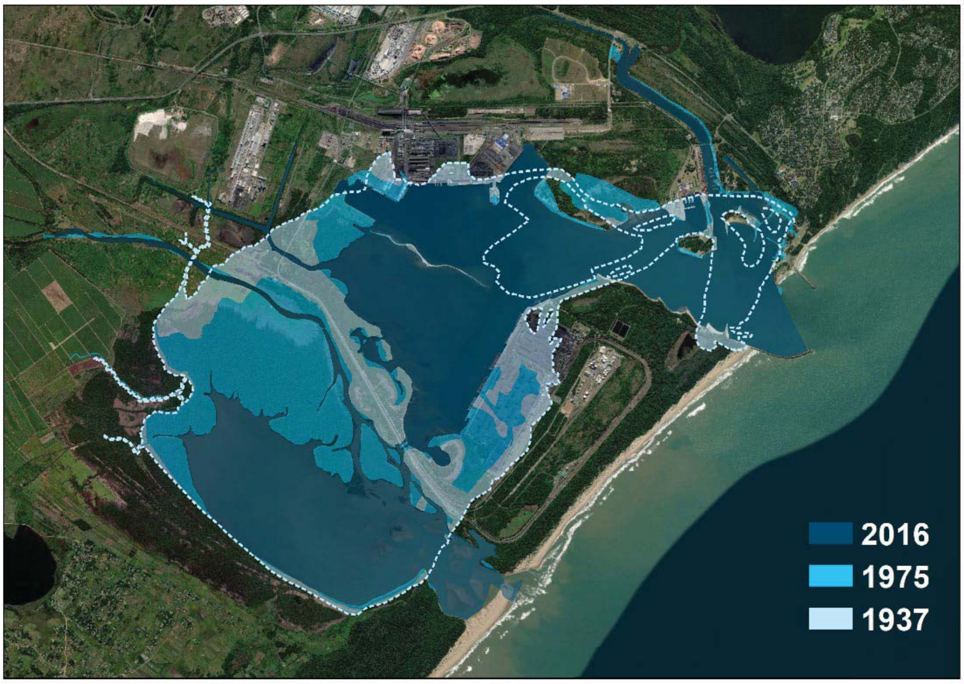

Figure 10.2 uMhlathuze: Effects of port development (Source: Weerts and Mackay 2019)

Three lakes, Nsezi, Cubhu and Mzingazi originally formed part of the uMhlathuze system (now disconnected). Of these Cubhu and Mzingazi could be categorised as being at least partly estuarine in character, up until the recent past at least. All three of these lakes are regulated at their outflows by weirs and maintain a surface elevation above sea level. Lake Nsezi is a drowned river valley with a surface area of 614 ha fed by the Nseleni River and augmented via an intrabasin water transfer from the uMhlathuze River. Drainage via the Nseleni flows into the lower reaches of the Mhlathuze River close to the tidal and saline head of the Mhlathuze and is thus not directly connected. Lake Cubhu, with a surface area of 450 ha is a relict estuarine lake (Cyrus and Martin 1988) and drains into Mhlathuze Estuary via the Mtantatweni River. Mzingazi is also a relict estuarine lake with a surface area of 1 216 ha and flows into Richards Bay. (Harding 2000), the only one that reaches depths below mean sea level in its basin (Kelbe and Germishuyse 2010). This prompted the construction of a saltwater barrier across the draining Mzingazi River to prevent possible intrusion of saline water into the lake during drought years. Saline harbour water pushes up the Mzingazi Canal to the base of this saltwater barrier with the incoming tide (Weerts et al., 2014). Of the three coastal lakes, Cubhu and Mzingazi have historically acted as significant nursery areas for estuarine associated fishes. This role has significantly declined in recent years due to the construction of weirs at their outlets prohibiting successful recruitment by most species, increasing the regional importance of Mhlathuze Estuary and Richards Bay Estuary as nursery habitats for estuarine fishes (Weerts and Cyrus 2001; Weerts et al., 2014).

The uMhlathuze catchment has a MAR of 560 million m^3. Goedertrouw Dam is a major dam in the catchment, located about 85 km inland of Richards Bay. It was completed in 1980 to supply water for irrigation in the lower catchment and assist in the bulk water supply for urban and industrial development near the coast. The original capacity was 321 million m^3 but this has been reduced by siltation to about 300 million m^3. In 1984 an abstraction weir (Mhlathuze Weir) was constructed across the river about 11 km from the estuary mouth. Water, released from Goedertrouw, is pumped from the resulting impoundment to Lake Nsezi where the water treatment plant that serves domestic and industrial demands in Empangeni and Richards Bay is located.

Ongoing port and urban development have seen continued losses of habitat, although these are marginal compared to the large changes brought about by initial port development (Figure 4.9). Between 1976 (after port development) and 2000 changes in the wider system were driven by natural processes playing out over a dramatically changed land- and waterscape, and the establishment of a new ecological equilibrium. Over the years new intertidal sand- and mudflats have been colonised by mangroves and by 2000 mangrove coverage in the estuary had increased from 150 ha to 652 ha (435%< Adams et al., 2000). Natural successional changes have therefore seen the establishment of significant new biological habitat which is now nationally important. uMhlathuze Estuary and Richards Bay now collectively support more than 50% of South Africa's national mangrove area. Moreover, efforts to re-establish *Zostera*, transplanted from St Lucia, were successful in uMhlathuze Estuary in 1991. By 1998 approximately 5 ha of *Zostera* beds had been established in the estuary (Adams 2016). This was less than 8% of the area covered before port development but this new *Zostera* area supported a diversity of fishes and crustaceans like the original *Zostera* beds (Weerts and Cyrus 2002).

10.2Present Health Condition

In the last twenty years increasing anthropogenic pressure has been the driver of change in both estuaries (uMhlathuze and Richards Bay). Expansion projects in the port have seen the extension of shipping basins, the development of new berths and renewed loss of estuarine habitat. Further development is planned, with the potential to further impact the ecological function of both systems. Even prior to 2000 beach disposal of dredged material from port expansion works impacted uMhlathuze Estuary *Zostera* beds (Cyrus et al. 2008). Although the beds recovered from this event, subsequently they have died-back, recovered, and died-back again, possibly as a result of herbicide use in upstream alien (water hyacinth, *Eichhornia crassipes*) eradication programs (Weerts and Mackay 2019). There are other indications of water quality problems in the upper reaches of uMhlathuze Estuary with algal blooms noted in the river-estuary interface zone. These blooms are irregular but more persistent presence of the submerged invasive alien aquatic macrophyte spiked water-milfoil (*Myriophyllum spicatum*) along with floating invasive alien water hyacinth suggests nutrient enrichment. An invasive alien gastropod, *Tarebia granifera*, has also infested the lower river and upper estuary over this period. In both the uMhlathuze Estuary and the Port of Richards Bay illegal gillnetting has increased dramatically since the early late 1990s (Weerts and Mackay 2019).

Although highly modified from the original state as an estuarine lake to the extent that they could now be regarded as novel ecosystems, Richards Bay (an estuarine embayment) and uMhlathuze Estuary (a permanently open estuary) are nationally important estuarine biodiversity areas, supporting globally important critical habitats (mangroves and eelgrass) (Weerts and Mackay 2019). They are important nursery areas supporting fisheries across the wider KwaZulu-Natal coast. Locally they are important for commercial (as an operational port, waterfront real estate, supporting hospitality and tourism industries) and recreational (leisure, sailing, boating, angling) reasons, and in the local subsistence economy (reed harvesting, fisheries). However, for all the present-day value of the permanently open uMhlathuze Estuary and the Richards Bay estuarine embayment, the system does not offset the loss of the original estuarine lake which is critically threated estuarine habitat in South Africa. The destruction of the near-pristine system for port development is one of many examples of widespread loss of estuarine resources to development pressure in South Africa, but one of very few that illustrate the resilience of estuaries if basic ecological processes are maintained. uMhlathuze Estuary as a permanently open estuary and Richards Bay as an estuarine embayment are highly modified from their natural condition but retain ecological functions that provide various valuable ecosystem goods and services locally and farther afield (Weerts and Mackay 2019).

Some ecological changes in these systems were anticipated at the outset of port development and provided the basis for initial suggestions on impact mitigation. Others were unexpected, but in hindsight are understood. In particular, processes of mangrove recruitment and establishment following changes in tidal ranges, and successional habitat changes from shallow subtidal mudflat to intertidal mangroves area were important determinants of ecological function in both emerging systems. In the largely undeveloped environs of Richards Bay and with protection afforded to the new estuary as well as port area, a critical criterion that allowed both to develop to stable and productive ecological states was the space and time afforded for ecological processes to run their course. Both new systems now face the same pressures as do other systems in KwaZulu-Natal and South Africa in general. Active management is now needed in these estuaries, their buffer zones and in their catchments. Climate change has to be factored into this as a driver which will affect fundamental hydrodynamic, biological and ecological processes on a scale that eventually might match those incurred by large scale port development in Richards Bay (Weerts and Mackay 2019). The original uMhlathuze system has been severely degraded, and no longer exists as an estuarine lake system. However, this is not reflected in the status allocated to the two estuaries that now make up this system, as a decision was made to ‘adjust’ the ‘Reference state’ of these systems to reflect that their revised categorisation as is summarised in Table 12.1 reflecting the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 10.1: uMhlathuze: Present ecological condition uMhlathuze (●) and Richards Bay Health (○)

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Reduction in flows. Impoundments of lakes.		●		○		
Hydrodynamics	Inlets redesigned for uMhlathuze and Richards Bay. Increased tidal flushing in both sections. Connectivity to lakes has been lost due to weirs.				●○		
Salinity	Salinity increased (now marine dominated) due to increased marine connectivity. Lakes now have no saline intrusion.				●○		
General Water Quality	Pollution from stormwater and agricultural activities in catchments. Richards Bay harbour also have pollution from dock yards (haul cleaning) and harbour activities (hydro carbons).					●○	
Physical habitat	Habitat loss and infilling due to port development and road infrastructure.					●○	
Microalgae	Change in community composition and biomass. Microalgae biomass decreasing due to decreased retention and freshwater input.			●	○		
Macrophytes	Loss of riparian vegetation due to port development. Mangrove expansions in uMhlathuze due to an increase in tidal range.					●	○
Invertebrates	Change in community composition and biomass, with an increase in marine species. Significant loss of intertidal species in Richards Bay due to port development. Loss of lake-estuary connectivity with ecological impacts.				●	○	
Fish	Change in community composition and biomass, i.e. loss of freshwater and brackish species. Reduction in abundance due to significant overfishing (illegal gill netting). Estuarine species can no longer access the lakes. Loss of lake-estuary connectivity with ecological impacts.					○	●
Birds	Change in community composition and biomass. Also, a significant reduction in bird abundance due to loss of habitat, human disturbance, reduction of prey species and loss of habitat.				○	●	
ESTUARY HEALTH	**HEAVILY DEGRADED with a downwards trajectory. Little natural functionality is intact. Limited opportunities for rehabilitation exits.**				●○		

11. iNHLABANE

11.1General Features

The iNhlabane Estuarine Lake system (Figure 13.1) historically comprised a freely connected lower estuary and lake system. The lake consisted of two basins with large areas of open water, mostly more than 1 m deep with a maximum depth of 5 m in the main basin. The larger upper lake was completely fresh, and the lower lake had some brackish characteristics (salinities recorded in the range of approximately 10). The lower estuary, a narrow channel some 4 km long, linked these lakes to the sea (Begg 1978).

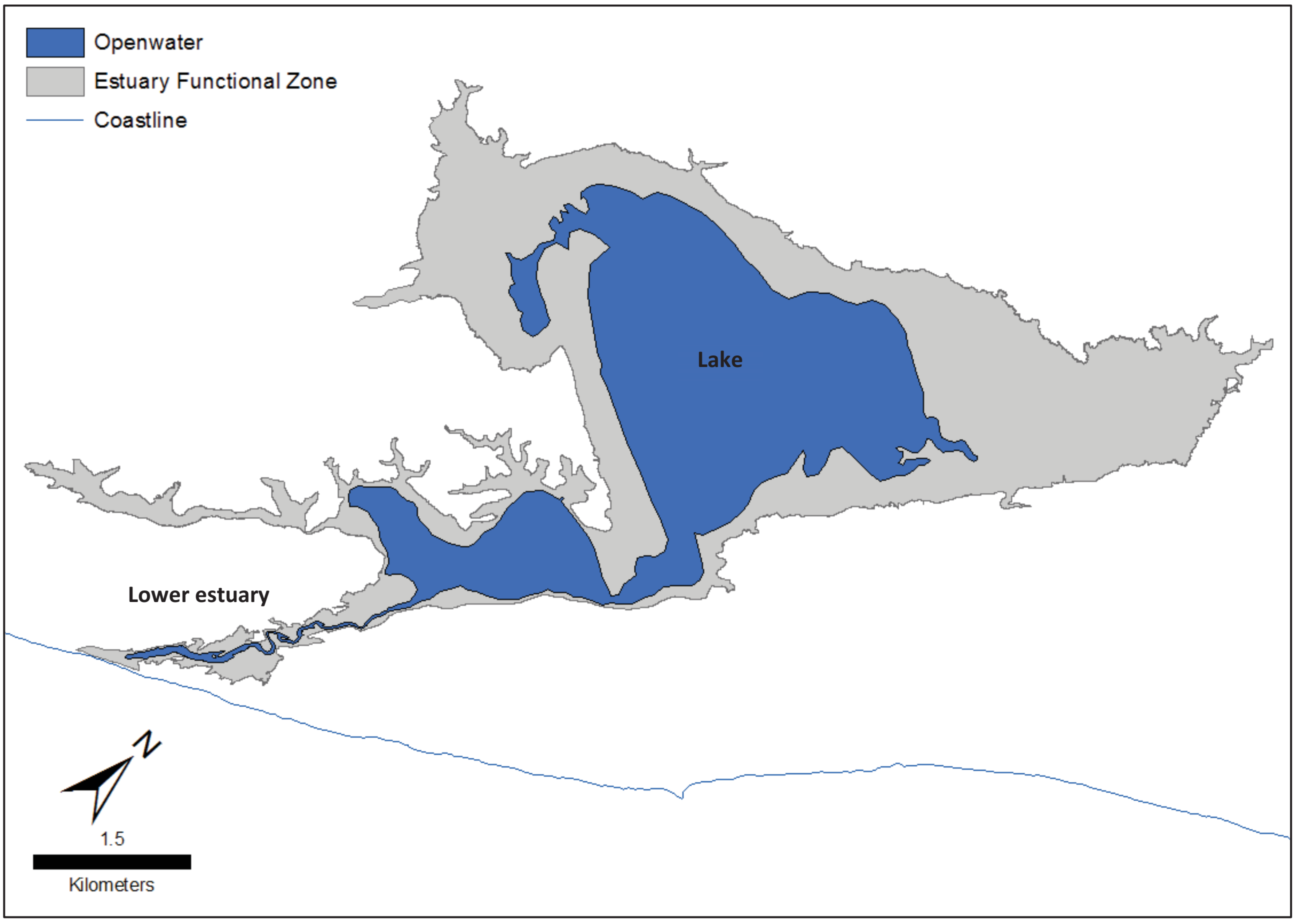

Figure 11.1 iNhlabane: EFZ and open water area

In 1977 Richards Bay Minerals obtained permission from the National Water Department to construct a barrage/weir across the upper reaches of the lower estuary, approximately 3 km from the mouth, to increase the storage capacity in the lakes to meet their freshwater requirements for purposes of dune mining. This construction divided the system into Lake Nhlabane, which is now a large freshwater lake, and the much smaller lower estuary, which is periodically open to the sea. Originally, in 1978, the barrage wall was 3.2 m high, elevating the lake level to 3.8 m MSL. In 1984 the wall was further elevated by 0.75 m bringing the lake level to 4.6 m above MSL. In 1998 the wall was raised a further 1.3 m to an overall height of 5.9 m above MSL. At the time of the last raising on the weir a fish ladder was installed to allow the migration of estuarine fishes into lake habitats. This has largely proven ineffective, and a very limited estuarine fish (and invertebrate) assemblage remains in the lake above the weir, restricted to the few estuarine species capable of completing their life cycles in freshwater (Weerts, unpublished).

The mouth of the system is situated on an open coastline and is directly exposed to wave action, without any protection. The beaches at the mouth are very steep, a feature that is also typical of this area and that is caused by the interaction of the local wave climate and the coarse sand particles on these beaches. An interesting situation can develop at the mouth at very small estuaries such as Nhlabane after the construction of the weir whereby a small outflow channel is maintained by a baseflow of between 0.2 and 0.6 m^3/s. This outflow channel will then be located in a perched position on the sand berm and tidal inflow will hardly occur, even at spring tides. However, such an outflow could allow limited immigration of juvenile fish and invertebrates to take place. Recruitment by wave overtopping has also been identified as a mechanism allowing immigration of estuarine fish into the system to occur, even during a period of mouth closure (Vivier and Cyrus, 2001).

11.2Present Health Condition

A considerable part of the present run-off is used for mining and the run-off to the estuary has been drastically reduced. In August 1995 the estuary was artificially opened for the first time in 4 years (it had closed in November 1991). This closure coincided with a low run-off period during which water was occasionally pumped directly from the estuary to meet the demands of RBM. The estuary has breached naturally on several occasions since 1995, due to the drought ending, ceasing of direct abstractions from the estuary, and the increased groundwater flow following the raising of the barrage wall.

The iNhlabane Estuarine Lake system is in a severely degraded state. Table 13.1 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 11.1: iNhlabane: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	A significant reduction in freshwater inflows as a result of large abstraction weir above the lower estuary.			●			
Hydrodynamics	Loss of connectivity with the lake as a result of the weir. Small remaining estuarine section filling up and breaching at regular intervals during the year.						●
Salinity	Lower estuary fluctuates between fresh and more saline states. Lake is now permanently fresh with no saline input.						●
General Water Quality	Some nutrient enrichment from agricultural activities in catchments.				●		
Physical habitat	Sedimentation caused by breaching without significant scouring caused by outflows from the lake. Intertidal areas are permanently inundated in the lake.						●
Microalgae	Microalgae biomass and community composition shifts due to increased retention, changes in salinity and nutrient enrichment.				●		
Macrophytes	Loss of habitat due to elevated lake levels, mining and weir.					●	
Invertebrates	A significant change in community composition and biomass, due to change in connectivity. Very restricted recruitment of estuarine biota and lake communities now isolated from the lower estuary.					●	
Fish	A significant change in community composition and biomass, due to change in connectivity, e.g. loss of marine species. Very few fish species can access the fishway (when operational). Very restricted recruitment of estuarine biota and lake communities now isolated from the lower estuary. Reduction in abundance due to overfishing.						●
Birds	Some reduction in bird abundance due to loss of habitat and human disturbance. Loss of estuarine associated species from lake part.					●	
ESTUARY HEALTH	**SEVERELY DEGRADED with a downwards trajectory. However, functionality is intact and opportunities for rehabilitation exist.**					⊙	

12. ST LUCIA/uMFOLOZI

12.1General Features

St Lucia/uMfolozi Estuarine Lake system (Figure 9.1) is one of the most important estuarine systems in Africa. It is the largest estuary in South Africa with a water surface of > 300 km^2 and a shoreline of over 400 km. The lake complex comprises two distinctly different, but interconnected parts – the St Lucia system and the fluvially dominated uMfolozi system. The St. Lucia system is divided into False Bay, North Lake, South Lake and the Narrows. The system is shallow (the normal average depth is 0.90 m) (DWAF 2004).

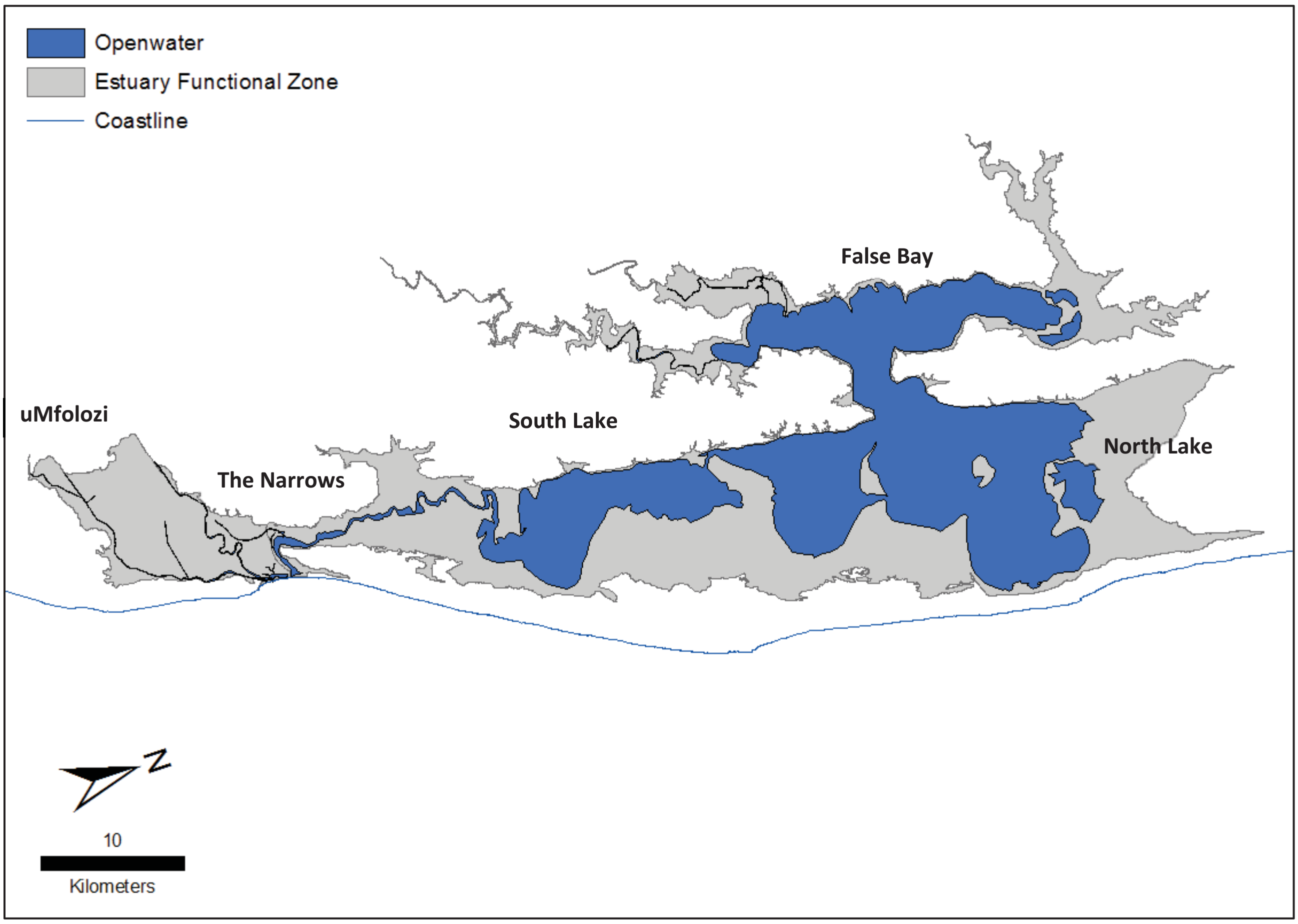

Figure 12.1 St Lucia/uMfolozi: EFZ and openwater area

Five rivers drain into St Lucia in order from north to south, the Mkuze, Mzinene, Hluhluwe, Nyalazi and Mpate Rivers. The uMfolozi and Msunduzi rivers enter the Indian Ocean together, south of the St. Lucia Mouth (Stretch and Maro 2013). The lake system is separated from the sea by large coastal dunes that flank its eastern bank (Taylor 2006). The Present MAR for the Mkuze, Mzinene, Nyalazi, Hluhluwe and Mpate rivers is 362.26 million m^3, which is 86% of the MAR under the Reference Condition (i.e. 417.89 million m^3). In addition, the influence of groundwater (23.14 million m^3), direct rainfall (273.25 million m^3), evaporation (-420 million m^3) and discharge to and from the sea also need to be considered to evaluate the consequences of changes in the surface runoff (DWAF 2004).

12.2Zonation and Abiotic States

No information is available on the zonation of St Lucia/uMfolozi system, but it can be expected that homogeneous functional zones comprise the following (DWAF 2004):

- St Lucia component can be divided into:
  - False Bay
  - North Lake
  - South Lake
  - The Narrows
- uMfolozi tidal section.

Based on the limited data available, three abiotic states were derived for the Lake St Lucia system, of which the occurrence and duration vary depending on river inflow rate (DWAF 2004) (Table 9.1). The estimated distribution of states under reference and present conditions are depicted in Figure 9.2 (DWAF 2004).

Table 12.1: St Lucia/uMfolozi: Abiotic states

STATE	DESCRIPTION	AVERAGE WATER LEVEL (m MSL)
1	Open, with marine influence	>0.1 m
2	Closed, brackish	0.1-3 m
3	Closed, potentially hypersaline	<0.1 m

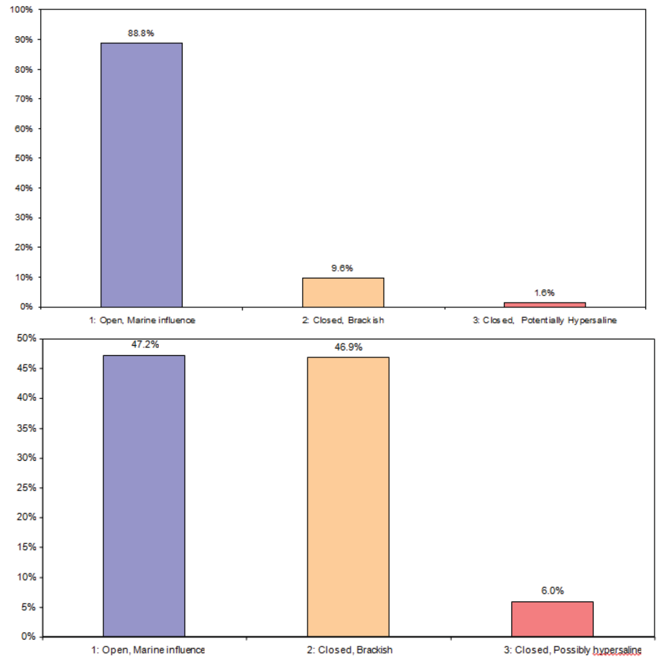

Figure 12.2 St Lucia/uMfolozi: Estimated occurrence of abiotic states – Reference (top) and present (bottom)

12.3Abiotic Response Indicators

12.3.1 Mouth dynamics and water levels

Mouth closures of the St Lucia system were regularly observed during previous centuries and should therefore consider part of the natural dynamic processes of the system. During low lake levels and closed mouth conditions especially, the flow of the uMfolozi River was a major contributor to the water balance of the Lakes. Separating the uMfolozi River from St Lucia in the early 1950s (Bate et al., 2011) therefore had major consequences on salinity concentrations in the lakes. It is also the main cause of the very low water levels in the Lakes which occurred recently under drought conditions. Under conditions of natural low flow input from the uMfolozi and Msunduzi and natural breachings following water level rises, markedly higher mouth open frequencies would have occurred in the system (Figure 9.2).

Closure occurs normally when the water levels in St Lucia are low and when a net inflow of seawater occurs through the mouth over the tidal cycle. The net inflow of seawater combined with wave action results in a net influx of marine sediments into the system. The ongoing build-up of sediments eventually results in considerable shallowing of the lower part of St Lucia and the constriction of the mouth. If the water levels in St Lucia remain low and the influx of marine sediments continues for some time, then this causes mouth closure. Available information indicates that closure of the mouth of St Lucia normally occurs at water levels close to mean sea level (MSL) (DWAF 2004). After closure natural breaching would have occurred if the St Lucia system, including the surrounding flood plains, had filled up to about + 3.0 m MSL. It is estimated that the water surface area of the Lakes is approximately 300 km^2 at average water levels. The surface area is probably considerably larger at +3.0 m MSL because of the flooding of the surrounding flat flood plains, including those of the lower uMfolozi. A preliminary estimate of the volume of water required to fill St Lucia before a natural breaching would have occurred in the past is therefore approximately 1 000 million m^3. Flows immediately after such a breach would have caused enormous scouring of St Lucia and the mouth. Natural mouth breachings were therefore probably very important for the long-term equilibrium of sedimentation and erosion in St Lucia. Breachings at much lower water levels and the efforts to keep the mouth open permanently have therefore probably resulted in ongoing sedimentation in St Lucia.

12.3.2 Salinity

St Lucia naturally experiences large fluxes in salinity, both temporally and spatially as a result of climatic events such as floods and droughts. The system is characterised by highly variable salinity (oligohaline to hypersaline) that are dependent on freshwater input, evaporation rates and the duration of an open mouth. On average, under Reference conditions salinity varied between 0 and 35 in the lakes. The large shallow basins that comprise the lakes are especially prone to evaporation driven hypersalinity after tidal inflows of saline water during periods of low flow, especially if followed by mouth closure. Various management practises to keep the mouth artificially open, have therefore increased salinities in drought periods in the northern lakes to 150 (DWAF 2004).

12.3.3 Temperature

Temperatures in the system show distinct seasonal trends averaging about 17°C during winter and 28°C in summer (DWAF 2004).

12.4Biological Response Indicators

12.4.1 Microalgae

The main microalgal communities in St. Lucia will include phytoplankton (water column), epipelon (sediment surface – mostly down to a depth of 10-20 mm), epilithon (growing on rock surfaces), epiphyton (growing on submerged plants) and epizoon (growing on animal surfaces). Of these, phytoplankton and epipelon make up the largest component. These two communities will produce most of the microalgal biomass and will produce most of the primary productivity relevant to ecosystem stability in St Lucia. Phytoplankton is important because it is present in the entire water column and the epipelon is important because it is present on all the sediment surfaces (DWAF 2004).

Johnson (1976) sampled the St. Lucia system during 1973 and concluded that *in situ* phytoplankton produced more biomass than imported biomass arriving in river flow or from the sea. Of the microalgae, the diatoms contributed most of the microalgal volume (and likely the greatest proportion of the biomass). In recent history, the extent of continuous anthropogenic manipulations (e.g. separation of the uMfolozi and St Lucia systems, agricultural practices) and severe climate conditions culminated in an extensive 10-year drought. During this period, the estuary was characterised by low water levels, extreme spatio-temporal salinity fluctuations, high N availability, as well as excessively high phytoplankton (32.3 ± 53.4 µg/l, max. 413 µg/l) and microphytobenthic (201 ± 377 mg/m^2, max. 2576 mg/m^2) biomass (Perissinotto et al., 2010). The Mouth and Narrows exhibited the highest phytoplankton levels, declining in the North and South Lakes, while the opposite spatial trend was observed for microphytobenthos. In terms of phytoplankton size classes, nanophytoplankton dominated (63.7 ± 24.1%) the community during drought conditions. Hypersaline conditions (> 100) favoured the growth of a mono-specific prokaryote bloom comprising *Cyanothece* sp. (Muir and Perissinotto, 2011). Coupled with high water residence time, increased nutrient availability (in-situ remineralization) and limited trophic interaction (e.g. grazing), the *Cyanothece* sp. bloom persisted for 18 months and only dissipated after the salinity decreased following an above average rainfall event (Carrasco and Perissinotto, 2012). Cyanobacterial bloom species tend to flourish when changing hydrologic characteristics result in increased water residence conditions, e.g. during extensive droughts.

The gradual reconnection of the turbid uMfolozi River the system shifted to a new limnetic state (post-2012), facilitating low phytoplankton (<5 µg l^{-1}) and microphytobenthos (<60 mg/m^2) biomass due to dilution and reduced light availability (Nunes et al., 2017, 2018, 2019). The oligohaline conditions (< 5) characteristic of this period culminated in chlorophytes, cyanophytes, diatoms and euglenophytes being the most prevalent groups. Phytoplankton biomass in the Narrows remained low (< 6 µg l-1) despite the increased nutrient input from the Mfolozi River. However, nutrient tolerant species were present during this period, including diatoms (e.g. *Cyclotella atomus*, *Diatoma vulgaris, Nitzschia closterium,* and *Nitzschia palea*), dinoflagellates (*Prorocentrum cordatum,* formerly *P. minimum*) and euglenophytes (*Euglena viridis*). In terms of benthic diatom communities, species diversity ranged from 0 to 2.74, with an overall classification of 'Poor '/polluted (< 2; Lemley et al., 2015). These symptoms of eutrophication may increase in the future as the re-establishment of the full connection between the Mfolozi River and St Lucia advances.

12.4.2 Macrophytes

Taylor et al. (2006) have described four primary habitats, each having a suite of vegetation types characteristic of that habitat. These primary habitats are: (i) open water; (ii) intertidal shorelines; (iii) 'dry' shorelines and islands where there is evaporation of saline water as well as exposure to desiccation, and; (iv) 'wet' shorelines where the effects of salinity are moderated by the inflow of freshwater – often in the form of groundwater seepage.

Open water represents the available habitat for submerged macrophytes. Three main species occur. These are *Stuckenia pectinata*, *Ruppia cirrhosa* and *Zostera capensis*. There is seldom co-occurrence of *Stuckenia* with the other two species at the same locality, as it prefers lower salinity (< 20). When the lakes are fresh and in the river areas *Ruppia maritima*, *Najas marina* subsp. *armata*, *Lamprothamnion papulosum* and other submerged macrophytes are found.

The intertidal habitat occurs along the shoreline of the Narrows when the mouth is open. At the mouth, when fully open, the tidal range is about 2 m, and at the upper reaches of the Narrows, 22 km away, this has diminished to a few centimetres. Mangroves, *Avicennia marina* and *Bruguiera gymnorrhiza* grow in the zone between the mid-tide and extreme spring high tidal levels. Stands of the rush, *Juncus kraussii* are found in sites less frequently flooded. In the drier sites on the fringes of the mangroves, salt marsh plants may be found and where there is some freshwater inflow common reed *Phragmites australis* occurs.

The dry shores occur on the western shoreline of the lakes and along the False Bay shoreline, where there is no significant groundwater inflow. It is also on the floodplains of the rivers entering False Bay, on the islands, the peninsulas, and along with those parts of the eastern shoreline where the system's edge topography acts as a barrier to freshwater inflow. Typical vegetation types associated with these habitats are succulent salt marshes (with species such as *Salicornia meyeriana* and *Sarcocornia natalensis*, saline lawns (with *Sporobolus virginicus*, *Paspalum vaginatum* and *Stenotaphrum secundatum*) and the 'dry' stands of *Phragmites australis*.

Freshwater entering St Lucia, as surface flow or groundwater-fed seepage, reduces the impact of salinity on the estuarine plants. This is especially the case for the 'wet' shorelines where there is groundwater seepage. Its constancy and persistence create a stable environment that contrasts markedly with the salinity fluctuations characteristic of the other primary habitats within St Lucia. The plants here are the sedge *Schoenoplectus scirpoides* and common reed, *Phragmites australis*. These habitats, fed by groundwater, occur along much of the eastern shoreline of St Lucia where there is an abundant supply of freshwater, but is virtually absent along the Narrows where there is almost no freshwater inflow. On the western shoreline and in False Bay it only occurs where incised drainage lines meet the system's shoreline. It is likely that there is subsurface groundwater flows in these drainages. It also occurs along the margins of the rivers entering False Bay. This habitat is often coupled to freshwater wetland systems composed of swamp forests or tall sedges. The St Lucia Estuary is currently transitioning (2020) to a freshwater silt-laden state where reeds are replacing mangroves in the Narrows.

12.4.3 Fish

Categorisation of the fishes in St Lucia according to the degree of dependence or association they have on estuaries allows insight into the community composition and its distribution spatially and temporally. Fish species that have been reported from the system range from marine to freshwater types that typically have little association with estuaries. To accommodate this wide range in estuarine dependence a modified version of Whitfield's (2019) estuary-association categories is used (Table 9.2). Specifically, Whitfield's estuary-association category (EAC) IV is divided into two groups. EAC IVa comprises euryhaline freshwater typically covered in Whitfield's EAC IV, while EAC IVb comprises stenohaline freshwater species with little or no tolerance for saline water and which do not breed in estuaries. A similar approach was adopted by Weerts and Cyrus (2001) in an analysis of coastal lake fish assemblages which included the same, or closely related stenohaline freshwater forms.

Table 12.2: Estuary-association Categories (EAC) applied to fishes occurring in St Lucia (modified from Whitfield (2019)

CATEGORIES	DESCRIPTION OF CATEGORIES
I	Estuarine species which breed in southern African estuaries. This category includes resident species that spawn only in estuaries, as well as species that also have marine or freshwater breeding populations.
II	Euryhaline marine species which usually breed at sea, with the juveniles showing varying degrees of association with southern African estuaries. Further subdivided into:
IIa	Juveniles dependant on estuaries as nursery areas.
IIb	Juveniles occur mainly in estuaries, but are also common at sea.

CATEGORIES	DESCRIPTION OF CATEGORIES
IIc	Juveniles sometimes occur in estuaries but are more abundant at sea
III	Marine stragglers which occur in estuaries in very small numbers and are not dependent on these systems.
IV	Freshwater species whose penetration into estuaries is determined primarily by salinity tolerance. Further subdivided into:
IVa	Euryhaline freshwater fishes that occur in coastal freshwaters, and which regularly and readily penetrate saline estuarine waters. This sub-category includes a few species which may breed in both freshwater and estuarine systems.
IVb	Stenohaline freshwater fishes that occur in coastal freshwaters but are seldom recorded in estuaries.
V	Obligate catadromous species which use estuaries as transit routes between the marine and freshwater environments.

Some 130 fish species, comprising some 76 families, have been recorded in the St. Lucia system (Table 9.3, collated from Whitfield 1980, Whitfield et al., 2006, Vrdoljak and Hart 2007). This includes many species (primarily marine stragglers and stenohaline freshwater fishes, see below) which occur sporadically or irregularly. Cyrus and Vivier (2006) regard 65 fish species as being 'regular' inhabitants of the St Lucia system.

Of the full list of species that have been reported from St Lucia and associated freshwater habitats (Table 9.3), twenty-five (19%) are fishes that have breeding populations in the system (EAC I). These fishes are invariably small-bodied and, by number of species, comprise mainly of members of the Gobiidae (13 species) which live on, or in close association with the substrate and feed on benthic invertebrates. However, by abundance (density of fish), species that shoal and school together higher in the water column (Ambassidae and Clupeidae) and which feed predominantly on zooplankton, are more dominant. Euryhaline marine species with strong estuarine dependence (EAC IIa) comprise 17 (13%) of the fish species reported in the wider system. This group is dominated by members of the Mugilidae, fishes which schools together and which are illiophagous, feeding on microphytobenthos, meiofauna, detritus, benthic floc and small epifauna (Whitfield 2016). Marine fishes which use both estuarine and marine nursery areas (EAC IIb) comprise 14 (11%) of species reported from St Lucia. Marine fishes have even less dependence on estuaries as nurseries (EAC IIc) comprise 25 (19%) of species. Although this latter group (EAC IIc) includes more species, their occurrences would be more sporadic and irregular than those of the former group (EAC IIb). Marine stragglers comprise 30 (23%) of the species recorded in the system. Freshwater fishes comprise 16 (12%) of the fish species in the St Lucia system. These include all but two of the species (Cape galaxias, *Galaxias zebratus* and Redbreast tilapia, *Coptodon rendalli*) listed by Whitfield (2019) as freshwater species that occur in South African estuaries. The absence of *G. zebratus* is expected for reasons of biogeography (being restricted to temperate Cape systems) but *C. rendalli* occurs in KwaZulu-Natal estuarine water to the south and the north of St Lucia (particularly in temporary open/closed systems and estuarine lakes). In addition to the seven euryhaline freshwater species (EAC IVa), a more stenohaline freshwater component (EAC IVb) comprising nine species is listed in Table 9.3. Six of these (*Ctenopoma multispine*, *Microctenopoma intermedium*, *Clarias theodorae*, *Enteromius bifrenatus*, *Enteromius viviparous*, *Marcusenius* sp.) are unique records from groundwater seeps on the eastern shores St Lucia (Vrdoljak and Hart 2007). Their presence in St Lucia is not confirmed but, in the case of some species at least, seems probable under conditions of high lake levels and freshwater conditions.

Salinity (and by implication lake levels and freshwater inflows) has been recognised as a primary driver of fish distribution in the greater St Lucia system (Whitfield et al., 2006). Given the large spatial and temporal fluctuations that characterise the system (especially since the anthropogenic impacts on the natural hydrology caused by separating the uMfolozi River from St Lucia) this is unsurprising. Under drought and low lake-levels hypersalinity is experienced in the lakes. Salinities in excess of 150 have been reported in False Bay in the northern section of the system (Whitfield et al., 2006). Many of the fishes in St Lucia can tolerate elevated (greater than seawater) salinities but most South African estuarine fishes are more tolerant of low rather than high salinities (Whitfield et al., 1981, 2006). The euryhaline freshwater species, *Oreochromis mossambicus* is a common species in the lakes under all salinity conditions but surprisingly (being of freshwater origin) strongly dominates fish abundance during periods of hypersalinity (Cyrus et al., 2005; Cyrus and Vivier, 2006). It is the only almost certainly the only species breeds successfully in the system at salinities >50, or that that survives extended periods of hypersalinity >110 (Whitfield et al., 2006). Under conditions of hypersalinity, freshwater seeps into the lakes become important refugia for estuarine associated biota, including fishes (Taylor et al., 2006; Vrdoljak and Hart 2007)>

Given the large spatial and temporal fluctuations in salinity widespread movement by marine, estuarine and freshwater species across the whole system could be expected. *Pomatomus saltatrix* for example, has been reported in South Lake some 30 km from the estuary mouth under mesohaline conditions (Whitfield, 2019). Under these conditions, marine fishes with stronger estuarine association (EAC IIa and IIb) occur across the wider system. Most marine species, however, and certainly the majority of which are not dependant on estuaries (marine stragglers, EAC III, Table 9.2), will be largely restricted to the lower part of St Lucia, for reasons of salinity, as well as proximity to the estuary mouth. Turbidity has also been identified as an important determinant of fish distribution in St Lucia. Fish species favouring clearer waters are present mainly on the eastern side of the lake while the western side is dominated by a group of species that favours more turbid waters (Cyrus 1987a, 1987b). This is influenced by the nature of the substrate and wind-induced turbidity.

Table 12.3: St Lucia/uMfolozi: List of all species and families recorded in St Lucia. Species are classified into five major estuary-association Categories (EAC) (see Table 9.2 modified from Whitfield (2019))

FAMILY NAME	SPECIES NAME	COMMON NAME	EAC
Ambassidae	*Ambassis ambassis*	Banded glassy	I
Ambassidae	*Ambassis dussumieri*	Bald glassy	I
Ambassidae	*Ambassis natalensis*	Slender glassy	I
Anabantidae	*Ctenopoma multispine*	Many-spined climbing perch	IVb
Anabantidae	*Microctenopoma intermedium*	Blackspot climbing perch	IVb
Anguillidae	*Anguilla bicolor*	Shortfin eel	V
Anguillidae	*Giant mottled*	Giant mottled	V
Anguillidae	*Longfin eel*	Longfin eel	V
Antennariidae	*Histrio histrio*	Sargassum fish	III
Atherinidae	*Atherina breviceps*	Cape silverside	I
Belonidae	*Strongylura leiura*	Needlefish	IIc
Blenniidae	*Entomacrodus striatus*	Pearly rockskipper	III
Blenniidae	*Omobranchus banditus*	Bandit blenny	III
Bothidae	*Bothus myriaster*	Disc flounder	III
Bothidae	*Bothus pantherinus*	Leopard flounder	IIc
Carangidae	*Caranx heberi*	Blacktip kingfish	III
Carangidae	*Caranx ignobilis*	Giant kingfish	IIb
Carangidae	*Caranx sexfasciatus*	Bigeye kingfish	IIb
Carangidae	*Lichia amia*	Leervis	IIa
Carangidae	*Scomberoides commersonnianus*	Largemouth queen fish	III
Carangidae	*Scomberoides tol*	Needlescaled queenfish	IIc
Carangidae	*Trachinotus africanus*	Southern pompano	III
Carcharhinidae	*Carcharhinus leucas*	Zambezi shark	IIb
Carcharhinidae	*Rhizoprionodon acutus*	Milk shark	III
Chanidae	*Chanos chanos*	Milkfish	IIc
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IVa
Cichlidae	*Pseudocrenilabrus philander*	Southern mouthbrooder	IVa
Cichlidae	*Tilapia sparrmanii*	Banded tilapia	IVa
Clariidae	*Clarias gariepinus*	Sharptooth catfish	IVa

FAMILY NAME	SPECIES NAME	COMMON NAME	EAC
Clariidae	*Clarias theodorae*	Snake catfish	IVb
Clupeidae	*Gilchristella aestuaria*	Estuarine round-herring	I
Clupeidae	*Hilsa kelee*	Kelee shad	IIb
Cyprinidae	*Enteromius paludinosus*	Straightfin barb	IVb
Cyprinidae	*Enteromius trimaculatus*	Threespot barb	IVb
Cyprinidae	*Enteromius bifrenatus*	Hyphen barb	IVb
Cyprinidae	*Enteromius vivparus*	Bowstripe barb	IVb
Dasyatidae	*Himantura uarnak*	Honeycomb stingray	III
Drepaneidae	*Drepane punctata*	Concertina fish	III
Echeneidae	*Remora remora*	Remora	III
Eleotridae	*Eleotris fusca*	Dusky sleeper	I
Eleotridae	*Eleotris melanosoma*	Broadhead sleeper	I
Eleotridae	*Hypseleotris cyprinoides*	Golden sleeper	IVa
Elopidae	*Elops machnata*	Tenpounder	IIa
Engraulidae	*Engraulis japonicus*	Cape anchovy	III
Engraulidae	*Stolephorus holodon*	Tropical anchovy	IIc
Engraulidae	*Thryssa setirostris*	Longjaw glassnose	III
Engraulidae	*Thryssa vitrirostris*	Orangemouth glassnose	IIb
Gerreidae	*Gerres longirostris*	Smallscale pursemouth	IIb
Gerreidae	*Gerres macracanthus*	Longspine pursemouth	IIb
Gerreidae	*Gerres methueni*	Evenfin pursemouth	IIb
Gerreidae	*Gerres oblongus*	Oblong pursemouth	III
Gerreidae	*Gerres oyena*	Slenderspine pursemouth	IIc
Gobiidae	*Acentrogobius nebulosus*	Shadow goby	I
Gobiidae	*Awaous aeneofuscus*	Freshwater goby	IVa
Gobiidae	*Croilia mossambica*	Burrowing goby	I
Gobiidae	*Glossogobius callidus*	River goby	I
Gobiidae	*Glossogobius giuris*	Tank goby	IVa
Gobiidae	*Gnatholepis cauerensis*	Weeper	III
Gobiidae	*Mugilogobius durbanensis*	Durban goby	I
Gobiidae	*Mugilogobius mertoni*	Chequered mangrove goby	I
Gobiidae	*Oligolepis acutipennis*	Sharptail goby	I
Gobiidae	*Paratrypauchen microcephalus*	Comb goby	I
Gobiidae	*Periophthalmus argentilineatus*	Bigfin mudhopper	I
Gobiidae	*Redigobius dewaali*	Checked goby	I
Gobiidae	*Silhouettea sibayi*	Barebreast goby	I
Gobiidae	*Stenogobius polyzona*	Chinstripe goby	I
Gobiidae	*Taenioides esquivel*	Bulldog eelgoby	I
Gobiidae	*Taenioides jacksoni*	Bearded eelgoby	I
Haemulidae	*Plectorhinchus gibbosus*	Harry hotlips	III
Haemulidae	*Plectorhinchus schotaf*	Minstrel	III
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
Haemulidae	*Pomadasys kaakan*	Javelin grunter	IIc
Haemulidae	*Pomadasys multimaculatus*	Cock grunter	IIc
Hemiramphidae	*Hemiramphus far*	Spotted halfbeak	IIc
Hemiramphidae	*Hyporhamphus affinis*	Shortfin halfbeak	III
Hemiramphidae	*Hyporhamphus capensis*	Knysna halfbeak	I

FAMILY NAME	SPECIES NAME	COMMON NAME	EAC
Leiognathidae	*Leiognathus equulus*	Slimy	IIb
Leiognathidae	*Secutor insidiator*	Slender soapy	III
Leiognathidae	*Secutor ruconius*	Pugnose soapy	III
Lobotidae	*Lobotes surinamensis*	Tripletail	IIc
Lutjanidae	*Lutjanus argentimaculatus*	River snapper	IIc
Lutjanidae	*Lutjanus fulviflamma*	Dory snapper	IIc
Megalopidae	*Megalops cyprinoides*	Oxeye tarpon	IIa
Monacanthidae	*Stephanolepis auratus*	Porky	III
Monodactylidae	*Monodactylus argenteus*	Natal moony	IIb
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mormyridae	*Marcusenius sp.*	Bulldog	IVb
Mugilidae	*Chelon dumerili*	Groovy mullet	IIa
Mugilidae	*Chelon tricuspidens*	Striped mullet	IIb
Mugilidae	*Moolgarda buchanani*	Bluetail mullet	IIc
Mugilidae	*Moolgarda cunnesius*	Longarm mullet	IIa
Mugilidae	*Moolgarda robusta*	Robust mullet	IIa
Mugilidae	*Mugil cephalus*	Flathead mullet	IIa
Mugilidae	*Planiliza alata*	Diamond mullet	IIa
Mugilidae	*Planiliza macrolepis*	Largescale mullet	IIa
Mugilidae	*Planiliza subviridis*	Squaretail mullet	IIb
Mugilidae	*Pseudomyxus capensis*	Freshwater mullet	IIa
Muraenesocidae	*Muraenesox bagio*	Pike conger	IIc
Muraenidae	*Strophidon sathete*	Slender giant moray	IIc
Paralichthyidae	*Pseudorhombus arsius*	Largetooth flounder	III
Platycephalidae	*Platycephalus indicus*	Bartail flathead	IIc
Poecilidae	*Aplocheilichthys katangae*	Striped topminnow	IVb
Polynemidae	*Polydactylus plebeius*	Striped threadfin	III
Polynemidae	*Polydactylus sextarius*	Sixfinger threadfin	III
Pomatomidae	*Pomatomus saltatrix*	Elf	IIc
Pristidae	*Pristis zijsron*	Largetooth sawfish	IIb
Sciaenidae	*Argyrosomus japonicus*	Kob	IIa
Sciaenidae	*Johnius dorsalis*	Small kob	III
Sciaenidae	*Otolithes ruber*	Snapper kob	IIc
Scorpaenidae	*Pterois volitans*	Devil firefish	III
Serranidae	*Epinephelus malabaricus*	Malabar rockcod	III
Serranidae	*Epinephelus marginatus*	Yellowbelly rockcod	III
Serranidae	*Grammistes sexlineatus*	Goldstriped rockcod	III
Siganidae	*Siganus rivulatus*	Mottled rabbitfish	III
Sillaginidae	*Sillago sihama*	Silver sillago	IIc
Soleidae	*Pegusa nasuta*	Blackhand sole	IIa
Sparidae	*Acanthopagrus vagus*	River bream	IIa
Sparidae	*Diplodus capensis*	Blacktail	IIc
Sparidae	*Rhabdosargus holubi*	Cape stumpnose	IIa
Sparidae	*Rhabdosargus sarba*	Natal stumpnose	IIb
Sparidae	*Rhabdosargus thorpei*	Bigeye stumpnose	IIc
Sphyraenidae	*Sphyraena jello*	Pick-handle barracuda	IIc
Syngnathidae	*Hippichthys cyanospilos*	Bluespeckled pipefish	I

FAMILY NAME	SPECIES NAME	COMMON NAME	EAC
Syngnathidae	*Hippichthys heptagonus*	Belly pipefish	I
Syngnathidae	*Hippichthys spicifer*	Bellybarred pipefish	I
Syngnathidae	*Microphis sp.*	Pipefish	I
Terapontidae	*Pelates quadrilineatus*	Trumpeter	IIc
Terapontidae	*Terapon jarbua*	Thornfish	IIa
Tetraodontidae	*Arothron hispidus*	Whitespotted blaasop	IIc
Tetraodontidae	*Arothron immaculatus*	Blackedged blaasop	IIc

12.5Present Health Condition

Due to anthropogenic impacts and a range of historical management decisions, freshwater inputs and the mouth status of the system have been altered on several occasions. The uMfolozi mouth, which has a high silt load and is shallow was separated from St. Lucia (they shared a combined mouth) in the early 1950s. A change in catchment activities and canalization of the upper reaches of the uMfolozi River caused an increase in sediment load and the combined mouths closed due to an accumulation of sediments brought down by the river (Stretch and Maro 2013). The decision was then made to artificially breach the St. Lucia mouth to allow marine water to enter the system. In 2002, the decision to stop dredging was made after a severe drought caused mouth closure. The connectivity of the combined system has been an appealing topic of research in recent years (e.g. Whitfield et al. 2013) as it is recognised, in terms of its exchange of water, salinity and biota between the different parts, as a very important hydrological and ecological driver. The separated St. Lucia mouth closes more frequently than the common St. Lucia/uMfolozi mouth did in the past and, once closed, remains closed for much longer. Modelling has shown that the separated mouth, instead of staying closed for less than 30% of the time as occurred with the common mouth in the past, could now remain closed for as much as 80% of the time before breaching naturally (Lawrie et al. 2011). At present, there is a large restoration programme in progress to reconnect St Lucia once again and uMfolozi system. However, a recent poorly planned artificial breach of St Lucia (6 January 2021) have resulted in lost opportunity to remove silt and muds from the systems.

Simulated runoff data indicate that the Present MAR for the Mkuze, Mzinene, Nyalazi, Hluhluwe and Mpate rivers was estimated to be 362.26 million m^3, which is 86% of the MAR under the Reference Condition (i.e. 417.89 million m^3) (DWAF 2004). In addition, the influence of groundwater (23.14 million m^3), direct rainfall (273.25 million m^3) and evaporation (-420 million m^3) were included in the estimate of the freshwater reaching St Lucia (Van Niekerk et al. 2004). The groundwater contribution to river runoff as base flow is not well quantified. However, the perennial nature of the rivers infers a significant contribution of base flow in the river runoff component. This contribution will increase with an increase in the flood plain storage, particularly for the Mkuze swamps. If the Mkuze swamps function in a similar manner to the eastern shores, they will contribute a significant proportion of the groundwater seepage into the lake that still needs to be determined. An indication of the groundwater contribution of the Mpate River has been presented by Kelbe et al. (1995). The simulated average groundwater discharge for the Mpate River from 1929 to 1994 is 1344 m^3/day for present conditions and 5396 m^3/day for reference state conditions. This represents 10% of the total average flow of 50.000 m^3/day for the Mpate under present day afforestation (DWAF 2004).

St. Lucia's plays a key role is as a nursery ground for estuarine and marine fish species, which spawn at sea and whose juveniles depend on St. Lucia to complete their life cycles (Cyrus et al. 2010a, 2010b). A closed mouth hinders the ability of the system to function as a nursery and have detrimental effects on fish stocks. Whitfield and Taylor (2009) reviewed the importance of freshwater from the uMfolozi River and results indicated that the system relied heavily on the river's inputs during drought conditions. The freshwater was needed to open the mouth, flush sediment, reduce salinity, and maintain fish stocks. The water from the uMfolozi River carries a high sediment load however and would have to be filtered by the uMfolozi swamp, before entering the system. Sediment can accumulate in both the lake and mouth area, the former would be irreversible and detrimental, as it cannot be removed, and the latter would have to be dredged (Whitfield and Taylor 2009). Primary production is also negatively affected by increased sediments, via turbidity and reduction in light (DWAF 2004).

Anthropogenic developments along the banks of the estuarine lake system, such as the drainage and canalisation of the uMfolozi swamps, the construction of weirs on the Nyalazi, Hluhluwe and Mpate and an overall reduction in bird habitat on a national and international scale also contribute to the decline in the St Lucia Lake system. It is therefore impossible to reverse modifications and to improve condition through river flow alone.

St Lucia is considered to be an estuary of 'high importance'. In addition, it is also a Ramsar site (i.e. protected area in particular for water birds), a World Heritage site and adjacent to a Marine Protected Area.

St Lucia/uMfolozi Estuarine Lake system is in a degraded state. Table 9.4 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 12.4: St Lucia/uMfolozi: Present health condition St Lucia (⍰) and uMfolozi Health (○)

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Some reduction in flow and groundwater input.		●○				
Hydrodynamics	System artificially separated with St Lucia mouth remaining closed for very long periods. Reduce connectivity with lakes as a result of very low lake levels. No longer extensive back flooding of uMfolozi floodplain during closed conditions (but some back flooding have been reintroduced).			○			●
Salinity	Extreme hypersalinity developed in St Lucia. Loss of complex salinity regime in the combined system (in the process of reinstating these conditions).			○		●	
General Water Quality	Nutrient enrichment agricultural activities in the catchment.			●		○	
Physical habitat	No longer have a deep mouth basin as a result of sedimentation caused by artificially keeping the St Lucia mouth open. Infilling by dredge spoil. Habitat loss due to canalisation and infilling of uMfolozi floodplain.			●	○		
Microalgae	Microalgae blooms have been detected in the system due to enrichment and hypersalinity conditions.				○	●	
Macrophytes	Loss of riparian vegetation due to agriculture and urban development. Change in community composition as a result of closed mouth conditions, increased turbidity and shifts in salinity regime. Some alien invasive species.			●		○	
Invertebrates	Change in community composition and biomass as a result of closed mouth conditions, increased sedimentation and shifts in salinity regime. Alien invasive species.				○	●	
Fish	Change in community composition and biomass, i.e. loss of marine species. Reduction in abundance due to very high fishing pressure (e.g. illegal gillnets).				●	○	
Birds	Significant reduction in bird abundance and community composition due to changes in physical processes, loss of habitat, reduce prey species and human disturbance.				●	○	
ESTUARY HEALTH	**LARGELY DEGRADED with a downward trajectory. The system is functionality intact and opportunities for rehabilitation exist.**				●○		

13. uMGOBEZELENI

13.1General Features

The uMgobezeleni Estuarine Lake (Figure 14.1) is located on the east coast of South Africa, in an exclusively rain-fed catchment, i.e. there is no river water flowing into the catchment (Bate et al. 2016, 2018). The system receives water that drains out of the ground into two streams of approximately 6 km in length, rising from two separate lakes (uMgobezeleni and Shazibe). A recent survey showed the catchment to be about 10 000 ha (Bate et al. 2016). The only visible water flowing into the sea is via the inlet channel, which flows out at Jesser Point.

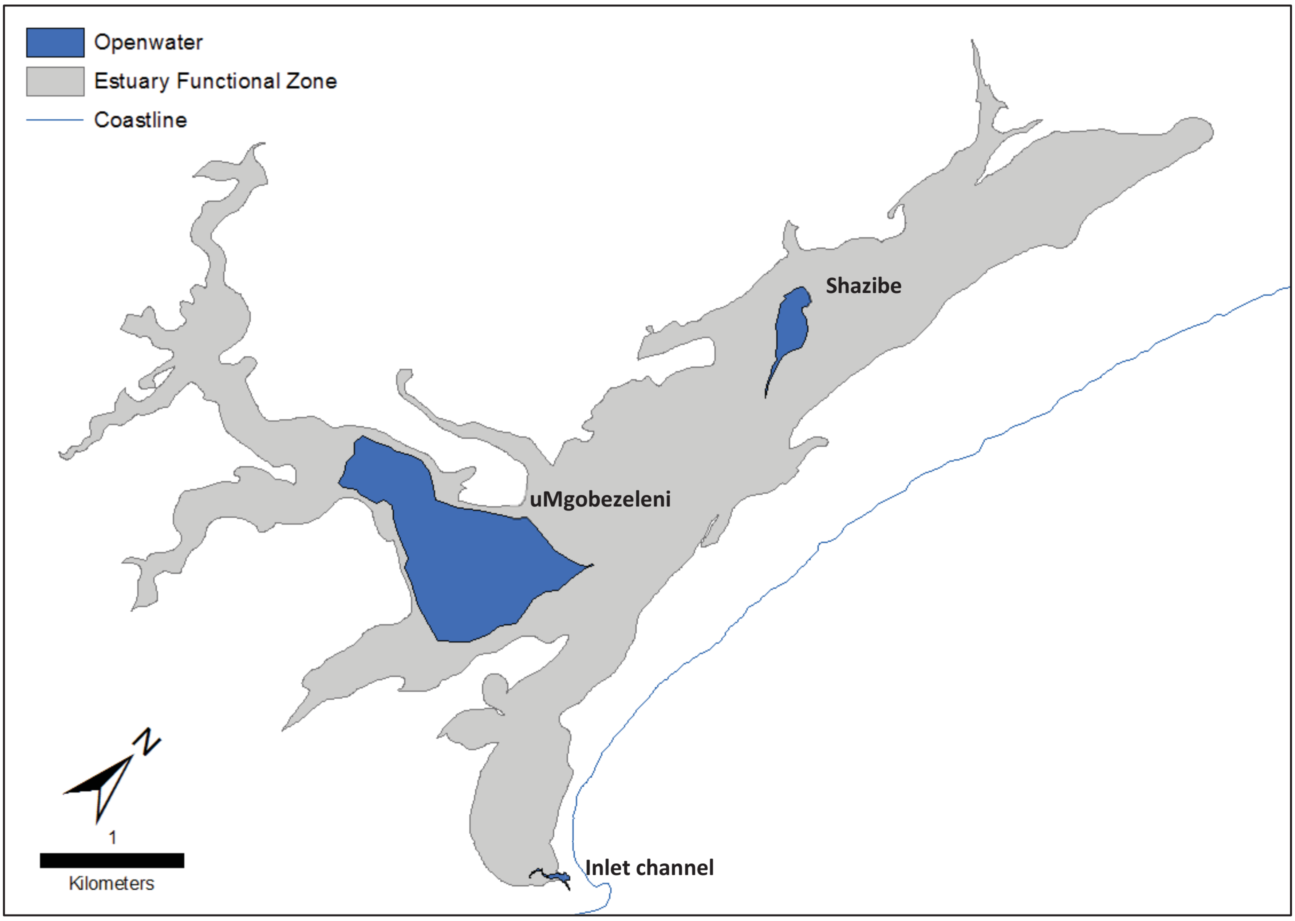

Figure 13.1 uMgobezeleni: EFZ and openwater area

The average rainfall in the UMgobezeleni catchment is about 1000 mm/a at the coast, but this decreases to 800 mm/a inland (Bate et al. 2018). There is almost no surface run-off from the catchment because of the very permeable sandy marine-derived soils, but a large amount of groundwater flows through the lakes and lower estuary, in addition to that which flows directly into the sea, under the eastern dunes situated parallel to the coastline (Bate et al. 2018).

The two lakes, uMgobezeleni and Shazibe, buffer the flow variability of the groundwater feeder streams providing a very consistent inflow to the system. The appearance of the water, in pools, flowing into the swamp above the lower estuary is completely black. The system breaches naturally when the water level is sufficiently high and not necessarily because of rainfall events. The water flow to the system is buffered by the lakes. Because of a large tourist population, management is periodically required to breach the mouth artificially. The water in the lower estuary is black and oligotrophic and phytoplankton and phytomicrobenthic biomass is accordingly low (Bate et al. 2016, 2018).

Under natural conditions, the catchment soils and groundwater into the lake system were oligotrophic with very low nitrogen and phosphorus concentrations. As a result of population increase in the early 1960s (forestry and tourism) and the introduction of water-borne sewage systems and pit latrines, elevated quantities of nitrogen and phosphorus are being washed into the groundwater. The swamp areas were/are severely impacted by small-scale agriculture resulting in a loss of swamp forest and sedges. Subsistence multi-cropping is rapidly changing to commercial mono-crop farming resulting in drying and decomposition of peat, which in turn is likely to lower the groundwater table.

The lakes are set in wide paleo-basins with sandy substrate, and both have the trajectory to become filled with peat. Lake Shazibe is much further along this trajectory than Lake uMgobezeleni (Bate et al. 2016). Because the lakes have very stable water levels, they support an abundance of associated emergent and (especially in the case of Lake Shazibe) submerged vegetation (Bate et al. 2016). Both lakes have clear, light, brown-stained water, with their sandy bottom substrates completely, or partially, covered in accumulated organic material (Lake Shazibe – throughout, Lake uMgobezeleni – deeper parts and vegetated fringes).

13.2Present Health Condition

The uMgobezeleni Estuarine Lake system is of average importance from a biodiversity perspective and a conservation priority (Van Niekerk et al. 2019). The system falls within the iSimangaliso Park National Park and a Ramsar site. The system is in a Natural to Near Natural state. Table 14.1 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system Van Niekerk et al. 2019).

Table 13.1: uMgobezeleni: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATE	LARGELY	SEVERELY	CRITICALLY
Hydrology	Some reduction in groundwater input.		●				
Hydrodynamics	Reduce water levels as a result of artificial breaching of the mouth. Boats launched through the mouth – may be the reason for artificial manipulation.			●			
Salinity	Relative similar to natural. Main water bodies retain fresh character. Some loss of saline intrusion in lower reaches is anticipated due to reduce groundwater input.		●				
General Water Quality	Similar to natural.	●					
Physical habitat	Relative similar to natural. Development on the floodplain.		●				
Microalgae	Relative similar to natural.		●				
Macrophytes	Some loss of riparian vegetation due to agriculture. Harvesting of reeds and sedges for housing.		●				
Invertebrates	Infestation of An invasive alien gastropod, *Tarebia granifera*. The exploitation of invertebrates.		●				
Fish	Significant reduction in abundance due to overfishing (illegal gill netting).				●		
Birds	Similar to natural.	●					
ESTUARY HEALTH	**NEAR NATURAL with a downwards trajectory. However, functionality is intact and opportunities for rehabilitation exist.**		◉				

14. KOSI

14.1General Features

The Kosi Bay Estuarine Lake system (Figure 10.1) is located on the east coast of South Africa, approximately 2 km south of the Mozambique border. The system is sited on the edge of the flat northern KwaZulu-Natal coastal plain, about 75 km from the Lebombo Mountain range. Except for the mouth, the system is separated from the sea by a high, vegetated barrier dune complex that reaches 130 m in height. Because of the tropical distribution of some species, Kosi Bay has recently been included as a system in a tropical transition zone (Van Niekerk, et al. 2019).

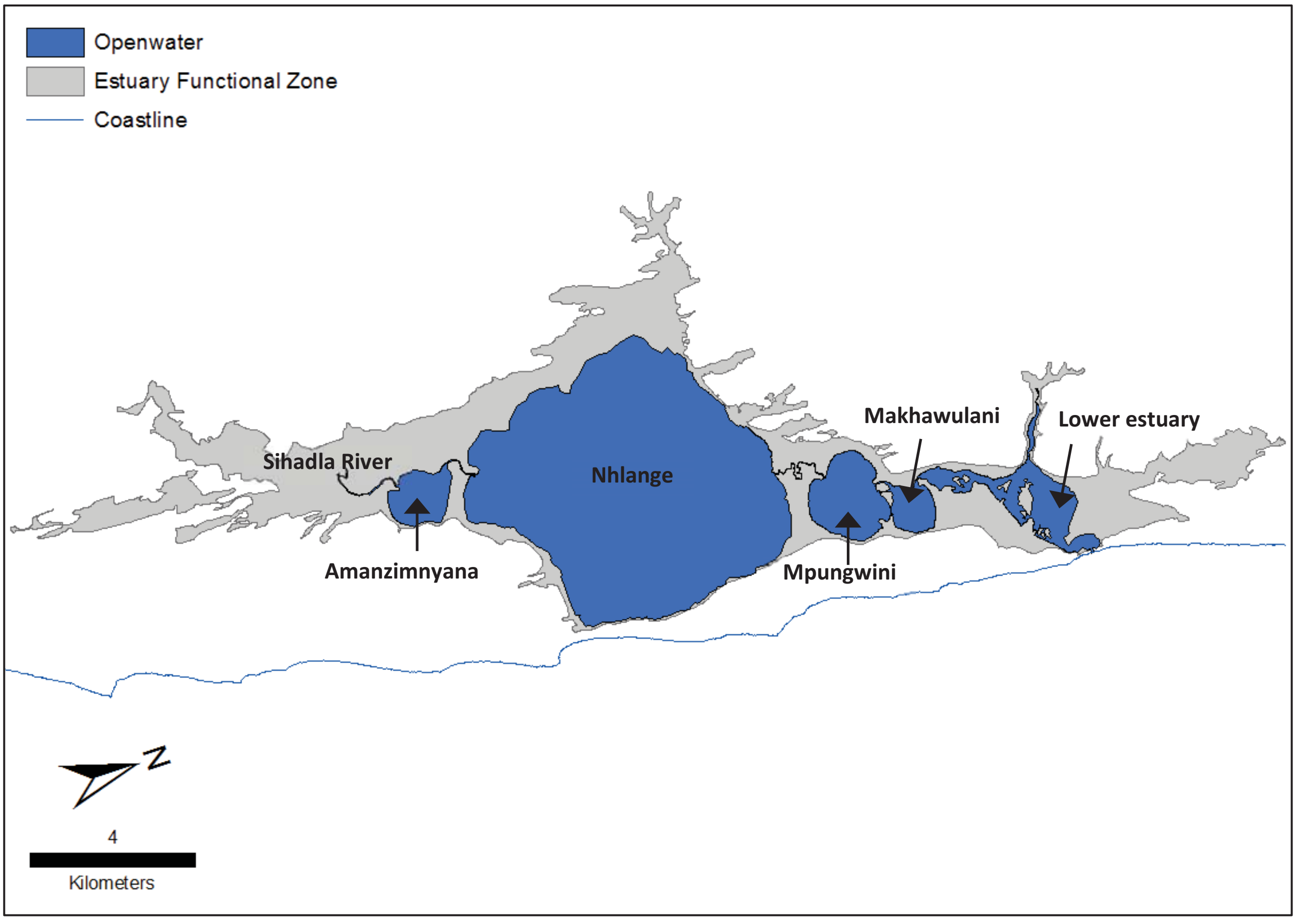

Figure 14.1 Kosi: EFZ and openwater area

The Kosi Bay Estuarine Lake comprises four interconnected estuarine lakes that link with the sea through a lower (tidal) estuarine section. A fifth freshwater lake (KuZilonde) lies directly north and is connected via outflow to the estuary. The estuary comprises a broad tidal flat that opens to the sea via a serpentine channel. Three rivers feed the system. The Kosi mouth is nearly always open and subjected to strong tidal movements, though at times the connection to the sea becomes tenuous. The mouth varies in size with every tide, particularly during the spring tides. Generally, it is between 20 to 50 m wide and about 3 m deep, but can vary in width from 5 to 100 m. On August 1965, the mouth closed, and remained closed until opened artificially on 4 January 1966. During the closed period a gradual rise in water levels (0.3 m) was followed by a dramatic water level rise of 1.6 m after Cyclone Claude, post mouth breaching (DWS 2016).

The Kosi catchment lies along the northern extreme part of the Zululand coastal plain of South Africa. Due to the flat nature of the topography, the study area is characterised by an ill-defined drainage system. Two perennial rivers, the Sihadhla and Gesiza (Swamanzi), drain into Lake Amanzimnyana and Lake Nhlange, respectively. The semi-perennial KuKhalwe stream(s) drains into the system from the northwest. The permeable nature of the cover sands, the relatively flat topography, and shallow water table result in a close relationship between both surface waters (i.e. lakes, streams and wetlands) and groundwater levels. The Zululand coastal plain is underlain by unconsolidated to semi-consolidated sediments and hosts the most extensive primary aquifer in South Africa. The majority of the sedimentary succession above the Cretaceous floor rocks can all be treated as potential aquifer units. The Quaternary sediments that cover the coastal plain are highly permeable, promote rapid recharge to the aquifer and have strong interactions with wetland and other surface water bodies, including lakes in the region. Borehole data indicate that the entire succession is generally fully saturated from the interface with the Cretaceous formations up to a generally shallow groundwater level.

Key features/ parameters that influence the physical processes of the Kosi lakes systems include (DWS 2016):

FEATURE/PROCESS	VALUE
Kosi Lakes surface area:	42.6 km^2
Catchment surface area:	609 km^2
Surface water runoff rate:	5% of precipitation
Groundwater catchment area:	331 km^2
Groundwater recharge rate:	13% of precipitation
Groundwater inflow into lakes:	30 $x10^6$ m^3/year
Direct precipitation on lakes surfaces:	40 x 10^6 m^3/year
Evaporation losses from lakes surface:	56 x 10^6 m^3/year
Evapotranspiration rate for study area:	15 $x10^6$ m^3/year

14.2Zonation and Abiotic States

The Kosi Estuarine Lake system (Figure 10.2) comprises four interconnected lakes that link with the sea through the lower (tidal) estuary.

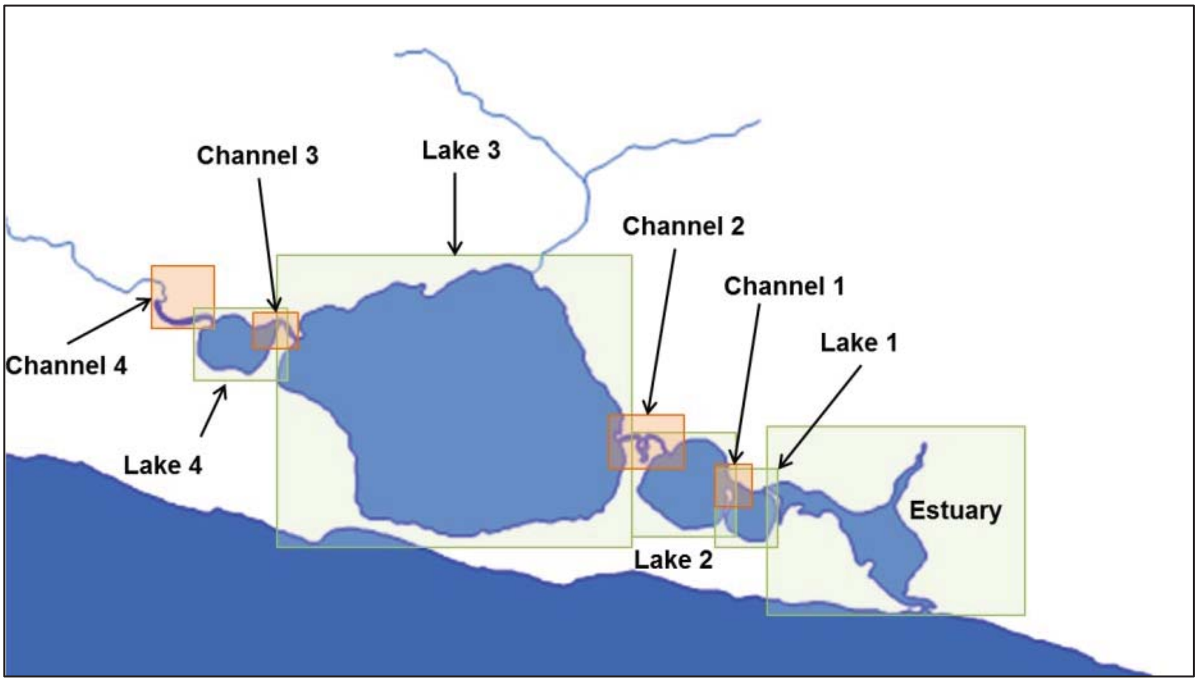

Figure 14.2 Kosi: Zonation

From north to south, the lakes are Makhawulani (Lake 1), Mpungwini (Lake 2), Nhlange (Lake 3) and Amanzimnyana (Lake 4). A fifth slightly perched freshwater lake system, KuZilonde, lies to the north of, and is connected by direct outflow to the estuary. The largest lake (Lake 4, Nhlange) is 31 m deep at its deepest point. Three rivers feed the system, KuKhalwe inlet into the estuary, the Sihadhla River into Lake 4 and the Swamanzi River into Lake 3 (DWS 2016).

Four typical abiotic states were defined for Kosi based on the mouth state, water levels, inundation patterns and salinity (DWS 2016) (see below in Table 10.1).

Table 14.1: Kosi: Abiotic states, and associated hydrodynamic characteristics

PARAMETER	MOUTH STATE	WATER LEVEL	INUNDATION	SALINTY IN LOWER ESTUARY AND LAKES 1 to 4				
				Est	L1	L2	L3	L4
State 1: Open, fresh	Open	> 0.8	Yes, during cyclones	20	15	10	0	0
State 2: Open, Saline	Open	0.8-0.55	N/A	30	25	20	0	0
State 3: Open, Very Saline	Open	< 0.55	N/A	*35*	*30*	*25*	*5*	*1*
State 4: Closed	Closed	1.5-2.5 (can reach ~3.5 m MSL if closed for extended periods)	Yes, back flooding during closed state	30	25	20	5	1

Overall, the present day relative occurrence of the abiotic state was very similar to that of the reference condition (Table 10.2) with only a slight increase in State 2: Open saline state at the expense of State 1: Open, fresh (DWS 2016).

Table 14.2: Kosi: Summary of the abiotic state's distribution under Reference and Present state

PARAMETER	REFERENCE (% occurrence)	PRESENT (% occurrence)
State 1: Open, fresh	30.0	27.6
State 2: Open, Saline	56.7	59.0
State 3: Open, Very Saline	13.4	13.4
State 4: Closed	<1	<1

14.3Abiotic Response Indicators

14.3.1 Mouth dynamics and water levels

While littoral drift is predominantly towards the north, the sandbar at the mouth has a south and north extending component, resulting in a highly mobile beach spit. The Uguma rocks immediately south of the mouth protect it to a certain extent from the prevailing swell direction, assisting with maintaining an open mouth state under low inflow conditions (DWS 2016).

The Kosi mouth is nearly always open and subjected to regular and strong tidal movements, though at times the connection is maintained with difficulty. The mouth varies in size with every tide, particularly during the spring tides. Generally, it is between 20 to 50 m wide and about 3 m deep, but can vary in width from 5 to 100 m.

On August 1965, the mouth closed and remained closed until opened artificially on 4 January 1966. During the closed period a gradual rise in water levels (0.3 m) was followed by a dramatic water level rise of 1.6 m after Cyclone Claude, post mouth breaching.

Tidal effects are noticeable in Lake 3 particularly in winter (low water periods). Tidal asymmetry is recorded in the system with the low water levels being lower at neap tides than during spring tides. This is because more water enters the system on a spring tide than can leave it before the next high tide starts. Outflow to the sea is greater during the summer, with water movement mostly contributing to tidal effects during the winter.

The tidal variation in the Kosi Bay is dependent on the mouth configuration and state of the mouth. Analyses of photographs and satellite imagery (1942, 1959, 1976, 1984, 2010 and 2013) show that the mouth configuration generally is stable but varies in the position and size of the mobile sand bodies and tidal channels (DWS 2016). Deep channels are normally located seaward of the flood-tidal delta but occasionally a channel is formed against the estuary bank opposite the inlet. On 17 August 1965 the estuary mouth closed and over a period of 140 days water level in the system rose gradually (increased by 0.3 m). In early January 1966 the area was subjected to 640 mm of rain in three days during Cyclone Claude, and water levels rose rapidly (increase by 1.6 m).

The following observations were made from the long-term water level recorders (W7T004, W7T005, W7T003) in between 2002 and 2014 (Table 10.3-10.5 and Figure 10.3) (DWS 2016):

- The tidal amplitude at W7T004 (between Lake 1 and Lake 2) is greater than at that of the recorder W7T005 in the connecting channel. W7T004 shows larger tidal amplitude than W7T005 which is in Channel 3, with the low tides lower and high tides higher than those measured at W7T005, i.e. the tides are less truncated/ damped by the channels.
- W7T003 shows very little tidal sensitivity; on average only about 5 cm rise and fall in the neap – spring cycle is observed. This effect is masked by wind-generated waves. Under the influence of wind-generated waves, significant short-term (days/hours) variation can be observed (in the order of 10 cm) at the water level recorder W7T005 in Lake 3. Field observations also show wind-generated waves up to 1.5 m in the centre of the lake.
- W7T004 and W7T005 show little sensitivity to increase in rainfall and associated runoff/groundwater input, while W7T003 (Lake 3) shows a response to high rainfall events. This is attributed to the large surface area and significant perimeter of this lake with only a relatively small outflow channel.
- The W7T003 (Lake 3) showed some sensitivity to the wet/dry cycle with water levels generally lower during the winter period, e.g. 30 cm difference observed between March and September 2005.
- The strong tidal flows over the spring-neap cycle (two-weekly cycles) keeps the mouth nearly permanently open.

Table 14.3: Kosi: Summary of average water level amplitude

RECODER	LOCATION	NEAP TIDE AMPLITUDE	SPRING TIDE AMPLITUDE	LEVEL DIFFRANCE BETWEEN NEAP AND SPRINGS
W7T004	Between the Lake 1 and Lake 2 (channel 1)	0-5 cm	20 cm	60-50 cm
W7T005	Between Lake 2 and Lake 3. Mantdo (channel 3)	0-5 cm	15-20 cm	40 cm
W7T003	Lake 3, E-KZN Wildlife campsite	-		5 cm rise and fall in the neap – spring cycle

Table 14.4: Kosi: Observations on relative increase in average water levels after a major rain event

DATE	RAINFALL (mm)	INCREASE IN RELATIVE WATER LEVELS (m)
05/02/1999	287.6	0.47 → 0.908
19/02/2001	109.4	0.74 → 1.083
25/01/2004	81	0.509 → 0.795
15/06/2008	80	0.581 → 0.762
28/01/2009	123.4	0.527 → 0.787

Table 14.5: Kosi: Observations on decline in average water levels after a major rain event

DATE	INITIAL WATER LEVEL (m)	AFTER 1 MONTH	AFTER 2 MONTHS	AFTER 3 MONTHS
05/02/1999	0.908	0.745	0.609	
19/02/2001	1.083	1.034	1.011	0.752
15/06/2008	0.762	0.718	0.65	0.644
28/02/2009	0.787	0.687	0.594	

A comparison of annual rainfall versus evaporative losses (Figure 10.4) shows that evaporative losses far exceed rainfall on the surface area of the lake system. This in combination with the occurrence of increasing salinity (see below) in the lakes highlights the potential impact of forestry and abstraction on the system (DWS 2016).

14.3.2 Salinity

The wind has a significant influence on water circulation in the Kosi Bay systems, and therefore also on salinity (DWS 2016). For example:

- **Lake 4 (Amanzimnyana):** The shallow bathymetry of Lake 4 ensures that it is dominated by wind-generated wave action. The wave action in turn reworks the sands and creates an environment around the shore that is too energetic for the settling of any fine matter (gyttja). A delta forming at the end of the Channel 3 where it discharges into Lake 3 indicates that very little sand is transported into Lake 3 due to low flow velocities.
- **Lake 3 (Nhlange):** Due to it large size, this lake has a large fetch and is consequently dominated by wind-induced wave action. The typical southerly and north-easterly bi-modal wind pattern sets up local currents that have modified the lake in a process called segmentation. The waves also flatten large areas into shallow terraces. Raised and submerged terraces indicate past lake levels. The lack of a delta forming where Channel 2 (Mtando) joins the lake indicates that the (inflowing) tidal currents do not have enough energy to transport sandy sediment into Lake 3.
- **Channel 2 (Mtando):** The channel is a narrow (~4 m wide) meandering channel that connects Lake 2 and 3. It is the only route that boats can use to gain access to the lower lakes. Due to its narrow width and steep margins, it is extremely susceptible to bank erosion by boat wakes undercutting the top peat horizon (Wright et al. 1997).
- **Lake 2 (Mpungwini):** Deltas have formed where the channels enter Lake 2 from both Lake 1 and Lake 3 (i.e. Channels 1 and 2 respectively). This indicates high tidal flows. On rare occasions, a combination of equinox spring tides can result in significant bottom water renewal. When combined with strong winds this causes the toxic bottom waters rich in hydrogen sulphide and depleted in dissolved oxygen to be brought to the surface in Lake 2.
- **Lake 1 (Makhawulani):** A large tidal delta has formed on the tidal-flat side of the lake (where water from the lower estuary flows into the lakes) indicating strong tidal currents active 5.5 km upstream of the mouth.
- **Lower estuary:** The tidal flats of the lower estuary are dominated by both ebb and flood orientated sedimentary structures, indicating very strong tidal currents. In general, flood features are found in the wide shallow areas, while ebb features are mostly confined to the deeper channels.

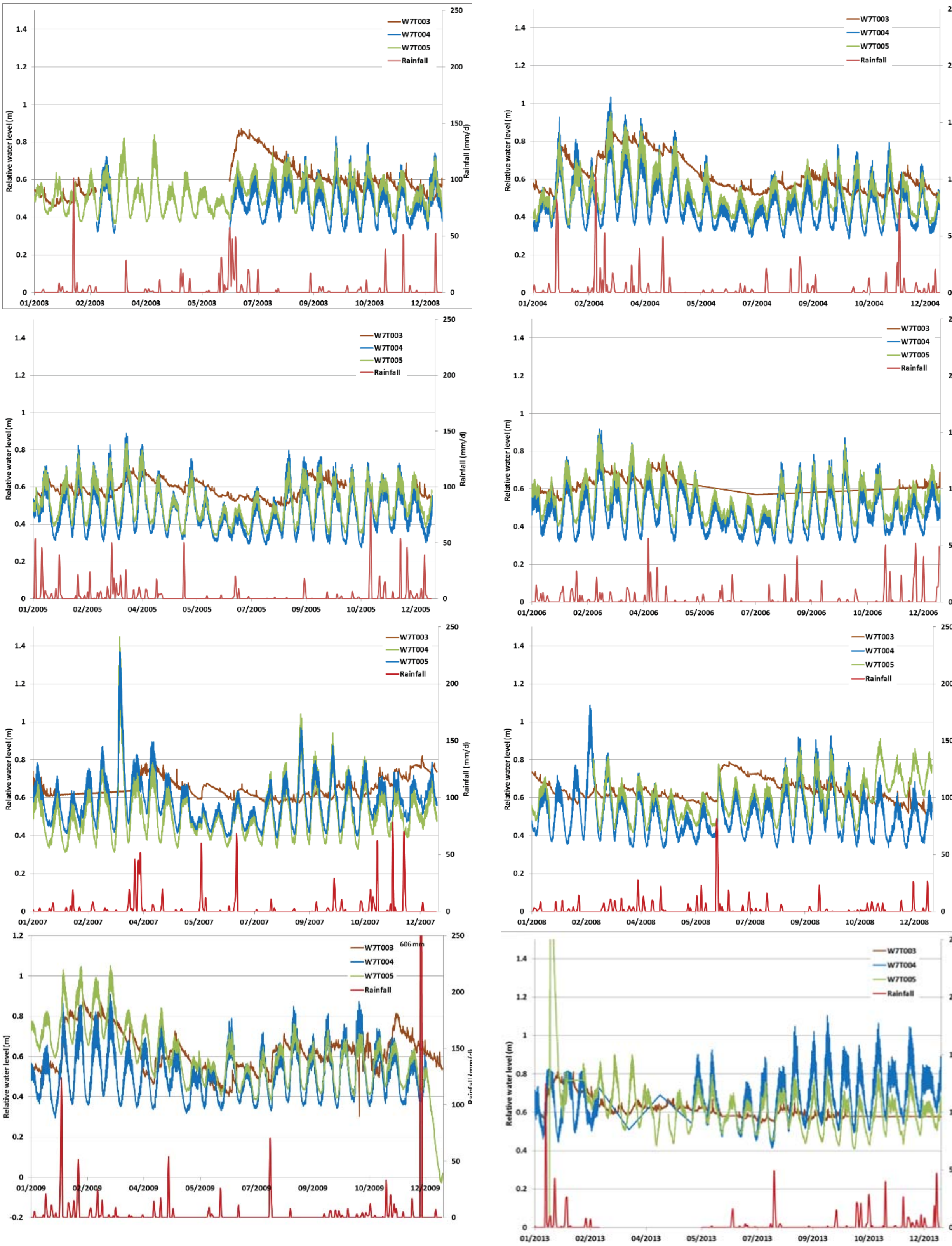

Figure 14.3 Kosi: Example of relative water level data (2003 to 2013)

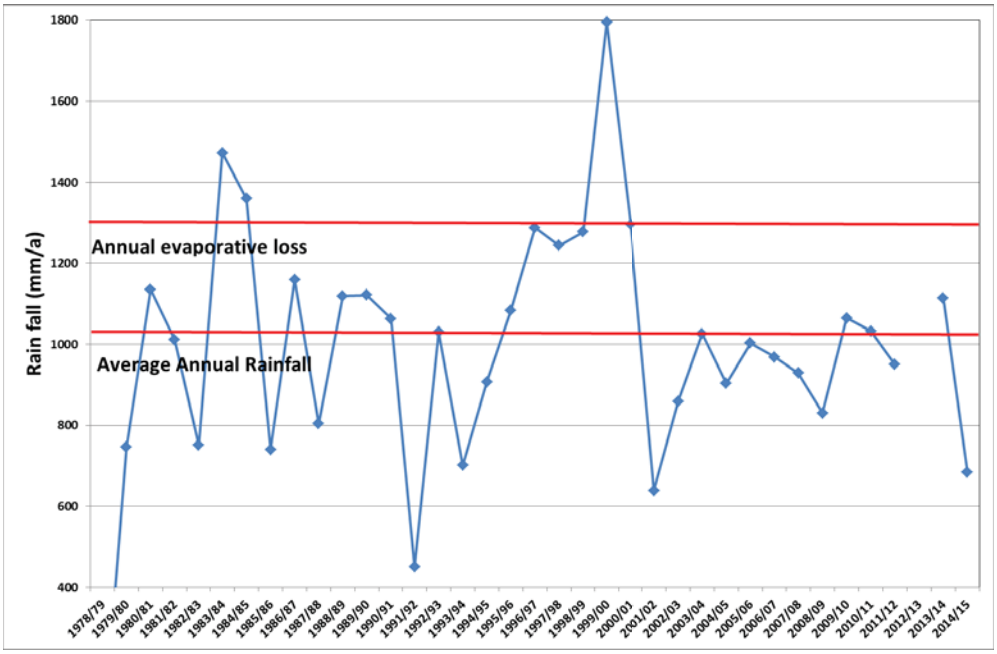

Figure 14.4 Kosi: Annual rainfall in comparison with evaporative losses

Very little measure data exist that shows the full salinity profile of the Kosi Bay Estuarine Lake System. Historical water quality data on Kosi Bay mainly comprise those provided in Allanson and Van Wyk, (1969), Hemens et al. (1971), Ramm (1992), Humphries (2013) and DWS 2016. Salinity data collected in the Kosi system are presented in Figure 10.5 along an axial distance calculated from the mouth. These data show average salinities varying considerably across the lakes from 20 to 35 (average 35) in the lower estuary, 20 to 30 in Lake 1, 10 to 20 in Lake 2, 0 to 5 in Lake 3, and 0 to 1 in Lake 4 (DWS 2016).

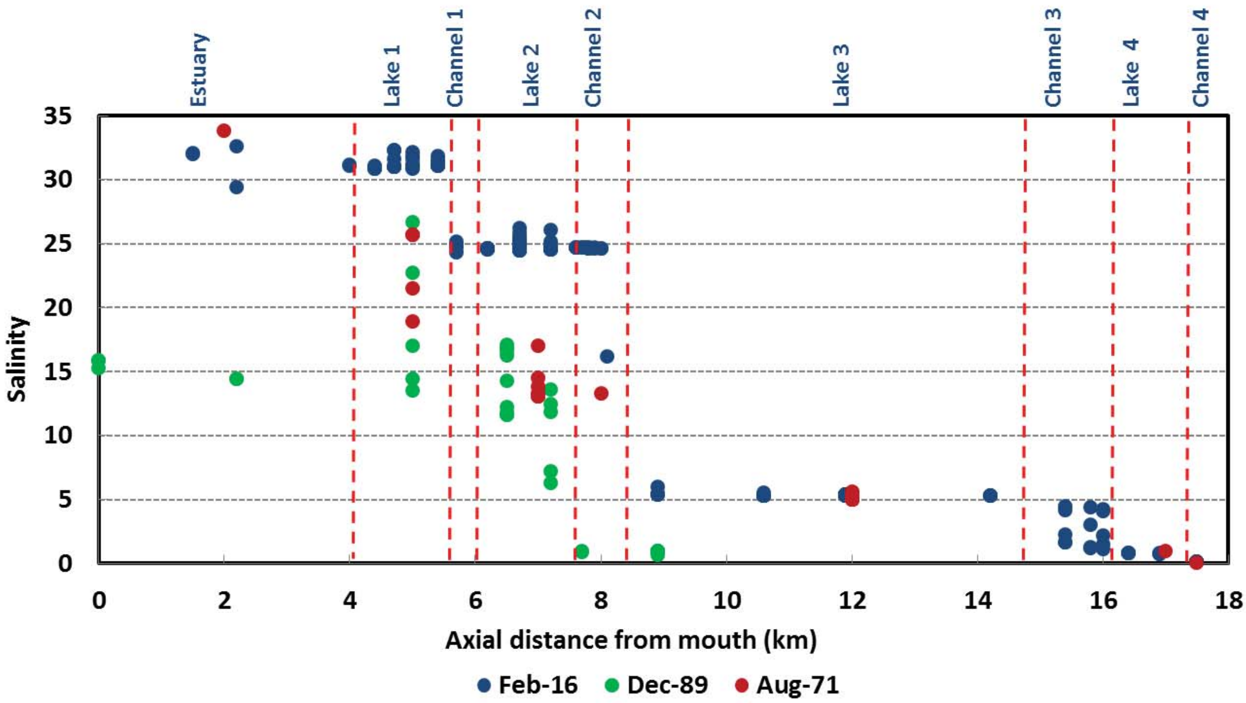

Figure 14.5 Kosi: Salinity measured in Aug 1971, Dec 1989 and Feb 2016

Salinity characteristics in the system are largely influenced by freshwater inputs, evaporation, and tidal exchange. In August 1971 Hemens recorded values of 35 in the lower estuary, with weak stratification in Lake 1 varying from 19 at the surface to 26 at the bottom, Lake 2 varied between 13 to 17, while Lake 3 was at about 5 and Channel 4 less than 1. Measurements conducted by the CSIR in December 1989 showed marked stratification in Lake 1 and

2. Surface salinities in Lake 1 were 14, while bottom salinity was 27. In Lake 2, surface salinity was 12 and bottom values of 17 were reported. Lake 3 salinities were less than 1. The February 2016 observations showed elevated salinity throughout the system, 34 in Lake 1, 25 in Lake 2, 5 in Lake 3, and 0.8 in Lake 4 (DWS 2016). Channels took on the salinities of the lakes feeding them. As the 2016 study was conducted on a spring tide, the dominant flow was towards the head of the system, resulting in the channels taking on the salinity of the lake below it. The lakes were very well mixed with little variance in salinity values in the individual water bodies. This is contributed to too little freshwater input and wind mixing over time (DWS 2016).

14.3.3 Temperature

Temperature data collected in Kosi Bay are presented in Figure 10.6 along an axial distance calculated from the mouth. As expected, the data show a strong seasonal signal with low winter temperature (18-21°C) and high summer temperature (22-30°C) (DWS 2016).

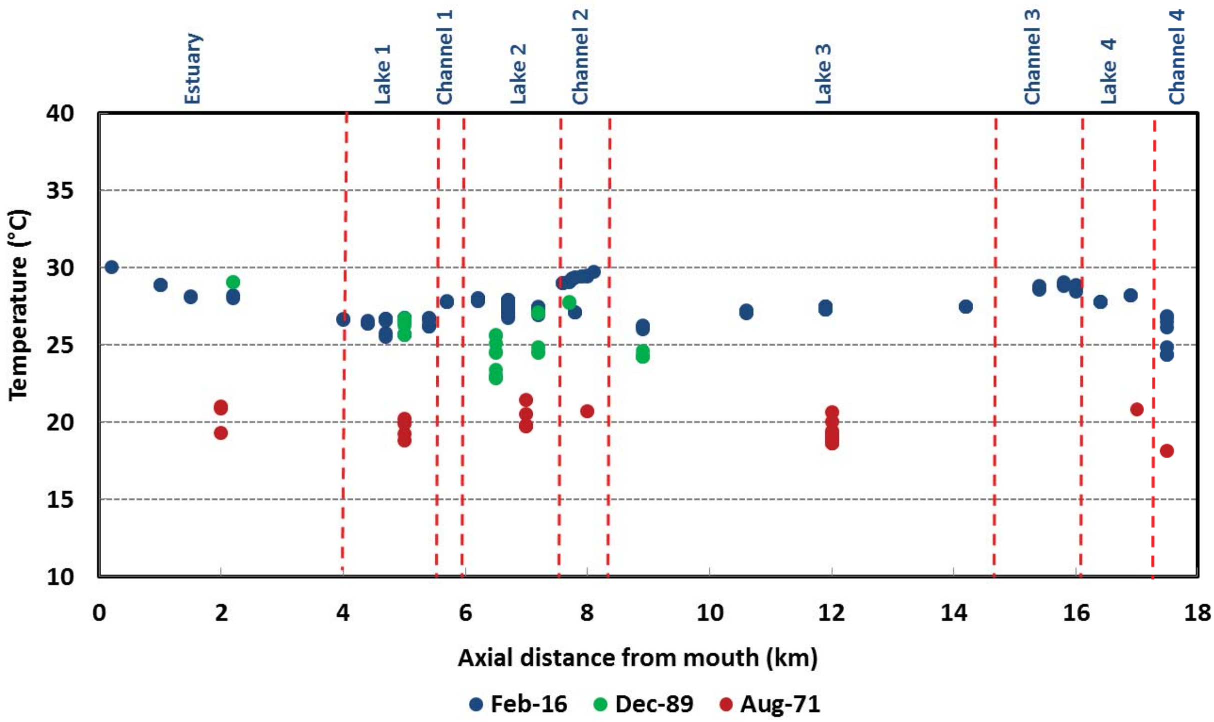

Figure 14.6 Kosi: Temperature measured in Aug 1971, Dec 1989 and Feb 2016

Although there was a tendency for the temperature to decrease with depth there was no marked vertical stratification evident in any of the lakes, even in their central, deeper reaches.

14.4Biological Response Indicators

14.4.1 Microalgae

Table 10.6 summarises the microalgal groups in the Kosi Lakes (DWS 2016). Average phytoplankton chlorophyll *a* showed a distinct increase with distance from the estuary mouth, ranging from 1.24 ± 0.44 µg/ℓ in the lower estuary to 10.29 ± 0.82 µg/ℓ in Lake 4. Phytoplankton chlorophyll *a* was usually highest near the surface with only the depth profile in Lake 3 indicating oligotrophic to mesotrophic conditions (<10 µg/ℓ) throughout the water column. The large Lake 3 had similar low biomass across the different sites with an average chlorophyll *a* concentration of around 6 µg/ℓ. Sites with visibly flowing water had no chlorophyll-*a* in the water, i.e. at the mouth, in the channel linking the lower estuary with Lake 1, and in Sihadhla River. Overall phytoplankton biomass is low and indicative of oligo-/mesotrophic conditions (< 20 µg/ℓ) (Lemley, et al. 2015). Cyanophytes (blue-green algae), and to a lesser degree chlorophytes, were dominant in the fresh Lake 3 and Lake 4. The co-occurrence of these two algal classes is indicative of freshwater environments. Flagellates (likely cryptophytes and chlorodendrophytes) and bacillariophytes (diatoms) were dominant in the brackish/marine Lake 1, Lake 2 and the lower estuary. Dominant cyanophyte species present in Lake 3 and 4 included *Merismopedia* sp., *Microcystis* spp., *Aphanothece* sp., and *Chroococcus* sp.; whilst *Oocystis* sp. and *Dictyosphaerium* sp. were the dominant chlorophytes present in Kosi Bay. *Nitzschia longissima* was the dominant marine diatom in Kosi Bay.

Table 14.6: Kosi: Main microalgal groupings and their defining/dominant features

MAIN GROUPINGS	DEFINING FEATURES AND TYPICAL/DOMINANT SPECIES
Flagellates (e.g. cryptophytes, chlorodendrophytes, euglenophytes)	The flagellate components of the microalgal community are able to maintain themselves in the water column using their flagellae and they are usually numerically dominant when counts are made. They are made up of both autotrophic and heterotrophic organisms, the latter being consumers rather than photosynthetically productive. Despite this, they are still components that are ingested and are therefore part of the food available to larger consumers and especially fish.
Bacillariophyceae	Being relatively large by comparison with other microalgal groups, diatoms are sometimes the most important group in an estuary even though they may not be numerically dominant. They have relatively large cells and can be present in the water column or on the bottom. Under very low flow conditions the diatom community is mostly on the sediment surface but under disturbed or high flow conditions they become suspended in the water column. The marine diatom *Nitzschia longissima* was dominant in the saline areas of Kosi Bay.
Dinophyceae	Dinoflagellates, like other flagellates, are able to maintain their position in the water column. They prefer stable, stratified conditions with warmer temperatures and high nutrient concentrations (but low Silica concentrations). *Peridinium* sp. was abundant in the fresher lakes in summer 2016.
Cyanophyceae	The cyanophytes (blue-green microalgae) are a group of non-flagellated photosynthetic bacteria that can make up a large component of both the planktonic and benthic microalgal communities. They can be important in that under certain conditions (including anaerobic) because they can utilise gasses such as hydrogen sulphide in order to grow. Some species are able to fix nitrogen and can become important under conditions where the water column is oligotrophic. Certain species of cyanophytes can produce toxins which are able to be harmful if present in high concentration. Cyanophytes were abundant in the fresh Lake 3 and 4. Prominent species were: *Merismopedia* sp., *Microcystis* spp., *Aphanothece* sp. and *Chroococcus* sp.
Chlorophyceae	The green microalgae are a very diverse group that can be present in estuary waters in fairly high proportions. They are included mostly in the flagellated group and because of the flagellum they are able to maintain their presence within the water column rather than sink to the sediment surface as do the diatoms. *Oocystis* sp. and *Dictyosphaerium* sp. were the dominant Chlorophytes recorded in 2016.

Benthic microalgal biomass also showed a distinct pattern with the highest values in Lake 4 (441.13 ± 94.43 mg/m^2) decreasing to Lake 1 (51.14 ± 14.45 mg/m^2); while the average benthic chlorophyll *a* for all sites was 130.1 ± 22.88 mg/m^2. Sediment type is important with regards to 'regulating' MPB biomass, with sheltered, fine cohesive sediments (i.e. mud) generally supporting elevated levels compared to exposed, non-cohesive sands and silts. For the Kosi system, the sediments with high organic content had the highest benthic chlorophyll *a*. Sheltered areas in Lake 4 had high benthic microalgal biomass compared with exposed sandy sites of Lake 3. Lake 2 also had low values except for the west bank which was characterised by high organic content and the west bank of Lake 1. It is significant that these are freshwater seepage sites and that the west bank of Lake 2 had almost the exact same biomass values as the other westerly sites. The sheltered characteristics of some of the sites in Lake 3 resulted in an even higher benthic microalgal biomass.

In terms of benthic diatom communities within the Kosi Estuarine Lake system, there were clear patterns observed regarding the diversity, evenness and dominant taxa. Generally, the diversity and evenness decreased from the estuary (H' = 1.41; J' = 0.60) towards the fresh Lake 4 (H' = 0.73; J' = 0.41). Most of the estuary is classified as 'Poor' (moderately impacted) based on the diversity scores, with only Lake 4 receiving a 'Very Poor' (heavily impacted) rating (Lemley et al., 2015). Interestingly, the estuary displayed both marine (*Seminavis robusta* and *Mastogloia affirmata*) and freshwater (*Achnanthidium exiguum*, *Cocconeis placentula* var. *euglypta and Planothidium engelbrechtii*) diatoms; however, this is due to some sites being located at the confluence with a freshwater inlet. In the tidally influenced Lake 1, marine species such as *Amphora arcus*, *Amphora arenaria*, *Seminavis robusta* and *Diploneis bombus* prevailed. A more heterogeneous community was observed in Lake 2, with marine (*Amphora coffeaeformis*, *Amphora laevis*, *Catenula adhaerens* and *Fallacia nyella*), brackish (*Mastogloia lanceolata*) and freshwater (*Bracysira aponina, Achnanthidium exiguum*, and *Fragilaria tenera*) species dominating. Finally, Lake 3 and Lake 4 were primarily dominated by freshwater taxa, including *Cocconeis placentula* var. *euglypta, Rhopalodia gibberula, Cavinula scutelloides*, and *Cocconeis placentula*.

There have been minor changes in the microalgal condition over time with most being in response to nutrient input from the catchment and localized eutrophication. If uncontrolled there is the potential for toxic cyanophytes to dominate in Lakes 3 and 4 where they are currently occurring in low biomass. Domestic sewerage has not been a problem but with increasing human habitation in the catchment and several domestic water supply schemes this may change. Activities along the banks such as clearing, paths, cattle grazing and trampling would have resulted in some changes in the benthic microalgal habitat.

14.4.2 Macrophytes

The Kosi Estuarine Lake supports a nationally important area of swamp forest and mangrove habitat in South Africa. It is the only system in the country to support six tree species of mangroves: white mangrove *Avicennia marina*, black mangrove *Bruguiera gymnorrhiza*, red mangrove *Rhizophora mucronata*, Tonga mangrove *Lumnitzera racemosa*, Indian mangrove *Ceriops tagal* and cannonball mangrove *Xylocarpus granatum*. The latter two species are at the southernmost limit of their distribution. The Kosi Lakes are of considerable botanical importance due to the presence of several Red Data species including the southernmost distribution of the giant palm *Raphia australis*. Extensive floating and submerged aquatic macrophytes also form an important component of the system. Aquatic macrophytes form the major portion of the primary energy source for the food webs of lakes (Howard Williams and Liptrot 1980). They also stabilise sediments, protect against bank erosion, increase habitat diversity and provide shelter and breeding areas for benthic invertebrates, fish and birds. Macrophytes play an important role in sieving and trapping allochthonous and autochthonous matter. The fringing vegetation in Kosi Estuarine Lake is thus important as it reduces nutrient inputs to the lake. A survey in February 2016 documented the distribution and species composition of the macrophyte habitats in relation to the controlling environmental factors (DWS 2016) (Table 10.7). The west bank of the system had a large expanse of swamp forest. The mangrove fern *Acrostichum aureum* occurred from Lake 4 all the way to the mouth. Other abundant plants are common reed *Phragmites australis* and the sedge *Schoenoplectus scirpoides*. *Hibiscus tilieaceus* is also widespread occurring throughout the system.

A vegetation map for present conditions was produced from the field survey (DWS 2016) (Figure 11.7). In the same study, the distribution and area covered by different macrophyte habitats were compared with the earliest aerial photographs available for 1942. These changes provide input to the assessment of the present ecological status of the system. *Ceratophyllum demersum* and *Najas marina* are dominant submerged macrophytes. Unique to this lake are the algae mats in the deeper waters consisting of *Chara globularis* and green algae. *Potamogeton schweinfurthii* is known to prefer clear water. *Ceratophyllum demersum* is indicative of eutrophic and brackish water. The macroalgae *Spirogyra* sp. is abundant in Lake 3 and 4. *Spirogyra* is widespread in all freshwater habitats where it is common in standing water. Under favourable conditions it forms floating green filamentous mats (Janse van Vuuren, et al. 2006). *Lumnitzera racemosa* is a dominant mangrove in the lakes first appearing in the Mtando channel and then Lake 2. *Bruguiera gymnnorhiza* is also found on the south side of Lake 2 indicative of more saline conditions. Salinity at this site is 24 and the vegetation on the east bank consists of a distinctive row of reeds, the mangrove *Lumnitzera racemosa* and then *Hibiscus tilieaceus* representative of swamp forest.

Table 14.7: Kosi: Macrophyte habitat and functional groups

HABITAT TYPE	DISTRIBUTION	AREA IN 2016 (ha)
Open surface water area	Serves as a possible habitat for phytoplankton.	3367 (+652 from submerged)
Intertidal sand and mudflats	Intertidal zone occurs in the lower estuary and lower lakes whereas Lakes 3 and 4 have extensive areas of shallow water habitat for microphytobenthos colonisation.	23
Macroalgae	*Chara globularis* and green algae formed mats offshore in Lake 3. In the other shallow water areas macroalgae were epiphytic on the emergent plants.	-
Floating macrophytes	Floating leaved aquatics included *Nymphaea nouchali* and *Nymphaea lotus* in Lake 4 with some in the channel linking Lake 4 and 3.	-
Submerged macrophytes	*Ceratophyllum demersum, Najas horrida* (can tolerate brackish water), *Najas marina, Potamogeton schweinfurthii* and *Urticularia* sp. were found in Lakes 3 and 4. Other species appeared as the salinity increased for example *Stuckenia pectinata* (grows best salinity < 20) was only observed in Lake 3, *Ruppia cirrhosa* in Lake 1 and the seagrasses *Zostera capensis* and *Halodule universis* in the lower estuary.	652
Reeds and sedges	Common reed *Phragmites australis* and the sedge *Schoenoplectus scirpoides* are abundant fringing the banks of the system. *Juncus kraussii* replaces *Schoenoplectus scirpoides* in more saline areas. Extensive areas of reeds, sedges, grasses and shrubs occur in lower lying areas (often fresh water seepages) and between the lakes. Common species present included *Cyperus natalensis, Cyperus textilis, Cyperus prolifer* and *Cyperus thunbergii. Cladium moriscus, Typha capensis* and *Pycreus nitidus* occurred in the freshwater lakes and channels.	127
Salt marsh	*Juncus kraussi* was abundant in low-lying areas surrounding Lake 1 and 2. *Triglochin striata* and *Sporobolus virginicus* were also present in this habitat. This habitat was interspersed between saline grasslands and fringing the banks in some places.	58
Saline grasslands (grasses, herbs and sedges_	Saline grasslands of *Paspalum vaginatum, Stenotaphrum secundatum, S. dimidiatum* and some herbaceous species occurred on the peninsulas between the lakes. In some areas the palm *Phoenix reclinata* and the fern *Acrostichum aureum* interspersed this habitat.	229
Swamp forest	Extensive swamp forest occurs alongside the streams, channels and banks of the Kosi lakes. *Hibiscus tiliaceus* is abundant fringing the open water and interspersed between mangroves. *H. tiliaceus* is well adapted to grow in the coastal environment as it tolerates salt and waterlogging. *Raphia australis* was more prominent surrounding the freshwater lakes and channels and *Phoenix reclinata* increased towards the mouth of the system often interspersed amongst forest habitat or grassland matrix. Ferns such as *Cyclosorus interruptus, Stenochlaena tenuifolia* and *Lygodium microphyllum* were prevalent in the undergrowth of this habitat. Climbers and creepers were conspicuous in this habitat with common species including *Derris trifoliata, Mikania natalensis, Smilax anceps* and *Ipomoea* spp.	869
Mangroves	The greatest concentrations of mangroves occur on the islands and south-eastern shore of the tidal basin where all 5 species are represented. *Lumnitzera racemosa* and *Bruguiera gymnorrhiza* are more tolerant of prolonged basal inundation by water and low salinities and thus extend further from the mouth than any of the other mangrove species. Only a single mature *Xylocarpus granatum* is known in the system. The mangrove fern, *Acrostichum aureum* clearly has wide tolerance ranges as it occurred from Lake 4 to the lower estuary. It is known to grow in brackish water but the spores germinate best in freshwater. Ward et al. (1982) reported 59 ha of mangrove habitat, updated by Pillay (CSIR, unpublished) to be 60.7 ha.	71
Coastal forest and grassland	Trees and shrubs occurring on the higher elevations surrounding Kosi Bay. Common species include Umdoni *Syzygium cordatum, Ficus trichopoda*, *Bridelia cathartica*, *Rapanea melanophleos,* and *Morella serrata*.	721
Disturbed habitat	Areas that have been developed, cultivated or cleared or disturbed for access to the lakes (e.g. roads, cleared areas for maintenance of fish traps). From the aerial photographs some areas appear to have been previously cultivated. The 2016 field surveys found these areas to be grasslands, however, this habitat was still included as disturbed.	119

Resource utilisation is pronounced in all zones of Kosi Bay with evidence of burning, cattle grazing and harvesting of mangroves, reeds, sedges and palms. Mangrove brushwood is used for the construction and maintenance of fish traps. Invasive plant species in the system are minimal.

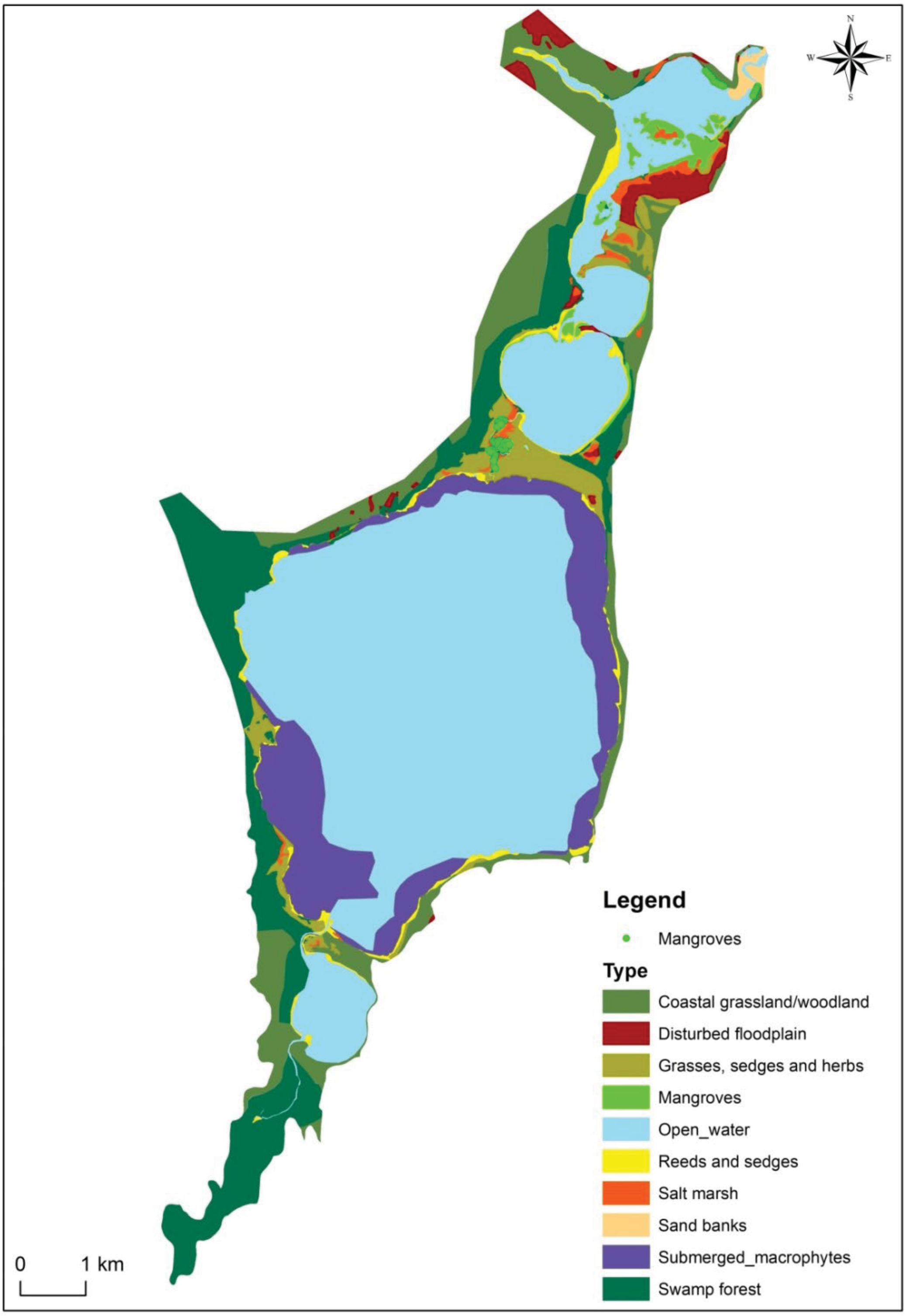

Figure 14.7 Kosi: Macrophyte habitats

There has been little change in the macrophyte habitat distribution between 1942 and 2016 (DWS 2016). Forest and floodplain habitat previously cleared for agriculture in the 1942 aerial photographs has regrown. Over time there has been a small increase in mangrove habitat in Kosi Bay with some of the islands in the tidal basin merging. Although the overall area of mangroves has increased there is intense harvesting of the trees particularly for brushwood to construct and maintain fish traps. Reed and sedge habitat has increased in cover where the Sihadhla River enters Lake 4 and an area north of Lake 2. Harvesting of mangroves, reeds, palms, sedges and grasses is evident throughout the system. Burning of surrounding floodplain and forest habitat is also problematic and previous studies have emphasised the susceptibility of mangroves to fires (DWS 2016)

14.4.3 Fish

The Kosi Bay is unique in South Africa as a series of connected estuarine lakes with very clear subtropical waters and salinities ranging from fresh (0) to near seawater (35). Kosi is also the only estuarine system of significant size that flows into an area of coastal sea where coral reefs occur, a reflection of its location on the warm, Agulhas influenced coast of KwaZulu-Natal near the South Africa/Mozambique border. These factors contribute to the system supporting a particularly wide diversity fishes, including species of importance in recreational and subsistence fisheries. Over 170 species have been reported from the system (Whitfield, 1980; Weerts unpublished; Table 10.2). Twenty-one (12%) of these are estuarine dependent species that complete their life cycle in the estuary or the linked lakes. These are dominated by Ambassidae and the Clupeid *Gilchristella aestuaria*. Over 140 of the species (82%) are marine spawning fishes, with a range of dependencies on estuaries (EAC II, III, V). The majority of these are marine stragglers (EAC III) which are restricted in their use of the system to the mouth (see below). Estuarine dependent marine species (EAC IIa and IIb) include predominantly several species of mullet (Mugilidae), pursemouths (Gerreidae) and spotted grunter (*Pomadasys commersonnii*). Predatory (piscivorous) fishes include several kingfish species (Carangidae) and barracudas (Sphyraenidae). Nine (5%) freshwater species in the system are dominated by members of the Cichildae (*Oreochromis mossambicus rendalli*, *Coptodon*, *Pseudocrenilabrus philander* and *Tilapia sparrmanii*). These occur predominantly in areas of low salinities in Lakes 3 and 4, although Mozambique tilapia *O. mossambicus* occurs in the lower lakes as well. This species occurs with some abundance in the Mtando Channel connecting Lakes 2 and 3, together with Sharptooth catfish *Clarias gariepinus* and an abundance of estuarine associated species (Weerts, pers. obs.)

The Kosi Bay Estuarine Lake system supports many species not reported from other estuarine systems in South Africa. The presence of a small section of reef at the estuary mouth is largely responsible for this. This reef is inhabited by an abundance of marine species which are primarily associated with reef habitats and have little or no dependence on estuaries. These include members of the Acanthuridae, Scaridae, Labridae, Chaetodontidae, Pomacentridae, Serranidae and Muraenidae. Most of the species in this group do not occur in any of the systems estuarine habitats (see Blaber 1978). However, several species, which are normally associated with reef and other marine habitats, also occur in what are typical estuarine habitats in the lower reaches of the Kosi estuary (where salinities are >25). For example, Apogonidae, Scorpaenidae, and even Sargassumfish *Histrio histrio* (Antennariidae) have been sampled in *Zostera* and *Ruppia* seagrasses near the estuary mouth, as have Muraenidae and Blenniidae from mangrove areas (Weerts, unpublished). The occurrence of many of these marine species, although interesting, cannot be attributed to any estuarine function of the system.

There are, however, an abundance of marine fishes which occur in the Kosi system, and which are strongly associated with its estuarine nature. Many of these fishes occur in the lakes in higher abundances and at larger size classes than in other South African systems. This holds true for several estuarine dependent marine fishes (EAC IIa, IIb and V) as well as estuarine opportunistic marine species (EAC IIc and III). In the case of both these latter groups these fishes occur in the lakes as juveniles as well as adults, and rich prey abundances appear to be an influential factor in this. There appear to be some linkages between estuarine habitats, particularly clear water mangroves, and the offshore coral reefs. This is evidenced by the abundance and large sizes of several members of the Lutjanidae (snappers) in the Kosi lakes. This family of fishes includes many species that rely on linkages and demonstrate strong connectivity between mangroves and coral reef habitats in other parts of the world (e.g. Mumby et al., 2004, 2006, Nagelkerken 2000, 2016).

Several of the obligate estuarine dependant species (estuarine residents; EAC I) occur in the Kosi lakes in higher abundances and frequencies of occurrence than any other South Africa system. These are typically small-bodied species, which are important in the trophic dynamics of the system. They are dominated by Ambassidae and Clupeidea as indicated above, but also include several members of the Gobiidae and Syngnathidae, which are otherwise rare in our estuaries.

Table 14.8: Kosi: List of fish species and families recorded, species are classified into five major estuary-association Categories (EAC) (see Table 9.2 modified from Whitfield (2019))

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE
Acanthuridae	*Acanthurus mata*	Tailring surgeon	III
Acanthuridae	*Acanthurus nigricans*	Whitecheek surgeonfish	III
Acanthuridae	*Acanthurus triostegus*	Convict surgeon	III
Acanthuridae	*Acanthurus xanthopterus*	Dusky surgeon	III
Acanthuridae	*Ctenochaetus strigosus*	Spotted bristletooth	III
Ambassidae	*Ambassis ambassis*	Banded glassy	I
Ambassidae	*Ambassis dussumieri*	Bald glassy	I
Ambassidae	*Ambassis natalensis*	Slender glassy	I
Anguillidae	*Anguilla mossambica*	African longfin eel	V
Antennariidae	*Antennarius striatus*	Striped angler	III
Apogonidae	*Apogon semiornatus*	Threeband cardinal	III
Apogonidae	*Ostorhinchus cookii*	Blackbanded cardinal	III
Atherinidae	*Atherinomorus lacunosus*	Hardyhead silverside	III
Atherinidae	*Hypoatherina barnesi*	Slender silverside	III
Balistidae	*Rhinecanthus aculeatus*	Blackbar triggerfish	III
Belonidae	*Strongylura leiura*	Needlefish	IIc
Belonidae	*Tylosurus crocodilus crocodilus*	Crocodile needlefish	III
Blenniidae	*Antennablennius bifilum*	Horned rockskipper	III
Blenniidae	*Istiblennius edentulus*	Rippled rockskipper	III
Blenniidae	*Parablennius pilicornis*	Ringnecked blenny	III
Blenniidae	*Plagiotremus rhinorhynchos*	Twostripe blenny	III
Blenniidae	*Plagiotremus tapeinosoma*	Piano blenny	III
Bothidae	*Bothus pantherinus*	Leopard flounder	IIc
Carangidae	*Atule mate*	Finlet kingfish	III
Carangidae	*Caranx ignobilis*	Giant kingfish	IIb
Carangidae	*Caranx melampygus*	Blue kingfish	IIc
Carangidae	*Caranx papuensis*	Brassy kingfish	IIb
Carangidae	*Caranx sexfasciatus*	Bigeye kingfish	IIb
Carangidae	*Pseudocaranx dentex*	Underjaw kingfish	III
Carangidae	*Scomberoides commersonnianus*	Largemouth queen fish	III
Carangidae	*Scomberoides lysan*	Doublespotted queen fish	IIc
Carangidae	*Scomberoides tol*	Needlescaled queenfish	IIc
Carcharhinidae	*Carcharhinus leucas*	Zambezi shark	IIb
Chaetodontidae	*Chaetodon auriga*	Threadfin butterflyfish	III
Chaetodontidae	*Chaetodon lunula*	Halfmoon butterflyfish	III
Chaetodontidae	*Chaetodon unimaculatus*	Limespot butterflyfish	III
Chaetodontidae	*Chaetodon vagabundus*	Vagabond butterflyfish	III
Chaetodontidae	*Heniochus acuminatus*	Coachman	III
Chanidae	*Chanos chanos*	Milkfish	IIc
Cichlidae	*Coptodon rendalli*	Redbreast tilapia	Iva
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	IV
Cichlidae	*Pseudocrenilabrus philander*	Southern mouthbrooder	IV
Cichlidae	*Tilapia sparrmanii*	Banded tilapia	IV
Clariidae	*Clarias gariepinus*	Sharptooth catfish	IV
Clupeidae	*Gilchristella aestuaria*	Estuarine round-herring	I
Clupeidae	*Herklotsichthys quadrimaculatus*	Onespot herring	III
Clupeidae	*Hilsa kelee*	Kelee shad	IIb
Clupeidae	*Sardinella albella*	White sardinelle	III
Clupeidae	*Spratelloides delicatulus*	Delicate round-herring	III

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE
Cyprinidae	*Enteromius viviparus*	Bowstripe barb	Ivb
Dichistiidae	*Dichistius capensis*	Galjoen	III
Dichistiidae	*Dichistius multifasciatus*	Banded galjoen	III
Eleotridae	*Eleotris fusca*	Dusky sleeper	I
Elopidae	*Elops machnata*	Tenpounder	IIa
Ephippidae	*Platax pinnatus*	Batfish	III
Fistulariidae	*Fistularia petimba*	Smooth flutemouth	III
Gerreidae	*Gerres longirostris*	Smallscale pursemouth	IIb
Gerreidae	*Gerres macracanthus*	Longspine pursemouth	IIb
Gerreidae	*Gerres methueni*	Evenfin pursemouth	IIb
Gerreidae	*Gerres oblongus*	Oblong pursemouth	III
Gerreidae	*Gerres oyena*	Slenderspine pursemouth	IIc
Gobiidae	*Awaous aeneofuscus*	Freshwater goby	IV
Gobiidae	*Bathygobius cyclopterus*	Spotted frillgoby	I
Gobiidae	*Bathygobius fuscus*	Frill goby	I
Gobiidae	*Coryogalops william*	Kaalpens goby	I
Gobiidae	*Croilia mossambica*	Burrowing goby	I
Gobiidae	*Favonigobius melanobranchus*	Blackthroat goby	I
Gobiidae	*Favonigobius reichei*	Tropical sand goby	I
Gobiidae	*Glossogobius callidus*	River goby	I
Gobiidae	*Glossogobius giuris*	Tank goby	IV
Gobiidae	*Oligolepis acutipennis*	Sharptail goby	I
Gobiidae	*Periophthalmus argentilineatus*	Bigfin mudhopper	I
Gobiidae	*Psammogobius biocellatus*	Sleepy goby	I
Gobiidae	*Redigobius dewaali*	Checked goby	I
Gobiidae	*Silhouettea insinuans*	Phantom goby	I
Gobiidae	*Silhouettea sibayi*	Barebreast goby	I
Haemulidae	*Caesio caerulaurea*	Blue-and-gold fusilier	III
Haemulidae	*Diagramma pictum*	Sailfin rubberlip	III
Haemulidae	*Plectorhinchus gibbosus*	Harry hotlips	III
Haemulidae	*Plectorhinchus playfairi*	Whitebarred rubberlip	III
Haemulidae	*Plectorhinchus sordidus*	Sordid rubberlip	III
Haemulidae	*Pomadasys commersonnii*	Spotted grunter	IIa
Hemiramphidae	*Hyporhamphus capensis*	Knysna halfbeak	I
Kuhliidae	*Kuhlia mugil*	Barred flagtail	IIc
Kuhliidae	*Kuhlia rupestris*	Rock flagtail	III
Kyphosidae	*Neoscorpis lithophilus*	Stone bream	III
Labridae	*Halichoeres scapularis*	Zigzag sand wrasse	III
Labridae	*Labroides dimidiatus*	Bluestreak cleaner wrasse	III
Labridae	*Stethojulis albovittata*	Four-ribbon wrasse	III
Labridae	*Stethojulis strigiventer*	Three-ribbon wrasse	III
Labridae	*Thalassoma hebraicum*	Goldbar wrasse	III
Labridae	*Thalassoma lunare*	Crescent-tail wrasse	III
Lethrinidae	*Lethrinus nebulosus*	Blue emperor	III
Lutjanidae	*Lutjanus argentimaculatus*	River snapper	IIc
Lutjanidae	*Lutjanus fulviflamma*	Dory snapper	IIc
Lutjanidae	*Lutjanus fulvus*	Yellowstriped snapper	III
Lutjanidae	*Lutjanus kasmira*	Bluebanded snapper	III
Megalopidae	*Megalops cyprinoides*	Oxeye tarpon	IIa
Monodactylidae	*Monodactylus argenteus*	Natal moony	IIb

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE
Monodactylidae	*Monodactylus falciformis*	Cape moony	IIa
Mugilidae	*Chelon dumerili*	Groovy mullet	IIa
Mugilidae	*Chelon tricuspidens*	Striped mullet	IIb
Mugilidae	*Crenimugil crenilabis*	Fringe-lip mullet	III
Mugilidae	*Moolgarda buchanani*	Bluetail mullet	IIc
Mugilidae	*Moolgarda cunnesius*	Longarm mullet	IIa
Mugilidae	*Moolgarda robusta*	Robust mullet	IIa
Mugilidae	*Mugil cephalus*	Flathead mullet	IIa
Mugilidae	*Planiliza alata*	Diamond mullet	IIa
Mugilidae	*Planiliza macrolepis*	Largescale mullet	IIa
Mugilidae	*Planiliza subviridis*	Squaretail mullet	IIb
Mugilidae	*Pseudomyxus capensis*	Freshwater mullet	IIa
Mullidae	*Upeneus vittatus*	Yellowbanded goatfish	III
Muraenidae	*Echidna nebulosa*	Floral moray	III
Muraenidae	*Gymnothorax flavimarginatus*	Yellow-edged moray	III
Muraenidae	*Gymnothorax margaritophorus*	Trunkeyed moray	III
Muraenidae	*Gymnothorax undulatus*	Leopard moray	III
Ophichthidae	*Cirrhimuraena playfairii*	Fringelip snake-eel	III
Ophichthidae	*Pisodonophis boro*	Giant snake-eel	IIc
Ostraciidae	*Lactoria cornuta*	Longhorn cowfish	III
Pempheridae	*Pempheris oualensis*	Blacktip sweeper	III
Platycephalidae	*Platycephalus indicus*	Bartail flathead	IIc
Poecilidae	*Aplocheilichthys myaposae*	Natal topminnow	Ivb
Pomacanthidae	*Pomacanthus semicirculatus*	Semicircle angelfish	III
Pomacentridae	*Abudefduf sexfasciatus*	Stripetail damsel	III
Pomacentridae	*Abudefduf sordidus*	Spot damsel	III
Pomacentridae	*Abudefduf sparoides*	False-eye damsel	III
Pomacentridae	*Abudefduf vaigiensis*	Sergeant major	III
Pomacentridae	*Chromis nigrura*	Blacktail chromis	III
Pomacentridae	*Chrysiptera brownriggii*	Blueribbon damsel	III
Pomacentridae	*Chrysiptera glauca*	Blue damsel	III
Pseudochromidae	*Pseudochromis dutoiti*	Dutoiti	III
Scaridae	*Scarus ghobban*	Blue parrotfish	III
Sciaenidae	*Argyrosomus japonicus*	Kob	IIa
Scorpaenidae	*Dendrochirus brachypterus*	Shortfin turkeyfish	III
Scorpaenidae	*Pterois antennata*	Broadbarred firefish	III
Scorpaenidae	*Pterois miles* (*Pterois volitans* also reported)	Devil firefish	III
Scorpaenidae	*Scorpaenopsis gibbosa*	False stonefish	III
Serranidae	*Cephalopholis argus*	Peacock rockcod	III
Serranidae	*Epinephelus chlorostigma*	Squaretail rockcod	III
Serranidae	*Epinephelus marginatus*	Yellowbelly rockcod	III
Serranidae	*Epinephelus tauvina*	Bullnose bass	III
Serranidae	*Grammistes sexlineatus*	Goldstriped rockcod	III
Siganidae	*Siganus stellatus*	Starspotted rabbitfish	III
Siganidae	*Siganus sutor*	Whitespot rabbitfish	III
Sillaginidae	*Sillago sihama*	Silver sillago	IIc
Solenostomidae	*Solenostomus cyanopterus*	Ghost pipefish	III
Sparidae	*Acanthopagrus bifasciatus*	Twobar bream	III
Sparidae	*Acanthopagrus vagus*	River bream	IIa
Sparidae	*Diplodus capensis*	Blacktail	IIc
Sparidae	*Lithognathus mormyrus*	Sand steenbras	IIc
Sparidae	*Rhabdosargus holubi*	Cape stumpnose	IIa

FAMILY NAME	SPECIES NAME	COMMON NAME	DEPENDENCE
Sparidae	*Rhabdosargus sarba*	Natal stumpnose	IIb
Sparidae	*Rhabdosargus thorpei*	Bigeye stumpnose	IIc
Sparidae	*Sarpa salpa*	Strepie	IIc
Sphyraenidae	*Sphyraena barracuda*	Great barracuda	IIb
Sphyraenidae	*Sphyraena flavicauda*	Yellowtail barracuda	III
Sphyraenidae	*Sphyraena jello*	Pick-handle barracuda	IIc
Synanceiidae	*Synanceia verrucosa*	Stonefish	III
Syngnathidae	*Hippichthys heptagonus*	Belly pipefish	I
Syngnathidae	*Hippichthys spicifer*	Bellybarred pipefish	I
Synodontidae	*Saurida gracilis*	Graceful lizardfish	III
Terapontidae	*Terapon jarbua*	Thornfish	IIa
Tetraodontidae	*Amblyrhynchotes honckenii*	Evil-eyed blaasop	III
Tetraodontidae	*Arothron hispidus*	Whitespotted blaasop	IIc
Tetraodontidae	*Arothron immaculatus*	Blackedged blaasop	IIc
Tetraodontidae	*Arothron nigropunctatus*	Blackspotted blaasop	III
Tetraodontidae	*Arothron stellatus*	Plainfin blaasop	III
Tetraodontidae	*Canthigaster janthinoptera*	Honeycomb toby	III
Tetraodontidae	*Canthigaster valentini*	Blacksaddled toby	III
Tripterygiidae	*Helcogramma obtusirostris*	Lowcrest triplefin	III
Zanclidae	*Zanclus cornutus*	Moorish idol	III

This is probably also true of several of the Eleotridae that have been reported from the system, although little is known about these species because of the cryptic habits. The freshwater species of fish that occur in Kosi include euryhaline freshwater forms (EAC IVa) noted above, with varying degrees of salinity tolerance and which typically also occur in estuaries elsewhere in South Africa. More stenohaline freshwater species (EAC IVb) occur but are restricted to freshwaters in the upper reaches of the Kosi linked lake system, and in the inflowing streams. Because of the flat topography of the region and the small size of peripheral freshwater streams, these fishes are most threatened by reduced freshwater inputs, and are at greatest risk in the Kosi system during times of drought.

Obligate catadromous fishes (EAC V) in Kosi are represented by eels of the family Anguillidae. Only one species is listed in Table 10.2, but others undoubtedly occur. These eels occur as elvers, juveniles and adults in the lakes as well as their connected freshwaters, although spawning and egg and larval distribution occur in the marine environment. Kosi's catchments are not particularly large, but its associated freshwaters are probably significant for the shortfin eel, *Anguilla bicolor bicolor*, a species apparently restricted to coastal lowlands (Skelton 1993). Kosi is also the only (near) permanently open estuary, connecting the marine environment with estuarine and freshwaters along a very long stretch of coast from uMfolozi-St Lucia to Maputo, a distance of some 300 km. This renders the system important for all anguillid eels, as well as other estuarine associated marine spawning fishes.

In terms of both its overall morphology and physicochemical conditions, Kosi in the present day is similar to its reference condition. In its natural condition the system was used by a diversity of fishes from all groupings as estuarine habitat for breeding, nursery and feeding purposes. Indeed, the species assemblages and abundances of the freshwater and estuarine resident component of the fish assemblage were likely to have been very similar to those of the present day. There is, however, clear indication of resource utilisation that has impacted the system and its fishes. This is evident in the harvesting of various forms of vegetation, both in the system and the surrounding lowlands, as well as clearing of vegetation for footpaths, cattle paths, and increasingly for vehicles. Most noticeable from aerial photography is the proliferation of fish traps, which have undoubtedly changed the nature of the system to some degree at least, through impacts on sediment movement and stimulating growth of mangroves "islands" in basin areas. Fish traps of course also have a direct impact on the fishes of the system in being the primary method of exploitation and forming the basis for a fishery, which has increasing impacts on the systems present ecological state. Key species impacted in the system are *Acanthopagrus vagus*, *Lutjanus argentimaculatus*, *Pomadasys commersonnii*, *Rhabdosargus sarba*, and various mullet species. These species are all estuarine dependant marine species that characterised the system in its reference condition. Others, such as *Chanos chanos*, and (perhaps) *Caranx* spp., appear to have undergone declines regionally. It is therefore also likely that increasing fishing pressure on estuarine dependant marine species elsewhere on the coast (in South Africa and Mozambique) has affected the fishes in the Kosi linked lakes, although this is secondary in terms of an impact compared to direct exploitation in the system itself.

There has been a marked decline in the size distribution of the main target species flathead mullet (*Mugil cephalus*), Natal stumpnose (*Rhabdosargus sarba*) and spotted grunter (*Pomadasys commersonnii*) over the past 30 years (see DWS 2016). This may be attributed to one or a combination of the following factors: change in trap orientation from upstream to downstream, increasing use of synthetic materials, illicit gillnetting and regional changes in the availability of estuarine nursery habitat. Historically, and by agreement with fishers, trap-openings were faced upstream to catch larger fish exiting the system after their estuarine sojourn whereas nowadays there's a trend towards orientating them downstream to catch recruiting and therefore smaller fish. There's also a tendency to deviate from traditional materials such as reeds, palm fronds and wild banana leaves to construct and line traps towards gum poles and synthetic materials such as plastic and even gillnet. The overall effect is to reduce the "mesh-size" of the traps and increase the catch of smaller fish. Illicit gillnetting may also be playing a role in selecting for larger fish before they're caught in the traps. The end result is that recruitment and growth overfishing are occurring in the system. Alternatively, or concomitantly, the unavailability of St Lucia over much of the past two decades may have seen more juvenile and adolescent fish using the Kosi system as an alternative estuarine nursery area.

Prior to 1994 trap numbers were low and catches sustainable and there was little overlap between recreational and other fishing sectors. Since then and emigration and mortality aside, a very high recapture rate (35%) of tagged fish suggest a very high and unsustainable impact on the stocks of the main species caught. There has also been an increase in the proportion of immature fish across all species caught. Whilst some of this may be due to the closure and unavailability of the St Lucia nursery, the main drivers are likely to be the reorientation of the traps from upstream to downstream and synthetic trap materials catching smaller fish. Overall, the increase in fishing power and commercialization of the trap fishery has led to it becoming unsustainable. Management realises this and has recommended and initiated appropriate action to maintain sustainable catches and livelihoods in this World Heritage Site.

14.5Present Health Condition

The Kosi Bay Estuarine Lake system is of considerable botanical importance because the salinity gradient that characterises the transition from the lakes to the sea supports nationally important areas of submerged macrophytes (largest in the country), swamp forest (second largest in the country) and mangrove habitat (fifth largest in the country). Macrophyte species are distributed in the system in relation to salinity, depth and turbidity. The system has high ecological and biodiversity value and is an important nursery area for both invertebrates and fish, as well as being an important bird area for migratory and nomadic birds due to the undisturbed nature of the marginal vegetation. Although the system is impacted by exploitation resource use of macrophytes (mangrove and reed harvesting) this is relatively minor at this stage. The main threats to this unique system are eutrophication, changes in water level, and groundwater abstraction. Overfishing is also clearly impacting the fish community. The estuary falls within the iSimagaliso Wetland Park.

The Kosi Bay Estuarine Lake system is in a Natural to Near Natural state. Table 10.9 summarises the condition of the abiotic and biotic components to determine the level of functionality retained in the system (Van Niekerk et al. 2019).

Table 14.9: Kosi: Present ecological condition

COMPONENT	SUMMARY	NATURAL	NEAR NATURAL	MODERATLY MODIFIED	LARGELY MODIFIED	SEVERELY MODIFIED	CRITICALLY MODIFIED
Hydrology	Some reduction in flows.		●				
Hydrodynamics	Similar to natural.	●					
Salinity	Similar to natural.	●					
General Water Quality	Similar to natural.	●					
Physical habitat	Similar to natural.	●					
Microalgae	Near natural.		●				
Macrophytes	Some loss of riparian vegetation due to agriculture. Harvesting of reeds and sedges for housing. Harvesting of mangroves for fish traps.		●				
Invertebrates	Severe infestation by the gastropod *Tarebia granifera*. The exploitation of invertebrates.			●			
Fish	Significant reduction in abundance due to overfishing by a traditional subsistence fishery which is increasingly commercial.			●			
Birds	Similar to natural.	●					
ESTUARY HEALTH	**NATURAL TO NEAR NATURAL with a downwards trajectory. However, functionality is intact and opportunities for rehabilitation exist.**	⦿					

15. KEY CONSIDERATIONS FOR CONCEPTUAL MODELLING

15.1Patterns in Key Feature and Abiotic States

Based on the overview of South Africa's estuarine lakes in the preceding chapters, Table 15.1 summarises the general characteristics of connectivity, morphological complexity, and salinity regimes in these systems. This insight is important in the development of conceptual models on the dynamics of lake systems, and to identify sub-categories within estuarine lake systems.

Table 15.1 summarises some of the key complexities of South African estuarine lakes. It highlights estuarine lakes can have one or two mouths, which can be fully tidal, very constricted or perched. From a temporal scale perspective connectivity varies from permanently open to only open on near decadal scales. Connectivity to the sea can occur via constricted inlet channels, fully functional estuaries, or in some cases, large estuarine lakes can be directly connected to the sea with no clearly defined channels (e.g. Klein). Estuarine lakes can comprise single basins, or they can occur as a series of linked lake systems (up to five), which can be linked through several meandering channels (e.g. Kosi has four connected lakes which are connected to the sea by a large shallow estuary). Across the country's estuarine lakes, average depth varies from 2 m to more than 30 m, with most lakes around 3 to 5 m. Most lake systems also have more than one river feeding them, while two systems are fed nearly exclusively by groundwater. Salinity regimes vary from 0 to 35, but most lakes are brackish to fresh, with some lakes showing a tendency to become hypersaline during dry periods.

This high level of complexity and variability amongst systems warrants the development of individual conceptual models of the physical processes for all the lake systems as one generic model would not suffice in furthering the understanding of and climate change stressors on estuarine lakes.

This complexity is further compounded by the occurrence of a wide range of generic abiotic states that is observed in estuarine lake systems of South Africa. In total, seven open and five closed generic abiotic states were observed in the lakes systems that form part of this study. Table 15.2 provides a summary of the typical abiotic conditions in each state focusing on mouth state, salinity regime and water levels as key distinguishing characteristics. While there is individual lake differences in the states as a result of the interplay between bathymetry and freshwater input, some common features could nevertheless be grouped into the 12 states as listed in Table 15.2.

Reflecting on the range of abiotic states occurring in the estuarine lake systems, Table 15.3 provides a comparison between the various lakes systems and attempts to categorise observed states for application in the design of conceptual modelling (the next phase of the study). Symbols were used to indicate abiotic states identified in the literature (●) and states identified in the literature, but that did not meet generic abiotic state criteria/description (Table 15.2) and required reclassification/unbundling. The misidentified (○) can mostly be contributed to lack of sufficient data, the short duration of some physical states, e.g. days under flood conditions, or simplification for flow requirement studies ('fit-for-purpose' approach).

Table 15.1: Overview of connectivity, complexity, and salinity regimes in South Africa's estuarine lakes under present conditions

ESTUARINE LAKE	CONNECTIVITY			MORPHOLOGICAL COMPLEXITY					SALINITY	
	# Mouths	Tidal exchange	Temporal scales	Inlet channel/ Lower estuary (tidal)	Lakes	Depth (m)	Connecting channels	Rivers	Inlet/ Estuary	Lakes
Verlorenvlei	1	Perched	1-4 yrs	Inlet channel	1	2.5 m (Max: 5)	-	1	0-110	Fresh
Zeekoevlei	1	Perched	Open (100%)	Canalised	2		2	2	0-100	Fresh
Bot/Kleinmond	2	Tidal/ Constricted	1-4 yrs	Estuary (Kleinmond)	1 (Bot)		1 (Rooisand)	2/1	0-35 (Kleinmond)	0-45 Bot
Klein	1	Tidal	1-2 yrs	-	1	3 (Max: 2)	-	2	-	0-40
Heuningnes	1	Tidal	Open (95%)	Estuary	1			2	0-45	0-6
Touw/Wilderness	1	Tidal	1-3 yrs	Estuary (Touw)	3 (Wilderness)	4-6 (Max:7)	3	1/2	0-35	0-20
Swartvlei	1	Tidal	1-4 yrs	Estuary	2	5 (Max: 17)		3 + Groundwater	0-35	5-12
uMhlathuze*	2	Tidal/Tidal	Open (100%)	-	2	1/12 (Max: 2/20)	2	2/3 + Groundwater	- -	0-35 35
iNhlabane	1	Constricted	>1 yr	Estuary	1	2 (Max: 5)		1 + Groundwater	0-35	0
St Lucia/uMfolozi	2 (during floods)	Tidal	1-10 yrs	Estuary (Narrows)/ Estuary	3	1/1 (Max: 3 /2)	1	5 / 2 + Groundwater	0-35	0-250
uMgobezeleni	1	Constricted	Open (99%?)	Inlet channel	2	3 (Max: 5)	2	Groundwater +2		Fresh
Kosi	1	Tidal	Open (99%)	Estuary	4+1 (Zilonde)	3 (Max: 31)	4	Groundwater + 3	0-35	0-20

*uMhlathuze has been artificially separated into two systems with the construction of the Port of Richards Bay

Table 15.2: Description of generic abiotic states occurring in estuarine lake systems

ABIOTIC STATE		DESCRIPTION
Open	Fresh	Mouth is open and the system is (nearly) fresh throughout. Average water levels. Can have elevated water levels due to flooding for short periods.
	Marine/ Fresh	Mouth is open with limited salinity penetration in lower reaches (estuarine zone), while lakes are generally fresh. Average water levels.
	Gradient	Mouth is open and full salinity gradient is observed throughout the system. Average water levels.
	Marine/ Brackish	Mouth is open and salinity varies from marine (near mouth) to brackish. Average water levels. Average water levels.
	Marine	Mouth is open and a marine salinity regime is observed throughout the system. Average water levels.
	Marine/ Hyper	Mouth is open and the salinity regime varies from marine to hypersaline in parts of the system. Average water levels. Some parts of system may become isolated.
	Hyper-saline	Mouth is open and majority of lake system is hypersaline. Very low water levels.
Closed	Fresh	Mouth is closed and the system is (nearly) fresh throughout. High to very high-water levels.
	Brackish	Mouth is closed and the system is brackish throughout. High water levels.
	Gradient	The mouth is closed, and partial longitudinal salinity gradient is observed. High water levels.
	Marine/ Brackish	Mouth is closed and salinity regime varies from marine to brackish in parts of the system. Low water levels.
	Marine/Hyper-saline	Mouth is closed and salinity regime varies from marine to hypersaline in parts of the system. Very low water levels, some littoral habitats may be exposed, or parts of lakes isolated from larger system.

Table 15.3: Comparison of typical open and closed abiotic states in various estuarine lakes system (● literature; ○ identified in literature, but not meet generic criteria of abiotic state)

	OPEN							CLOSED					
	Fresh	Marine/ Fresh	Gradient	Marine/ Brackish	Marine	Marine/ Hyper	Hyper-saline	Fresh	Brackish	Gradient	Marine/ Brackish	Marine	Hyper-saline
Verlorenvlei	●							●	●				
Zeekoevlei	●												
Bot/Kleinmond					●			●	●			●	●
Klein	●		●		●				●			●	○
Heuningnes	●		●		●		●		●				●
Touw/Wilderness	●		●					●	●		●		
Swartvlei	●		●						●	●	○	●	
iNhlabane	●							●					
uMhlathuze*			●		●								
St Lucia/uMfolozi	●				●	●				●			●
uMgobezeleni	●							●					
Kosi	●	●	●	●	○					○	●		

* uMhlathuze has been artificially separated into two systems with the construction of the Port of Richards Bay and no longer supports natural occurring abiotic states

Reflecting on the typical abiotic states occurring in the estuarine lakes of South Africa listed in Table 15.3 it is clear that the highly modified system does not exhibit highly complex abiotic states, and/or do not manifest significant changes in states under different climatic conditions (e.g. wet/dry cycles) due to anthropogenic interruption of their natural cycles. Therefore, Zeekoei, INhlabane and uMhlathuze/Richard's Bay systems will not be further evaluated as part of this Climate Change vulnerability study.

Furthermore, in recognition of the complexity of St Lucia/uMfolozi lake system and the plethora of recent research outputs (including a climate change vulnerability analysis) on this system, this study from here on would focus on the lesser-known functional estuarine lakes systems in South Africa.

15.2Abiotic Response Indicators

Climate change pressures (shifts in seasonal rainfall, increased drought and flood events, increased temperature and evaporation) together with anthropogenic influences (increased pollution and water abstraction, development) put pressures on the estuarine lakes. Water level in lakes fluctuates annually and inter annually as a natural response to local climate and rainfall events. These fluctuations are expected to amplify under climate change as rainfall reduces and abstraction for human consumption increases, aggravated by is the issue of increased sea storms and SLR with consequent saline water intrusion. Table 15.3 summarises some of the impacts Climate Change driven temperature and rainfall shifts may have on key abiotic processes in estuarine lakes.

Table 15.4: Overview of the possible influence of Climate Change vectors linked to changes in temperature and rainfall on key abiotic response indicators in estuarine lake systems

CLIMATE CHANGE VECTOR	INFLUENCE ON ABIOTIC PROCESSES
Temperature	**Water levels:** An increase in temperature is likely to increase evaporation rates and decrease lake water levels during the closed phase (e.g. Verlorenvlei, Bot, St Lucia). This will particularly be a problem during drought conditions.
	Mouth state: Rising temperatures and evaporation rates are likely to increase evaporation rates, decrease lake level and thus also decrease opportunities for open mouth conditions due to high evaporative losses. This will particularly be a problem under drought conditions.
	Salinity: Rising temperatures and evaporation rates may lead to hypersalinity developing in some lakes systems (Klein), or increase the duration and intensity of existing hypersalinity cycles (e.g. St Lucia). However, in some systems, like the Bot/Kleinmond, it could lead to a freshening of the lake system under prolonged closed conditions due to seepage losses and outflow through Kleinmond.
Rainfall	**Water levels:** An increase/decrease in direct rainfall on the lakes will be a related increase/decrease on lake water levels as these systems have large surface areas and can be sensitive to direct input. The larger the system the more sensitive it will be to rainfall changes.
	Mouth state: An increase/decrease in direct rainfall on the lakes will have an impact on breaching frequencies. The larger the system the more sensitive it will be to rainfall changes.
	Interactive effects: Increased rainfall could result in increased breaching and prolonged open mouth states that decreased water levels
River runoff	**Nearshore marine environment:** A decrease /increase in runoff will have a related impact on the fluvially dependant nearshore marine habitats that rely on river inflow for salinity and turbidity fronts, nutrient input, sediment supply and detritus (organic matter).
Floods	**Mouth dynamics:** An increase/decrease in floods will increase/decrease opportunities for mouth breaching, which, in turn, will change connectivity with the marine environment.
	Sediment dynamics: An increase/decrease in floods will change the sediment equilibrium in lake systems. In many cases, lakes are sediment sinks and thus sensitive to increased sediment input.
	Salinity: During a flood event salinity can be fresh or nearly fresh. However, after a flood event salinity tend to increase significantly due to increase tidal amplitude and related seawater flushing. Thus an increase in floods and related scouring of the mouth area, can result in an increase in salinities post a flood event. Systems such as Swartvlei may thus experience an increase in the maximum salinity achieved during the open cycle if floods were to intensify.
	Water levels: Low tide levels can be dramatically lower after a flood event, reducing subtidal habitat and causing dieback /desiccation of submerged vegetation that is now exposed. Thus, reduction in habitat can impact biota such as fish.
Droughts	**Water levels:** An increase in droughts is likely to decrease lake water levels under extreme conditions.
	Mouth state: An increase in droughts is likely to decrease marine connectivity (less open mouth conditions).
	Salinity: An increase in droughts is likely to increase the likelihood of hypersalinity developing (Klein) or increase the duration and intensity of exiting hypersalinity cycles (St Lucia). However, in some systems, long closed periods may lead to freshening of the lake system.
	Lake connectivity: Drastically reduced lake levels are likely to isolate parts of the estuarine lake systems from each other (e.g. Rondevlei).

15.3Biological Response Indicators

15.3.1 Microalgae

The effect of abiotic characteristics and processes, and other biotic components, on microalgae is described in Table 15.3. The above information, in turn, can be used to estimate the ecological health of the microalgae component in estuaries.

Studies have shown that at moderate levels of water level disturbance, littoral habitats and their biota are affected (Zohary and Ostrovsky 2011). The littoral zone usually extends to a depth of between 1 and 5 m. This littoral zone usually has high species diversity because it acts as an ecotone between the terrestrial and aquatic habitats. At higher disturbance, keystone species weaken, invasive species increase, biodiversity is reduced and microalgal blooms increase even in the absence of nutrient loading. The latter is due to internal nutrient recycling. Hydrodynamic modelling on the impacts of climate change in Lake Manzala in Egypt shows forecast changes in water level, temperature and salinity (Elshemy and Khadr 2015).

Table 15.5: Effect of abiotic characteristics and processes, as well as other biotic components on microalgae

PROCESS	MICROALGAE
Mouth condition (temporal implications where applicable)	Once the berm at the estuary mouth is breached, there is a major outflow of estuarine water to sea that results in a rapid drop in the water level. This results in previously submerged sand and/or mud banks becoming exposed for long periods (weeks to years). The exposure of previously inundated sediments has a profound impact on the available microphytobenthic habitat within a lake system, impacting on higher trophic levels (e.g. providing a food source to intertidal crab species).
Retention times of water masses	Short water retention times favour the dominance of chlorophyte and diatom taxa in the upper and middle reaches of estuaries. The efficient intrusion of marine water replenishes oxygen-rich water in the lower reaches of estuaries, preventing cyanobacteria from becoming dominant and favouring the prevalence of marine diatoms and flagellated life-forms that require vertical stratification (e.g. dinoflagellates, cryptophytes, raphidophytes). The intrusion of oxygen-poor groundwater typically supports cyanobacteria in the microphytobenthos, a process that can also occur in some lake systems.
Flow velocities (e.g. tidal velocities or river inflow velocities)	In the upper reaches of lakes under high river flow, the phytoplankton is typically dominated by the chlorophytes, diatoms, and euglenophytes. As river flow decreases flagellated life-forms (e.g. dinoflagellates, cryptophytes, raphidophytes) become dominant in the middle reaches of estuaries where the water column is stratified, particularly in nutrient-rich water. The water column tends to become dominated by small phytoplankton, the picophytoplankton (<2 µm), when river flow is low. If there is very little exchange of water in the estuary and there is a high oxygen demand, then conditions favour the presence of cyanobacteria in the phytoplankton and in the microphytobenthos.
Total volume and/or estimated volume of different salinity ranges	When a lake is breached, the reduction in water level causes a decrease in the volume of water occupied by phytoplankton, limiting the potential area for colonisation of microalgae as well as overall primary production throughout the estuary.
Floods	Large-scale floods are important in scouring accumulated sediment, organic material, and ‘old’ water from estuaries, effectively resetting the system. The flood itself as well as the improved tidal exchange following the event support the presence of chlorophytes and diatoms in the water column and provides intertidal habitat for microphytobenthos.
Salinity	Distinct communities containing microalgae, both phytoplankton and microphytobenthos, are present in marine and freshwater environments. The presence of either of these two communities in an estuarine lake system is dependent on the hydrodynamics (e.g. tidal intrusion and freshwater flow).
Turbidity	Microalgal primary production is light dependent and an increase in turbidity is likely to inhibit this, resulting in a decrease in the biomass of microalgae, particularly phytoplankton.
Dissolved oxygen	Dissolved oxygen is a function of several variables including organic loading, water exchange (through river flow or tidal exchange), and the presence of primary producers, etc. If there is a high oxygen demand and poor water exchange, then the resulting oxygen-poor environment is likely to support microalgal communities dominated by cyanobacteria.
Nutrients	High nutrient loads in estuarine lakes support high microalgal biomass (phytoplankton chlorophyll *a* > 20 µg.l-1, and benthic microalgal chlorophyll *a* > 100 mg.m^{-2}). Strong stratification in a nutrient-rich estuarine lake is likely to support a dinoflagellate and/or raphidophyte dominated phytoplankton community. Extended periods of low river flow and limited, or no, tidal exchange in a nutrient-rich system will accelerate the process of eutrophication, resulting in an organic-rich and oxygen-poor environment that supports a cyanobacteria dominated microalgal community.
Sediment characteristics (including sedimentation)	The accumulation of fine sediment (silts and clays) provides an ideal benthic habitat for epipelic microphytobenthos. This can be a very productive environment supporting a complex food chain (e.g. mobile diatoms, polychaete worms, intertidal crabs, mud prawns, etc.). However, if there is a high organic content then the sediment environment is likely to become anoxic to the sediment surface in extreme cases and is likely to be dominated by cyanobacteria. Sedimentation by fine sediment is unlikely in environments exposed to strong flow. These environments are typically dominated by coarse sediment, and exposed rocks and boulders providing a suitable habitat for episammic and epilithic microalgal taxa.

PROCESS	MICROALGAE
Other biotic components	The dominance of microalgae in an estuary is influenced by the presence of other biotic components. In a recently flushed estuary, the fast-growing microalgae is perfectly adapted to colonise the environment, with little competition for space and resources. However, with time the higher trophic levels begin to recover, and herbivory increases, particularly from the invertebrates, impacting on microalgal biomass. In addition, the presence of macrophytes and macroalgae impact on the microalgae, fringing vegetation and submerged aquatic vegetation provide habitat for epiphytic microalgae (at the expense of epipelic microalgae) but fast-growing macroalgae (e.g. *Cladophora glomorata* and *Ulva intestinalis*) compete with microalgae for light and nutrients.

15.3.2 Macrophytes

Macrophyte habitats provide important ecosystem services such as filtering and detoxification. They cycle nutrients by taking them up and releasing them again through decomposition processes. They provide a habitat for fish and invertebrates. Salt marsh, mangrove and reed and sedge wetlands protect the land from floods and sea storms, sequester carbon and serve as a source of raw materials for humans. A diversity of macrophyte habitats creates sites desirable for recreation, tourism, and research. A summary of the effect of abiotic processes, as well as other biotic components on macrophyte habitats are described in Table 15.4.

As freshwater inflow is an important determinant of the structure and function of estuarine lakes, any changes to this influence macrophytes. Changes in flow velocity and subsequent sedimentation mostly results in macrophytes encroaching into open water areas. Changes in mouth state and water level can cause die back of macrophytes. Salinity influences species richness, biomass, and community composition. In an estuary with a longitudinal salinity gradient different macrophytes will be distributed along the gradient. Deterioration in water quality is an increasing problem in South African estuaries and estuarine lakes. This results in reed expansion, increases in macroalgal blooms and invasive aquatics such as water hyacinth. Floating invasive aquatics frequently occur in the upper reaches of estuaries in response to agricultural return flow. Most estuarine habitat has been lost due to residential and industrial developments. In many systems agriculture also takes place within the 5 m contour line. Grazing and associated trampling by livestock is a pressure in some lake systems, e.g. Verlorenvlei. Mangroves are harvested for building material and fuel wood. Reeds and sedges are also harvested but this activity is more common in subtropical compared to Warm-Temperate estuaries, e.g. *Juncus kraussii* (ncema) and *Phragmites australis* (common reed), are commonly used in KwaZulu-Natal by the local community for mats and basketry. Alien vegetation also displaces estuarine macrophytes. This particularly occurs along the boundaries of estuaries where the ecotone between the terrestrial and estuarine habitat has been disturbed. In the Temperate estuaries common invasives are *Acacia cyclops*, *Acacia longifolia*, *Acacia mearnsii*, *Lantana camara*, *Solanum americanum* and *Ricinus communis.* Common reed *Phragmites australis* can spread and colonise disturbed Eco tones characterised by low sediment and groundwater conductivity from adjacent development and freshwater runoff. Other impacts not quantified in this assessment are activities influencing submerged macrophytes such as bait digging, damage by boats and dredging (Adams et al. 1999).

Table 15.6: Effect of abiotic characteristics and processes, well as other biotic components on macrophyte habitats

PROCESS	MACROPHYTES
Mouth condition (temporal implications where applicable)	Open mouth conditions create intertidal habitat. Salt marsh species occur along a tidal inundation gradient. Closed mouth conditions would promote the growth and proliferation of macroalgae and submerged macrophytes.
Retention times of water masses	Greater water retention time would provide better opportunities for nutrient uptake by macrophytes thereby favouring their abundance. Low flow conditions could cause the expansion of littoral/fringing vegetation into the water body.
Water levels	High water level: result in some flooding of macrophyte habitats. Macroalgae and submerged macrophytes flourish in this state. Mangroves and swamp forests are sensitive to flooding, standing water and anoxic conditions and will not survive prolonged inundation (months).
Water level fluctuations	Lakeshores are ecotones (a transitional zone between terrestrial and aquatic habitats) characterized by limited fluctuation in water levels. Any rapid changes in water level will result in vegetation changes. Stable water levels can also cause an expansion of macrophytes such as reeds and sedges.
Wave action	The edges of the estuarine lakes are defined by distinct zones of emergent macrophytes, which act as a wave barrier for submerged macrophytes that grow in the shelter of these plants. In exposed areas were wind-driven wave action can prevent the growth of submerged macrophytes.

PROCESS	MACROPHYTES
Flow velocities (e.g. tidal velocities or river inflow velocities)	High flow prevents the establishment of large submerged macrophyte beds. Currents less than 0.1 m s^{-1} favour the growth and establishment of submerged macrophytes such as *Stuckenia pectinata* (pondweed).
Total volume and/or estimated volume of different salinity ranges	The longitudinal salinity gradient promotes species richness, different macrophyte habitats are distributed along the length of the estuarine lake system, e.g. salt marsh in the lower reaches and reeds and sedges in the upper reaches.
Floods	Large floods are important in flushing out salts from the salt marsh area and preventing the encroachment of vegetation into the main water body. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal areas. High groundwater level and freshwater flooding maintain suitable moisture conditions for plant growth in salt marshes. Floods would also deposit rich organic mud in estuaries and thus floods have an important nitrifying effect.
Salinity	A change in salinity will influence the macrophyte habitats, e.g. reeds and sedges grow better in brackish water whereas salt marsh and seagrass grow better in salinity close to water. Development and runoff can often decrease salinity leading to reed expansion. Reeds and sedges are sensitive to increases in salinity but can survive if their roots and rhizomes are located in salinity less than 20. However, if freshwater seepage is reduced then it may lead to die back. Freshwater inflow dilutes salts, preventing hypersaline conditions in salt marshes. Rainfall and evaporation on the marsh, groundwater seepage from adjacent land and the salinity of the tidal water that inundates the marsh control the sediment salinity. Hypersaline sediments caused by evaporation and infrequent flooding will result in dry bare patches in the supratidal areas.
Turbidity	Increase sediment load within the water column results in a reduction in the photic zone and will limit submerged macrophyte establishment and distribution. Submerged macrophyte distribution is naturally limited in turbid estuaries, however, catchment degradation can increase silt load.
Dissolved oxygen	Accumulations of macroalgae can reduce the water quality of estuaries, not only by depleting the oxygen in the water column upon decomposition but also causing anoxic sediment conditions when large mats rest on the sediment under low flow conditions.
Nutrients	Increased nutrient inputs would increase macrophyte growth particularly in areas of freshwater seepage (i.e. reeds and sedges). Eutrophication responses are an increase in plant growth, e.g. expansion of reeds, blooms of macroalgae or invasive aquatic floating macrophytes such as *Azolla*. Inorganic nutrients (especially N and P) are known to stimulate the abundance of ephemeral and epiphytic macroalgae. *Ulva* and *Cladophora* often form accumulations due to their filamentous nature and higher nutrient uptake rates than algae with thicker thalli. These accumulations can reduce the water quality of estuaries, by depleting the oxygen in the water column upon decomposition.
Sediment characteristics (including sedimentation)	Catchment degradation and sediment input can lead to unnatural expansion of macrophytes e.g. reed encroachment into shallow water areas.
Other biotic components	Loss of macrophyte habitat due to invasion by exotic species. Colonisation of disturbed floodplains or estuary margins by invasive plants. Grazing, browsing and trampling by cattle and goats.
Groundwater seepage	Seepage shorelines where reeds, sedges and swamp forest occur are sensitive to changes in groundwater input.

As many estuarine lakes in South Africa contain large beds of submerged macrophytes, often lacking in the other estuarine types, an understanding of estuarine lakes and the consequences of climate change impacts is crucial for their conservation and management. The loss of submerged macrophytes following an extended period of mouth opening in the Swartvlei is likely to become a more common event in these estuarine lakes and increased sea storms and SLR potentially alter mouth dynamics and salinity intrusion into the lakes.

15.3.3 Fish

Many biotic and abiotic factors influence the abundance and diversity of estuarine-associated fishes, including latitude, seasonality, catchment size, estuary size, salinity gradients, habitat diversity, mouth condition, dissolved oxygen levels, turbidity, food resources, flooding, and anthropogenic impacts. The last of these can be direct, such as pollution, dredging, bait collection and fishing; or indirect, such as upstream impoundments, water abstraction and marine fishing. Impoundments trap sediment, reduce freshwater flow and obstruct the upstream migration of catadromous species, reduce the spatial extent and strength of migration cues for larvae and juveniles of estuarine-associated fishes in marine environments, whereas overexploitation in the marine environment reduces spawning stock of estuarine-associated species into estuaries. The response of estuarine fish assemblages to environmental and ecological change makes them good indicators of anthropogenic stress. In all, fish response varies according to the life-history characteristics of the individual species concerned. The life-history characteristics of most of South Africa's estuarine fish are known. The following response table (Table 15.5) was constructed to reflect the change that can occur in fish communities in response to the shifts in abiotic and biotic components.

Table 15.7: Effect of abiotic characteristics and processes, as well as other biotic components on fish groupings

DRIVER	IA. ESTUARINE RESIDENTS (BREED ONLY IN ESTUARIES)	IB. ESTUARINE RESIDENTS (BREED IN ESTUARIES AND SEA)	IIA. ESTUARY DEPENDENT MARINE SPECIES	IIB AND C. ESTUARY ASSOCIATED SPECIES	III. MARINE MIGRANTS	IV. EURYHALINE FRESHWATER SPECIES
Mouth condition	Mouth dynamics govern connectivity between estuarine lake habitats and marine waters. Mouth closure prevents recruitment of marine spawned fish into the system, and may also prevent movement (migration) of fishes within the system towards the mouth during spawning periods. It also results in loss of tidal currents and water movement in the system and a loss of salinity gradients that govern fish (and prey and habitat) distributions across the system. Intertidal area, already limited in most coastal lakes is lost, with implications for the productivity of intertidal habitats, and trophic effects to the fish community. Prolonged closure will result in vegetation changes and die off which could, in turn, result in oxygen depletion and fish kills. Increased mouth opening, and strong scouring could result in opposite effects, increasing tidal fluctuation, exposing open banks on a tidal basis, stimulating microhytobenthic production to the benefit of some components of the fish assemblage (e.g. Mugilidae), but the detriment of others either through direct loss of habitat (e.g. loss of shallow submerged vegetation such as Zoster beds as preferred or even critical – in the case of pipefish and seahorses – habitat) and/or through trophic effects (e.g. loss of benthic invertebrate productivity, sand prawns).					
Retention times of water masses	Increased retention of water favours phytoplankton production and allows greater opportunity for macrophytes development. This is dependant of nutrient inflows, uptake rates in the different compartments and cycling between compartments. Shifts in trophic pathways could occur, in extreme cases with the food base shifting from the water column to the benthos (or vice versa).					
Flow velocities (e.g. tidal velocities or river inflow velocities)	Persistently higher tidal flows impact the estuarine sections of estuarine lake systems, reducing productivity and habitat availability for most estuarine associated fishes. Increased river flows also reduce the penetration of most estuarine associated fishes into fluvial coastal freshwaters. Lake basins are protected from the effects of increased flow velocities to a large degree, depending on their morphologies. Increased flow through the whole system has the porosity to influence water chemistry, and nutrient cycling, and therefore effect trophic dynamics (including fishes). Impacts will be specific to system (type) and flow change scenarios.					
Total volume and/or estimated volume of different salinity ranges	Higher lake volumes increase potential fish habitat area. Fishes that reside in the water column clearly benefit from greater habitat, but volume increases mostly (***but not always***) lead to increased shoreline and shallow water habitat. In saline and brackish water most marine estuarine associated fishes benefit from additional open water habitat. These include Mugilidae, Gerridae, *Pomadasys commersonnii*, and predatory Carangidae and Sphyraenidae. In freshwater however, these benefits are reduced. Some estuarine resident species, notably the *G. aestuaria* and *A. breviceps* benefit from open habitat, but most freshwater species have a high affinity for vegetated habitats (especially in clear water systems). These species only benefit from increased volume if it results in an increase in vegetated habitat, which is mostly the case in the longer term.					
Floods	Floods result in the movement of fishes, in response to salinity changes, or in an effort to remain in the system, or to leave it. Estuarine resident species typically adopt strategies to prevent being washed out of the system in floods, either moving up the system away from the mouth, or into marginal habitats where they gain protection from strong outflows. Estuarine associated marine species may move down the system cued by floodwaters, in spawning migrations to marine waters. Some freshwater species similarly use floods as an opportunity to gain access to spawning areas. *Clarias gariepinus* for example undertakes spawning aggregations in newly flood marginal areas.					
Salinities	Salinity is a primary driver of fish distribution in estuarine lakes, either directly as different species have different salinity preferences, or indirectly, through affecting prey and habitat distribution. Most estuarine dependant fishes are tolerant of low rather than high salinity and several freshwater species can tolerate slight (or even marked) elevations in salinity. Distribution across wider estuarine lakes system is therefore possible by most fish species in these systems. Biological interactions become important considerations (predation risk, prey availability, habitat availability).					
Turbidity	Turbidity is an important determinant of phytoplankton and therefore zooplankton productivity, and therefore affects the food base in estuarine lakes. This has implications for the fish community. Visual fish predators are more effective in clear waters. Turbidity also plays an important role in the value of estuarine lake water as a predation refuge for fish themselves. In turbid systems fishes distribute widely across the systems and over areas of open water, whereas in very clear systems fishes are much more guarded and hold in structured vegetated habitats in littoral and shallow areas.					
Dissolved oxygen	Most fishes become stressed when oxygen levels drop below 4 $mg.l^{-1}$. While many estuary-associated fish use surface breathing as an adaptation to hypoxia, and some can also adapt by skin respiration, eutrophication and persistent night-time low oxygen levels may exhaust fish to an extent that mass mortalities occur. Low oxygen levels in very deep areas of some systems (e.g. Kosi) precludes their use by fishes (and their prey). Overturn events are rare but can result in fish kills naturally. Cold temperature can have a similar or exacerbating effect. Freshwater species *O. mossambicus* and *C. gariepinus* are generally the most tolerant members of the estuarine lake fish community to persistent low oxygen concentrations. Fish health impacts from oxygen saturation can also occur. Although less documented in South African systems (than occurrence and impacts of low oxygen events) fish health impacts can occur at levels as low as 120% saturation, a level that is easily attained in waters in the proximity of algal beds or submerged aquatic macrophytes.					
Subtidal, intertidal and supratidal habitat	Open water habitat is used by the planktivorous estuarine dependent species that live in the water column, but several most of the goby species have a close association with sand (or mud) substrates, sometimes co-inhabiting with crustaceans in burrows. Submerged aquatic macrophytes are also important for some estuarine resident species (notable pipefishes and seahorses, but also gobies and blennies). These habitats, in estuarine lakes, are typically shallow subtidal. Intertidal habitats are limited, but where they occur are important for estuarine dependant marine species, particularly members of the Mugulidae that feed of tidal microphytobenthic productivity. Shallow water subtidal habitat is also important to these species.					

DRIVER	IA. ESTUARINE RESIDENTS (BREED ONLY IN ESTUARIES)	IB. ESTUARINE RESIDENTS (BREED IN ESTUARIES AND SEA)	IIA. ESTUARY DEPENDENT MARINE SPECIES	IIB AND C. ESTUARY ASSOCIATED SPECIES	III. MARINE MIGRANTS	IV. EURYHALINE FRESHWATER SPECIES
	Deeper intertidal habitat is also used as a refuge from predation by wading birds and to the extent that it offers productive feeding grounds (for example in supporting Callianasa banks). Very deep subtidal areas in estuarine lakes are likely to have quite distinct water quality characteristics, including low oxygen levels, that might preclude use by fishes.					
Other abiotic components	Low temperatures increase tolerance to hypoxia and low salinities and lower risk of mass mortality. Greater volumes maintain lower temperatures and thermoclines develop in the water column. Sex ratios can be skewed in fish where sex determination is temperature related. Increases in temperature tend to skew towards males, decreases towards females. Consequently, climate change and local scale anthropogenic influences on temperature could have a profound impact on fish populations. Growth rates and gonadal development tend to decrease on either side of the optimal temperatures for individual species. Fish move according to their preferred temperature, constraints more in temporarily open/closed than permanently open estuaries. Many of the fish in southwestern Cape estuaries are tolerant of low pH inflow of blackwater systems, e.g. *Myxus capensis*. Shallow marginal areas tend to be warmer than deeper channel areas and are thus favourable for metabolic processes. Juveniles and small adults also use shallow water as a predation refuge. Indigenous fish adapted to low pH whereas introduced ones originate from high pH waters. Consequently, agricultural runoff raises pH to the advantage of the introduced species.					
Sediment characteristics (including sedimentation)	Individual species preferences are highly variable and often related to preferred food sources. Burying ability and crypsis of some fish (e.g. sole *Heteromycteris capensis*) are governed by sediment characteristics. Some fish are directly and indirectly impacted, e.g. *Psammogobius knysnaensis* and *Croilia mossambica* are psammophyllic but have commensal/mutual relationships with burrowing invertebrates which are distributed according to their burrowing ability and sediment characteristics. Members of the Mugilidae feed over areas of different grain size and in so doing reduce competition for food resources. *O. mossambicus* prefers sandy substrata for nesting					
Phytoplankton biomass	High phytoplankton production contributes to turbidity in estuaries and probably favours those species with higher turbidity preferences. Phytoplankton is also a food source for filter-feeding fish, e.g. *G. aestuaria* and invertebrates. Fish also benefit indirectly from the proliferation of invertebrates that feed on phytoplankton. Omnivorous filter-feeding fish will out-compete selective feeders during periods of high phytoplankton biomass. Harmful algal blooms in estuaries, usually a result of eutrophication, have a number of direct (toxicity) and indirect (e.g. hypoxia) impacts on fish. Blue-green *Microcystis* blooms, common in SA estuaries, can cause skin and/or organ lesions in fish resulting in poor health, reduced reproductive success and mortalities. Golden algae *Prymnesium parvum*, an invasive species recorded in Zandvlei, causes fatal gill haemorrhaging, and induces abortion and premature spawning in fish.					
Benthic micro-algae biomass	Benthic microalgae are an important contributor to the food base of many estuarine lakes, supporting a wide range of fishes directly, and indirectly. *G. aestuaria* and *A. breviceps* may both selectively feed/graze on benthic diatoms. Mugillidae feed extensively on benthic micro-algae. These fishes are a dominant part of the fish biomass in South African estuarine lakes and therefore overall fish biomass is largely reflective of benthic algal biomass.					
Zooplankton biomass	Zooplankton is the primary food source for most estuarine resident species, although many can feed opportunistically on benthic invertebrates. Zooplankton also supports most marine estuarine associated fishes in the early life stages, before they move onto larges benthic prey items.					
Aquatic macrophyte cover	Several estuarine resident species have a critical dependence on vegetated habitats. This includes several pipefishes and seahorses, bennies and gobies. *Zostera* is especially important, although other vegetation can be used, including *Ruppia* and *Potamegeton* in lower salinities and freshwaters. Marine estuarine dependant species are less dependent on structured (vegetated) habitats, although some forms may have life stages that do have strong preferences for submerged aquatic vegetation. *Rhabdosargus holubi* for example, occurs predominantly in *Zostera* beds, if available, as small juveniles < 50 mm SL, before moving onto open sandbanks. Moonies, *Monodactylus* spp. associate with structured habitat as a matter of preference throughout their lifecycle. In clear water systems especially, fishes have a high dependency on vegetation as a predation refuge, especially during daylight hours. In turbid systems, habitat associations with structured habitats are weaker.					
Benthic invertebrate biomass	Benthic invertebrates are the main source of prey for most fishes once they have passed through their very early life stages. Even estuarine resident species that are otherwise plantivorous will feed opportunistically on benthic prey items if they are available in good numbers. *Callianassa* is important in several estuarine lake systems. They can occur in high biomass and support large specialist invertebrate feeders such as *Pomadasys commersonni*.					
Fish biomass	*G. aestuaria, A. breviceps* and *Ambassis* spp. are fodder-fish and comprise a high proportion of the fish biomass in the estuary and support piscivorous fishes and avifauna. High predator biomass can suppress the abundance of these fodder fish. them. The value of benthic estuarine resident species (e.g. gobies) in playing a similar role in supporting piscivorous fishes and birds is probably underrated					

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APPENDIX A: INVENTORY OF AVAILABLE INFORMATION (updated from Whitfield 2013)

Verlorenvlei:

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APPENDIX B: INVENTORY OF KEY DATA SETS

Verlorenvlei

River flow	Not available.
Water Level	DWS Gauge G3T001
Mouth Observations	Not available.
Water Quality (including salinity)	Grindley et al. (1980); DWAF (2003); Roberston (1980)
Estuarine vegetation	Fernandes et al. 2017
Fish	CSIR Harrison unpublished data.
Other	

Zeekoevlei

River flow	
Water Level	
Mouth Observations	Not available.
Water Quality (including salinity)	Bickerton (1982); Scientific Services, City of Cape Town (2016, unpublished data)
Estuarine vegetation	
Fish	CSIR Harrison unpublished data.
Other	CWAC counts

Bot/Kleinmond

River flow	
Water Level	DWS Gauge G4R003
Mouth Observations	Not available.
Water Quality (including salinity)	Bally & McQuaid (1985); Coetzee (1985); Koop (1982); CSIR (1998, unpublished data); River inflow (DWS database G4H014Q01 at Roode Heuvel)
Estuarine vegetation	
Fish	3 years of historical data, 15 years of twice annual DEFF survey data, CSIR Harrison unpublished data.
Other	CWAC counts from 1993

Klein

River flow	
Water Level	G4T004
Mouth Observations	Not available.
Water Quality (including salinity)	Scott et al. (1952), De Decker (1989), DEFF, CSIR and Overberg Municipality (unpublished data, captured in Anchor environmental Consultants (2015); River inflow (DWS database G6H4)
Estuarine vegetation	DWS 2015d
Fish	15 years of twice annual DEFF survey data, CSIR Harrison unpublished data.
Other	CWAC counts

Heuningnes

River flow	G5H002
Water Level	G5T002
Mouth Observations	Not available.
Water Quality (including salinity)	Van der Ende (2015); Gordon (2012); Anchor Environmental Consultants (2017); DEFF (2008, unpublished data)
Estuarine vegetation	De Decker's (1989), Turpie and Clark (2007), Anchor Environmental Consultants2017
Fish	Scott et al. (1952), De Decker (1989), DEFF: 2000-2019, CSIR Harrison unpublished data.
Other	CWAC counts

Touw/Wilderness

River flow	
Water Level	K3T006
Mouth Observations	SANParks (Historical Record)
Water Quality (including salinity)	DWS (2015); Russell (2013); River Inflow (DWS database K3H005, K3H011); Lakes (DWS database K3R003, K3R004, K3R005); Watling (1979); Taljaard et al. (2018)
Estuarine vegetation	Russell 2010
Fish	SANparks
Other	SANparks

Swartvlei

River flow	
Water Level	
Mouth Observations	SANparks
Water Quality (including salinity)	DWA (2009); Watling (1977); Howard-Williams (1981); Howard-Williams (1977); Allanson and Howard-Williams (1984); Whitfield et al. (1983); Fijen (1995); River inflow (DWS database K4H001, K4H002, K4H003)
Estuarine vegetation	Russell 2010
Fish	SANparks
Other	SANparks

St Lucia/uMfolozi

River flow	Not available for St Lucia due to swamps.
Water Level	W3T005 (uMfolozi), W3T002, W3T003 (St Lucia)
Mouth Observations	Yes, Park
Water Quality (including salinity)	Isimangaliso/Ezemvelo
Estuarine vegetation	Nondoda 2012
Fish	Isimangaliso/Ezemvelo
Other	Ezemvelo (birds)

uMgobezeleni

River flow	N/A
Water Level	Bate et al. 2016.
Mouth Observations	Bate et al. 2016.
Water Quality (including salinity)	Bate et al. 2016.
Estuarine vegetation	Bate et al. 2016.
Fish	
Other	

Kosi

River flow	N/A
Water Level	DWS W7T004, W7T005, W7T003
Mouth Observations	1942, 1959, 1976, 1984, 2010 and 2013
Water Quality (including salinity)	DWS (2016); Allanson and Van Wyk (1969); Hemens et al (1971); Ramm (1992); Humphries (2013)
Estuarine vegetation	DWS 2016
Fish	Data from multiple sampling trips, seasonally 2002-2004 (shallow subtidal habitats from mouth to Lake 4), historical qualitative data, see reference list.
Other	CWAC